Physiological Rationale for Fixation Eye-Movements

Qasim Zaidi, Robert Ennis, Dingcai Cao, Barry Lee
Graduate Center for Vision Research, State University of New York

In this talk I will discuss a functional advantage conveyed by fixational eye-movements in detecting spatial transients, and how that is necessitated by primate retinal ganglion cells being different in spatial properties from the textbook examples of center-surround ganglion cells that do a spatial differentiation of image structure.

It is well established that visual sensitivity is affected by context. The luminance of a surround region substantially affects the detection of luminance flicker at low frequencies, so that the Temporal Contrast Sensitivity Function is band-pass on dark or light surrounds, but low-pass on surrounds at the mean-level of the flicker. The cause of the effect remains controversial. Some explanations invoke enhancement of edge responses by lateral inhibition, others rely on transients caused by the miniature eye-movements involved in maintaining fixation. We replicated the psychophysical luminance results and found that they also held for chromatic conditions: the TCSF for equiluminant red-green (L-M) flicker was low-pass on mean-level surrounds, but was surprisingly band-pass on red or green surrounds. Chromatic edges are an interesting counterpart to luminance edges because they are different in natural images and psychophysical detection, and their substrate is generally attributed to double-opponent cortical cells.

To identify the neural basis of the context effects, we used in vivo electrophysiological recordings of primate retinal ganglion cell responses to luminance (L+M+S) and red-green (L-M) modulations. We measured cell responses at various distances from the modulation edge to test neuronal sensitivity to stationary edge contrast. Effects of stationary edge-contrasts on ganglion cell responses were found to be minimal on all surrounds, excluding lateral inhibition as a mechanism for enhancement of responses to stationary edges. To simulate the effects of eye movements, we measured cell responses to abruptly displaced target patches. Abruptly displaced edges evoked transient bursts or suppression of spikes. On mean-level surrounds, transient neural responses depended on the modulation phase, but responses were equal across all modulation phases on the polarized surrounds. Eye-movements thus enhanced detection of low-frequency flicker on mean-level surrounds, and a neurometric analysis supported a primary role for eye movements in the context effects on temporal sensitivity.

These results show that in the absence of eye-movements, retinal ganglion cells do not signal the presence of edges. Fixation eye-movements transform spatial edges to transient retinal responses and thus provide the neuronal substrate for detecting chromatic and luminance edges in natural scenes.