A model of temporal integration during electrical stimulation of the human retina

Alan Horsager[1,2], Scott H. Greenwald[4], Geoff M. Boynton[5], Mark S. Humayun[1,2,3], Robert J. Greenberg[4], James D. Weiland[3], Matthew J. McMahon[4], Ione Fine[1,2]

[1]Neuroscience Graduate Program, [2]Zilhka Neurogenetic Institute, [3]Doheny Retina Institute, Keck School of Medicine, USC, LA, CA; [4]Second Sight Medical Products, Inc., Sylmar, CA; [5]The Salk Institute for Biological Studies, La Jolla, CA

Purpose: Retinitis Pigmentosa is a photoreceptor disease that frequently results in blindness (Friedman, 2004; Bunker, 1984). However, cells of the neural retina (bipolar, amacrine, and ganglion cells) remain functional, albeit in smaller numbers, and with disorganized connectivity (Marc, 2003). There have been recent attempts to restore vision in these patients using an epiretinal prosthetic, analogous to a cochlear implant, that can activate remaining neurons via direct electrical stimulation (Humayun, 1999; Rizzo, 2003). While it has been demonstrated that electrical stimulation can produce visual percepts in human subjects, the neural pathway from stimulation to percept is still unclear. Here, we present psychophysical threshold and suprathreshold data examining the temporal aspects of electrical stimulation. We fit this data using a biologically feasible model similar to those recently used to describe temporal contrast adaptation in retinal ganglion cells (Chichilnsky, 2001; Rieke, 2001; Meister, 2002).

Methods: Stimuli were pulse trains that varied in their temporal parameters (pulse width, frequency, and pulse number). We measured threshold for single pulse and pulse train stimulation. Current amplitude thresholds were measured using a yes-no paradigm where 50% of the trials were catch-trials containing no stimulus. Suprathreshold contrast was measured using a two-interval brightness-discrimination task so as to obtain equibrightness curves.

Results and Conclusions: Threshold and suprathreshold data were fit using a biologically plausible linear-nonlinear model. The model began with convolution of the stimulus with an impulse response filter that used a 1-stage gamma function, $r(t) = \int_{-\infty}^{\infty} f(\tau_1)\delta(t-\tau_1)dt = f(t) * \delta(t)$, and was then rectified before being passed through a shifting and expanding nonlinearity, $r(t) = \left(r(t) - k\int_{-\infty}^{\infty} r(t)\right)^{\beta} dt$. The output of the nonlinearity was then convolved with a second slow integrating filter. In our model, we assumed that the response reached threshold or a perceived brightness level when the maximum response reached some threshold value. This model fit a wide range of data with parameter values that varied little across subject or electrode.

The ability to predict the effects of stimulation is a prerequisite for developing a successful retinal implant. These data are the first to show that electrical stimulation patterns produce predictable and reliable percepts, which can modeled quantitatively.