Hue, saturation and brightness scaling of signals from single cones

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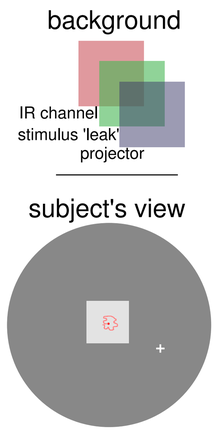
INTRODUCTION

The algorithm used by the visual system to extract hue, saturation and brightness from the ambiguous signals generated by cone photoreceptors is unknown. We investigated this computation by stimulating individual cones in human subjects and recording the associated percepts.

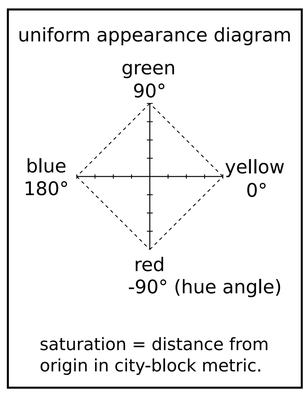
METHODS

An adaptive optics scanning laser ophthalmoscope was used to image and present stimuli to the retina ~1.5° from the fovea. The eye's optical aberrations were measured with a wavefront sensor (940 nm) and corrected with a deformable mirror. Imaging and eye-tracking was performed with 840 nm light. Cones were targeted with spots (543 nm; 500 ms; 0.45 arcmin) that varied in intensity. Chromatic aberration between the three channels was corrected following Harmening et al. 2012. The background appeared white. The spectral class of targeted cones were identified using densitometry (Sabesan et. al. 2015).

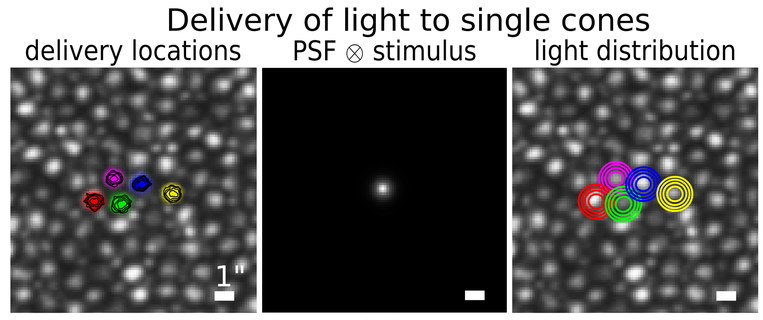


Hue, saturation and brightness scaling procedure

Subjects rated the brightness of each stimulus on a scale from 0 to 5. Stimuli that received brightness ratings above zero were also rated for hue and saturation (Gordon et. al. 1994). The subject indicated the percent of red, green, blue, yellow and white contained in each stimulus using five button presses that summed to 100%. Trials with delivery errors greater than 0.35 arc-min were discarded (see right).

