Luminance and chromatic contrast sensitivity for extended range of light levels

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Motivation

- To understand and model the appearance of achromatic and chromatic contrast sensitivity over a wide range of luminances
- To predict color and contrast appearance of complex images across a multitude of conditions (e.g., luminance, observer age, etc.)

Stimuli[1]

Color Direction		Background			From Colour			To Colour		
No.	Name	L_0	M_0	S_0	ΔL	ΔM	ΔS	ΔL	ΔM	ΔS
C1	Black and white	0.7383	0.3195	0.021	0.663	0.287	0.0188	-0.6631	-0.2869	-0.0189
C2	Red-Green	0.7383	0.3195	0.021	0.2869	-0.2869	0	-0.287	0.287	0
C3	Lime-Violet	0.7383	0.3195	0.021	0	0	0.0188	0	0	-0.0189

Table 1: The L, M, S cone excitations of the end points of the stimuli colour directions and of the background

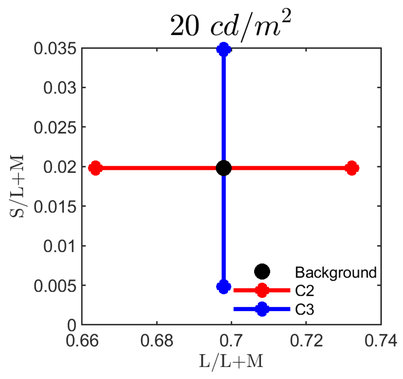

Figure 1 (left): The end points of cardinal colour directions plotted in MacLeod-Boynton diagram

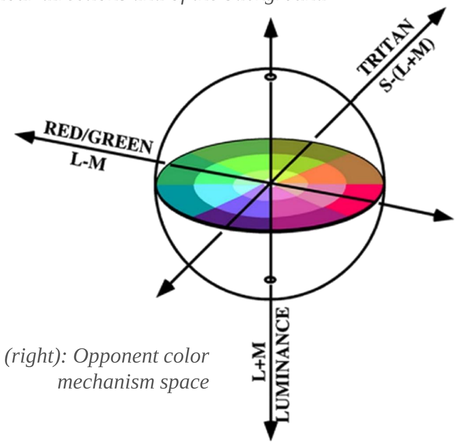

Figure 2 (right): Opponent color mechanism space

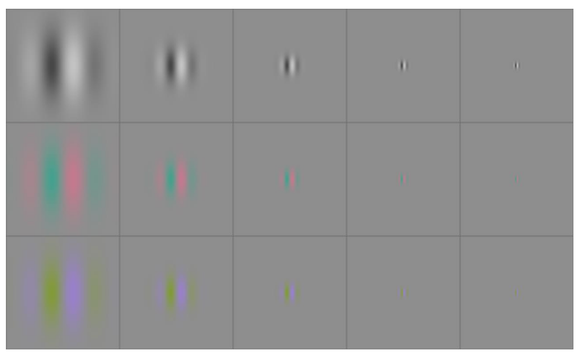

Figure 3: Stimuli Set

Spatial Frequencies

- Colour directions: Black-White (C1), Red-green (C2), and Lime-Violet (C3)
- Spatial Frequencies: 0.5, 1, 2, 4, 6 cycles per degree
- Luminances: 0.02, 0.2, 2, 20, 200, 2000, and 7000 cd/m^2

Procedure

- Apparatus: high-dynamic range (HDR) display capable of displaying up to 15,000 cd/m^2 viewed from 91cm in a dark room[2]

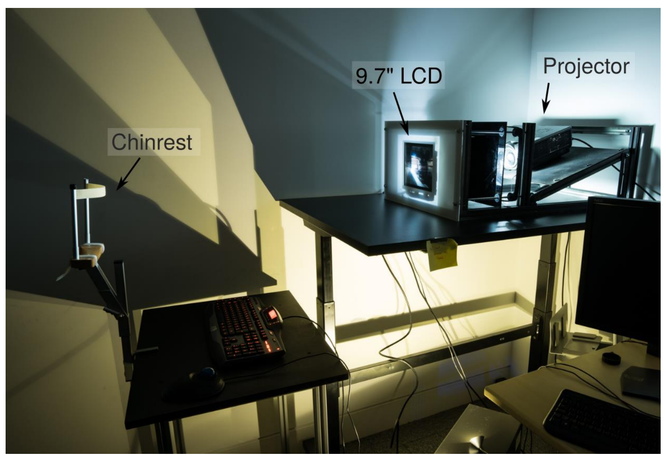

Figure 4 (above): HDR Experimental Setup

- No. of observers: 18
- Task: 4AFC detection
- Thresholds obtained using QUEST[3]

