Overview

Computer simulations of a neural model of lightness computation based fixational eye movements are presented. The model accounts to within 5% accuracy psychophysical lightness matches made with the Staircase Gelb and related displays. It also explains several other theoretically significant visual perception phenomena, including perceptual filling-in, edge integration in lightness, perceptual fading of stabilized images, and the *Chevreul illusion*.

Model Description

1) *Input image*. The input is either a 2D map of a Staircase Gelb display (five grayscale papers, arranged in order from darkest to lightest) or one of two spatially reordered versions of that display in which the paper with the highest reflectance was displaced either to the left or right of the lowest luminance. The papers in the display were 2.5 deg x 2.5 deg squares. Display parameters were taken from a lightness matching study by Zavagno, Annan, and Caputo (*Vision*, 2004), whose results are quantitatively modeled here (see Simulation Results).

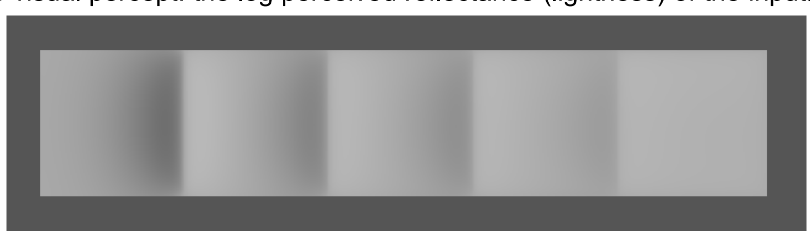
2) *Fixational eye movements* (FEMs) were modeled as a 2D random walk in which the eyes translated either left, right, up, or down on each discrete timestep of the simulation, each with probability 1/4. FEMs on successive time steps were independent. The retinal distance moved on each time was 2 times the standard deviation of a photoreceptor (see below), which was modeled as a 2D gaussian spatial filter of the input (in log units).

3) *Cortical maps of luminance increments or decrements sorted by eye movement direction*. On each time step *t*, eight spatial maps were computed. The activity at a location in each map represented the change in response of a photoreceptor at a given retinal location location with respect to its response on time step *t*-1 (before the last FEM), multiplied by a neural gain factor. The neural gain was 0.27 for incremental changes and 1.0 for decremental changes. Four of the eight cortical maps corresponded to increments and four to decrements. A separate cortical map was computed for each eye simulated eye movement direction.

4) *Spatial integration of increments and decrements by high-level cortical ON and OFF cells*. At a yet higher stage of visual processing, neurons in separate ON and OFF networks spatially integrated the activities across the four incremental or decremental activation maps. The integration had an exponential spatial profile with space constant 1.8 deg and also depended on angle. Specifically, the spatial integration magnitude was proportional to the halfwave rectified cosine of the angle θ between a vector drawn from the location of the neural activation in the map whose activity was integrated to the receptive field center of the ON or OFF neuron doing the integration and a second vector pointing in the direction of the eye movement that generated the neural activity in the low-level map. Thus, the activation $A(x_0,y_0)$ produced in an ON or OFF neuron at location (x_0,y_0) by a low-level incremental or decremental activation $a(x,y)$, respectively, at location (x,y) equaled

$$A(x_0, y_0) = \mathrm{a(x,y)}e^{-\frac{\sqrt{(x-x_0)^2+(y-y_0)^2}}{.8}}[cos\theta]^{+1}.$$

5) *Lightness map*. The output models the visual percept: the log perceived reflectance (lightness) of the input. The lightness map was computed by adding the spatial maps of the ON and OFF network activations, then averaging over timesteps with an exponential time constant that differed during the activation stage and a "relaxation" stage in which the eye movements were artificially halted (see below). The time-averaged lightness map was then adjusted by shifting the values of each pixel by a (different) constant for each simulated experiment. This shifting had the effect of anchoring the highest perceived reflectance in the lightness map to white (i.e. to match the highest perceived reflectance to a Munsell 9.5 standard), consistent with both the specific psychophysical results modeled here and the more general experimental finding that the highest reflectance in an achromatic scene always appears white.



Simulation results

The model reproduced the lightness matches made in the experiments of Zavagno et al. to within 5% accuracy. It also reproduced the *Chevreul illusion,* in which a series of abutting patches of homogeneous luminance generate a scalloped pattern of lightness (see figure above). It furthermore reproduced the finding that a stabilized image fades perceptually within a few seconds (Riggs, Ratliff, Cornsweet, & Cornsweet, *JOSA*, 1953). In addition to these specific results, the model also exhibits the more general properties of perceptual filling-in of lightness from borders and edge integration in lightness.