Computational Modeling of Contrast Sensitivity and Orientation Tuning in Schizophrenia

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Computational modeling is being increasingly used to understand schizophrenia, but, to date, it has not been used to account for the common perceptual disturbances in the disorder. We manipulated schizophrenia-relevant parameters in the GCAL (gain control, adaptation, laterally connected) model (Stevens et al., 2013), run using the Topographica simulator (Bednar, 2012), to model low-level visual processing changes in the disorder. Our models incorporated: separate sheets for retinal, LGN, and V1 activity; gain control in the LGN; homeostatic adaptation in V1 based on a weighted sum of all inputs and limited by a logistic (sigmoid) nonlinearity; lateral excitation and inhibition in V1; and self-organization of synaptic weights based on Hebbian learning. Data indicated that: 1) findings of *increased* contrast sensitivity for low spatial frequency stimuli in first episode schizophrenia (FES) can be successfully modeled as a function of reduced retinal and LGN efferent activity within the context of normal LGN gain control and cortical mechanisms (see Figure 1); and 2) findings of *reduced* contrast sensitivity and broadened orientation tuning in chronic schizophrenia can be successfully modeled by a combination of reduced V1 lateral inhibition and an increase in the Hebbian learning rate at V1 synapses for LGN input (see Figures 1-3). These models are consistent with many current findings (Silverstein, 2016) and they predict relationships that have not yet been explored. They also have implications for understanding links between perceptual changes and psychotic symptom formation, and for understanding changes during the long-term course of the disorder.

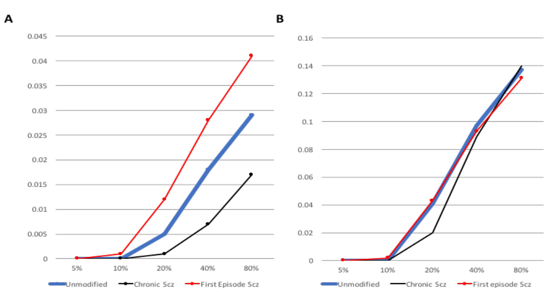

Figure 1. Activation (y-axis, in arbitrary units) values across contrast levels for the unmodified GCAL model (thick blue line), the best fitting chronic schizophrenia model (black line) and the best fitting FES model (red line), for: **A**. the low SF stimulus; and **B**. the medium SF stimulus.

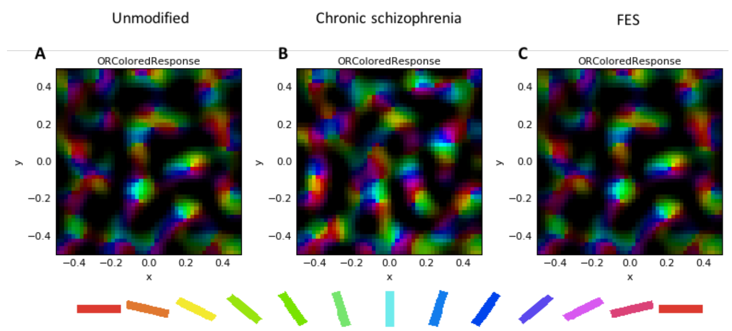

Figure 2. Combined orientation preference (color) and activation (brightness) maps showing response to the medium SF vertical stimulus at 80% contrast for **A**. unmodified GCAL model; **B**. best fit chronic schizophrenia model; **C**. best fit FES model. It can be seen that the broader orientation tuning in the chronic model (B) (see also Fig. 3) arises from greater activation of cells not selective for a vertical orientation (orientation key at bottom of Fig. 2).

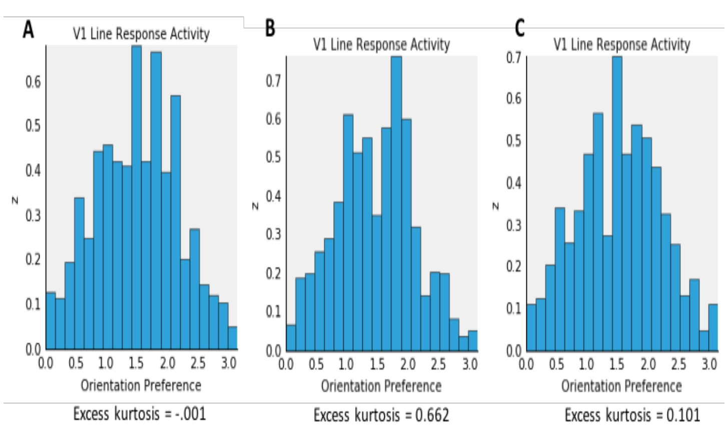

Figure 3. Orientation tuning histograms showing response to the medium SF vertical stimulus at 80% contrast for: **A**. unmodified GCAL model; **B**. best fit chronic model; **C**. best fit FES model. (**A**) shows a Gaussian curve with peak activation for a vertical stimulus (90º or ~1.57 radians). In (**B**) there is suppression of cells signaling this orientation and a bimodal distribution with peaks at lesser and greater orientations, as well as excess activity in units signaling orientations far from the target (as indicated by the highest excess kurtosis value), which underlies broadened orientation tuning. In (**C**) peak activation is for a vertical stimulus and the distribution is Gaussian.

References:
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Stevens, J. L., J. S. Law, J. Antolik, and J. A. Bednar. 2013. "Mechanisms for stable, robust, and adaptive development of orientation maps in the primary visual cortex." *J Neurosci* 33 (40):15747-66.