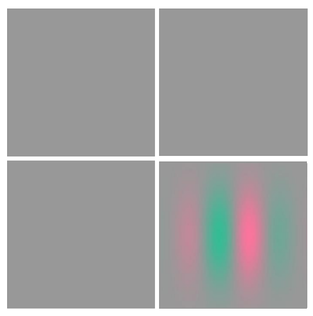

Figure 5 (right): Example 4AFC trial; participants identify the quadrant with the stimulus present

Results

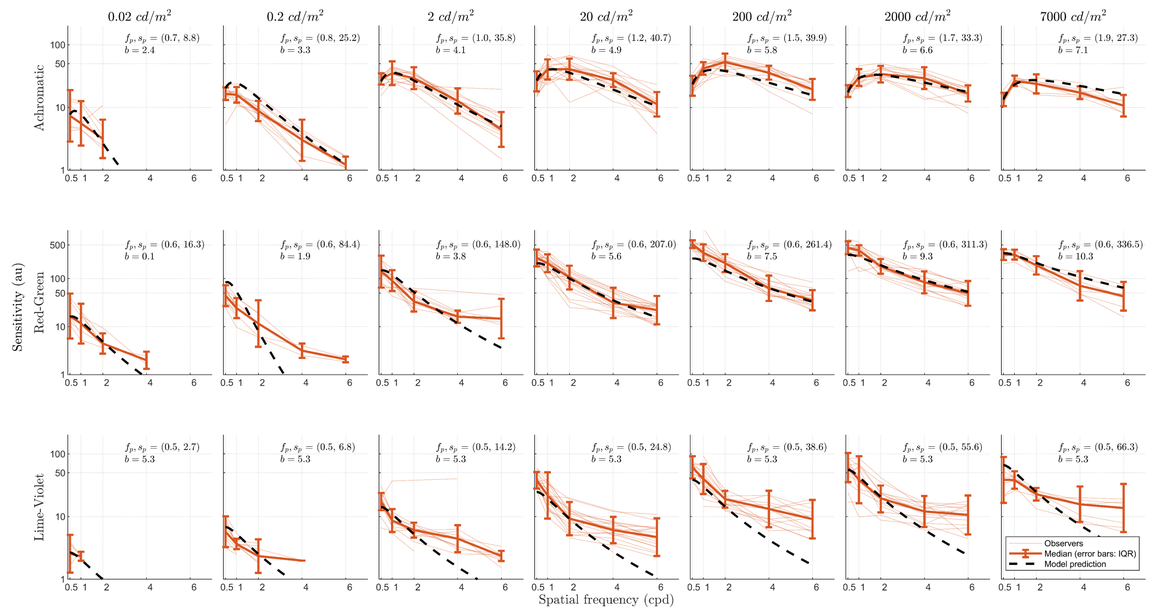

Figure 5: Contrast sensitivity data from 18 colour normal subjects, median observations for 3 colour channels, 7 luminance levels and 5 spatial frequencies, and model predictions

- Contrast Sensitivity Functions (CSFs) dependent on both spatial frequency and luminance levels.
- Achromatic channel (C1):
  - Band-pass
  - Peak sensitivity maximal at 200 cd/m^2
- Chromatic channels (C2 and C3):
  - Low-pass
  - Peak sensitivity saturates at luminance ≥200 cd/m^2

Modelling[4]