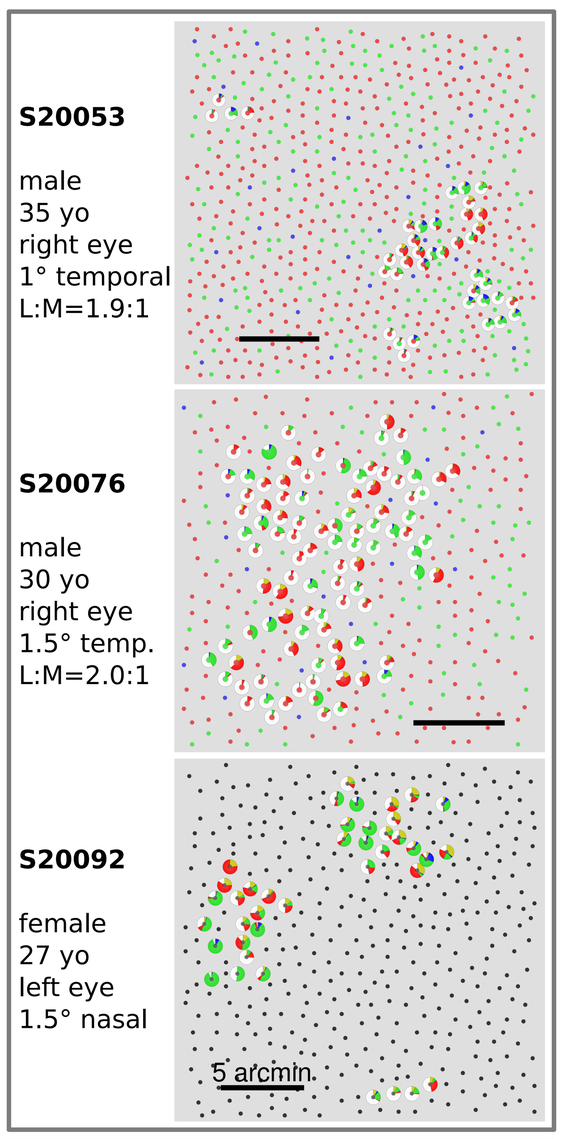


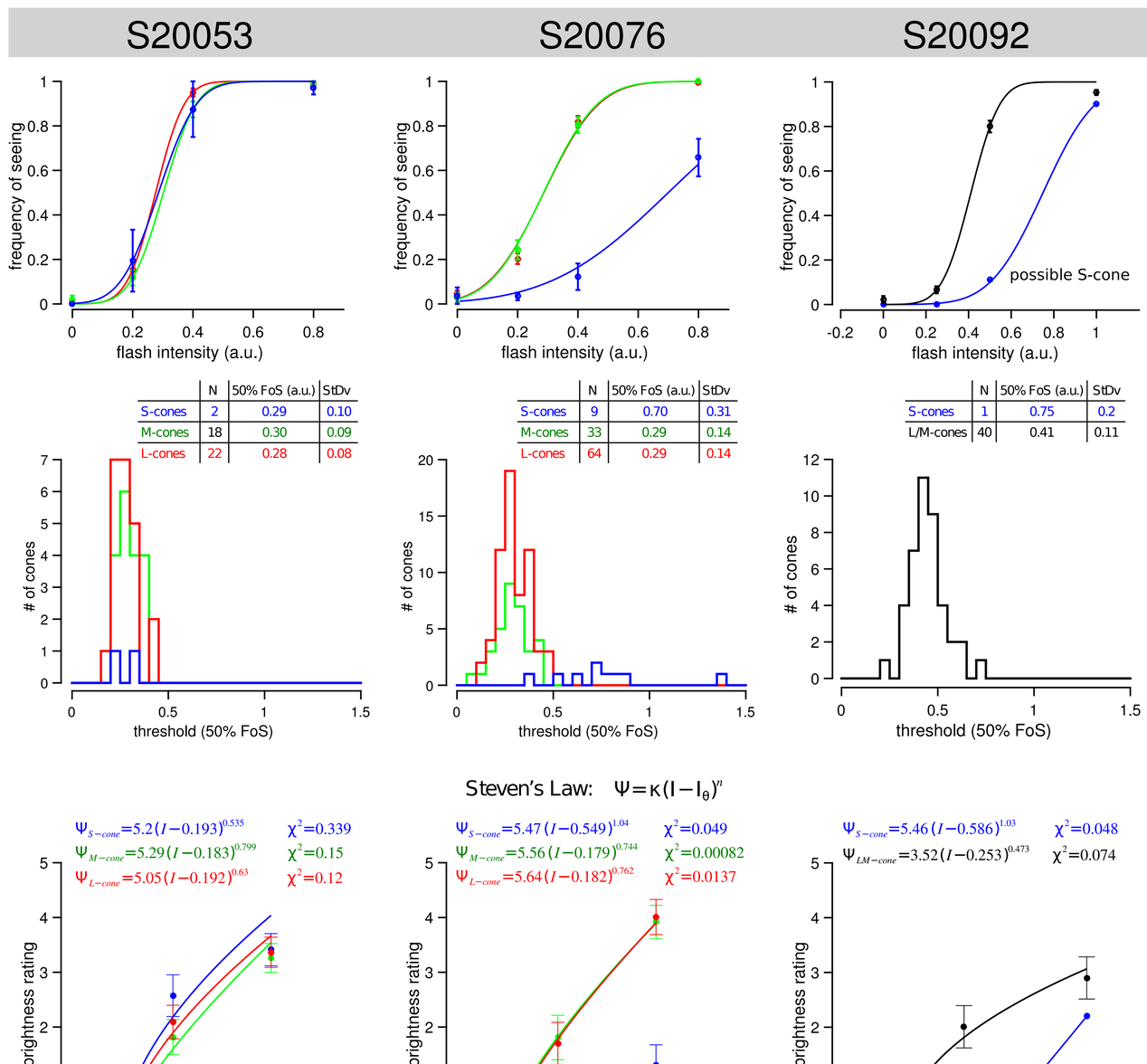
Delivery of light to single cones

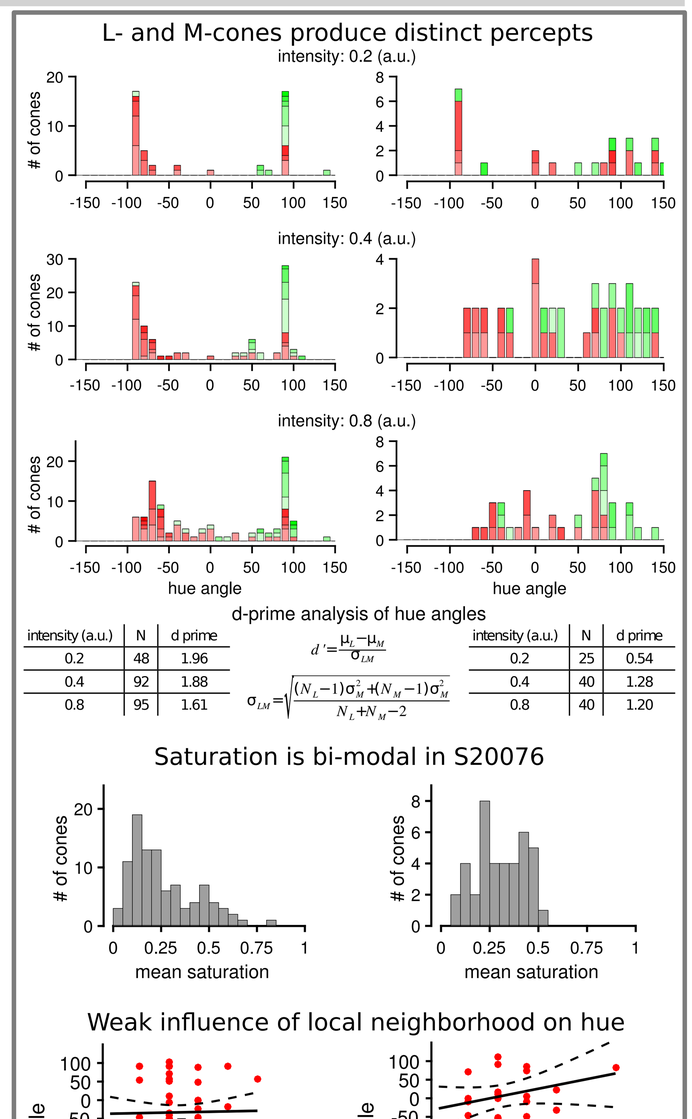


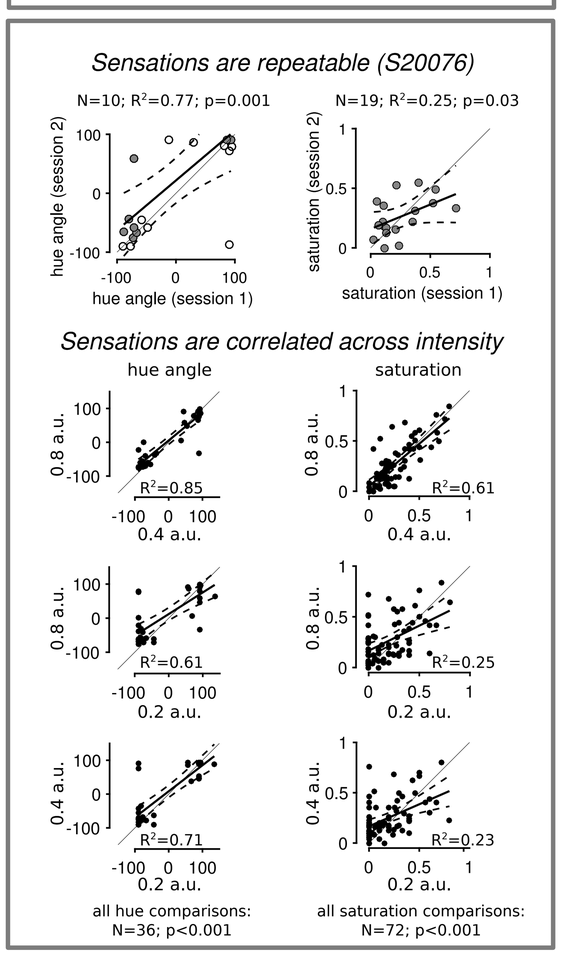
Left: delivery locations of 5 cones. Contours indicate delivery locations were concentrated at cone centers. **Middle**: 3x3 pixel stimulus convolved with diffraction limited PSF. **Right**: density profile of light computed by summing the PSF ⊗ stimulus at each location. Contours = 0.5 0.25, 0.125, 0.0625 of maximum light delivery.

RESULTS









CONCLUSIONS

The majority of cones tested mediated desaturated sensations (< 0.5) at all intensities, while a smaller group elicited saturated (>0.5) percepts. L- and M-cones produced sensations that were reliably discriminated at all three intensities. L-cones tended to generate red, and to a lesser extent yellow, hue reports. M-cones produced predominantly green reports. Hue was largely independent of stimulus intensity and brightness rating. Brightness ratings were positively correlated with stimulus intensity and fit by compressive exponential functions. In summary, over the range of intensities tested, a single cone produced a consistent hue sensation and relatively fixed saturation, but with brightness roughly proportional to stimulus intensity. This is consistent with the interpretation that for percepts associated with single cone stimulation, hue and saturation are independent of photoreceptor isomerization rate.

REFERENCES

Harmening et al. 2012. Biomedical Optics Express. 3 (9), 2066-2077.
Sabesan et al. 2015. PLOS ONE. 10 (12), e0144891.
Sabesan et al. 2016. Science Advances. 2 (9), e1600797.
Gordon, Abramov, Chan. 1994. Perception and Psycho., 56(1), 27-41.

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