Brightness Perception involves Local Adaptation opposed by Lateral Interaction

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Brightness perception has long been known to involve surround effects. These induced effects have most commonly been modeled as resulting from lateral inhibition, but that has ignored the fact that brightness gamuts are reduced by photoreceptor response compression, and the gamut needs to be expanded by cortical interactions. To investigate this role of brightness induction, we explore a simple two-stage model. The model first applies local photoreceptor response compression to the retinal image, so the response at each pixel ($R(x,y)_L$) is controlled by the gain (Γ_L) set locally by its mean luminance ($L(x,y)$):

$$R(x,y)_L = \Gamma_L * L(x,y) \tag{1}$$

$$\Gamma_L = \frac{\gamma_L}{\gamma_L + L(x,y)}, \; \gamma_L \text{ is a constant parameter} \tag{2}$$

In the second stage of the model, each pixel gets a signed induction signal from all other pixels ($I(x,y)$) added to its signal from the photoreceptors to give an estimate of perceived brightness/lightness ($B(x,y)$). The signed signal is the sum of weighted differences between the photoreceptor response at the test pixel ($T_{L(x_t,y_t)}$) and the photoreceptor response at each surrounding pixel ($S_{L(x_s,y_s)}$). Each difference signal decreases as an exponential function of distance between two pixels (W), and is gain-controlled as a function (Γ_I) of the absolute value of the difference signal. The second gain control serves to potentiate the lateral effect of gradual gradients over models based purely on discontinuous edges.

$$I(x_t,y_t) = -\sum_{x_s,y_s} W * \Gamma_I * (S_{L(x_s,y_s)} - T_{L(x_t,y_t)}) \tag{3}$$

$$\Gamma_I = \frac{\gamma_I}{\gamma_I + |S_{L(x_s,y_s)} - T_{L(x_t,y_t)}|}, \; \gamma_I \text{ is a constant parameter} \tag{4}$$

$$W = e^{-\alpha * distance} \tag{5}$$

$$B(x,y) = R(x,y)_L + I(x,y) \tag{6}$$

We show that this model explains brightness induction in a dynamic experimental paradigm that isolates and combines adaptation and induction effects, the perceived gamut expansion in a new lightness illusion in face perception that occurs when the image of a face is half-wave rectified, and perceived lightness in complex scenes in the presence of occlusion and translucency.