Gaining the system: Population limits on compensating color deficiencies through gain control

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Highlights
- Several studies have found evidence for post-receptoral gain changes that compensate for color deficiencies
- However, this compensation is rarely complete – why?
- We modeled limitations on gain compensation imposed by the population codes mediating retinal and cortical color vision
- Within these codes the cardinal dimensions of color are not independent, and this limits the capacity of the system to fully correct for a loss along one of the dimensions

Background
- A number of studies have found that the suprathreshold color responses of anomalous trichromats are stronger than predicted from the reduced spectral separation of their longer wave cone pigments (Bosten, 2019; Isherwood et al 2020).
- These compensatory effects could occur if post-receptoral neurons amplify their gain to discount the weaker difference signal provided by the cones.
- However, this compensation is typically incomplete, and the factors that limit it are not well understood.
- We modeled the consequences of color deficiencies and gain changes within a population code for retinal and cortical color vision, to assess the impact of adaptation at different stages.

1. Limits to gain in independent cardinal mechanisms
Decreasing the LM cone separation is not equivalent to a gain loss, thus increasing the LM gain cannot fully discount the loss.

2. Compensation and population codes for luminance and color
Luminance (L+M) and color (L-M) are jointly coded in P cells. Cortical gain changes could restore individual responses, but would leave the L-M population response under-corrected and predict the L+M response will be over-corrected

Gain changes assuming a uniform distribution of channels
Gain changes assuming a non-uniform distribution of channels

3. Compensation and population codes for LM and S
Cortical color coding involves multiple channels tuned to different combinations of LM and S signals. The partial compensation within the LM population may carry over as a reduced LM contribution to channels in the LM vs. S chromatic plane, biasing the distribution of chromatic channels and their responses along the S axis. If the S and LM populations are gain controlled before combining, this predicts residual LM losses without corresponding S gains.

Gain changes assuming a uniform distribution of channels
Gain changes assuming a non-uniform distribution of channels

4. Probing cortical coding in normal and anomalous observers with color contrast adaptation
These models predict testable differences in short-term contrast adaptation for normal and anomalous observers. For color normal observers, the adaptation effects are symmetrical along the LM and S axes, while the biases in the anomalous population predict asymmetrical and more selective effects for LM than S adapting conditions.

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color normal vs anomalous trichromats
LM Sensitivity
LM and LUM channel density
Gain changes assuming a uniform distribution of channels
Gain changes assuming a non-uniform distribution of channels

Adapt Axis = LM or S
Adapt Axis = 45 or 135°