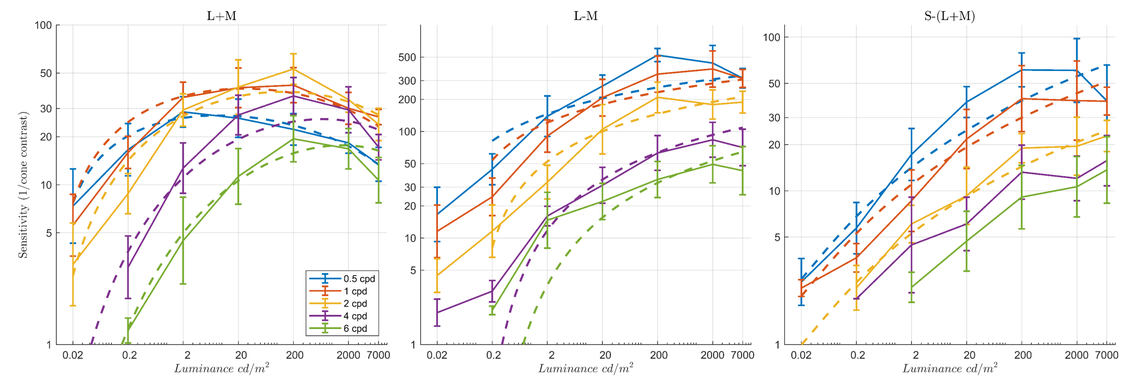

Figure 6 (below): Comparison of average observer data with predicted luminance dependent contrast sensitivity functions

$$S(f) = \log_{10}(S_p) - \kappa\left(\frac{\log_{10} f - \log_{10} f_p}{\frac{b'}{2}}\right)^2, \quad \kappa = \log_{10}(2), \quad b' = \log_{10}(2b) \qquad [5]$$

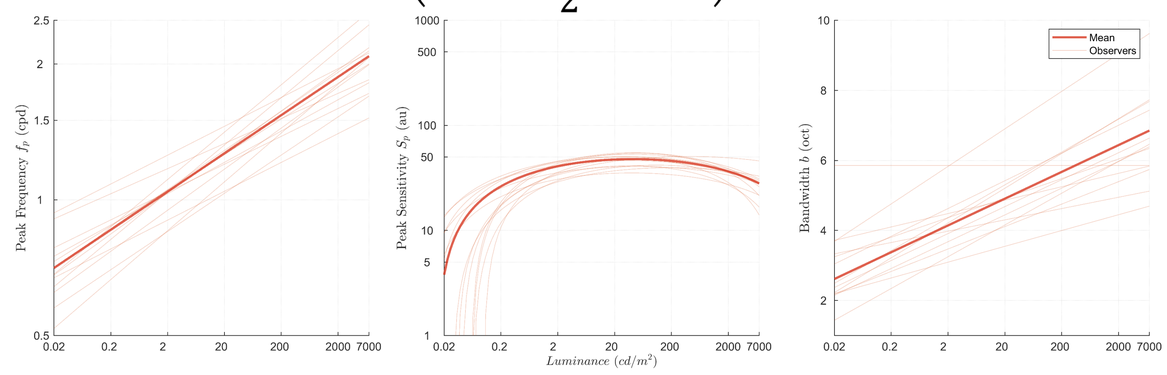

Figure 7: Peak frequency, peak sensitivity, and bandwidth of achromatic contrast sensitivity (C1) as functions of luminance

$$\log_{10}(f_p) = \alpha_1 \log_{10}(l) + \beta_1 \qquad f_p = Frequency\ at\ peak\ sensitivity$$

$$S_p = \chi(\log_{10}(l) - \log_{10}(\psi))^2 + \omega \qquad S_p = Peak\ Sensitivity$$

$$b = \alpha_2 \log_{10}(l) + \beta_2 \qquad b = Bandwidth$$

Conclusions

- Achromatic and chromatic contrast sensitivity is modelled as a two-dimensional function of spatial frequency and luminance.
- CSFs consistent with Weber's law in limited luminance range (achromatic: 20 - 200 cd/m^2; chromatic: >200 cd/m^2).
- For achromatic channel, peak sensitivity reduces at high luminances; possibly cone bleaching[6].
- Future application: Adaptive display systems to account for chromatic and achromatic contrast sensitivity changes with age

References

[1] Wuerger, S. M., Watson, A. B., & Ahumada, A. J. (2002, May). Towards a spatio-chromatic standard observer for detection. In *Human Vision and Electronic Imaging VII* (Vol. 4662, pp. 159-173). International Society for Optics and Photonics.

[2] Kim, K. J., Mantiuk, R., & Lee, K. H. (2013, March). Measurements of achromatic and chromatic contrast sensitivity functions for an extended range of adaptation luminance. In *Human Vision and Electronic Imaging XVIII* (Vol. 8651, p. 86511A). International Society for Optics and Photonics.

[3] Watson, A. B., & Pelli, D. G. (1983). QUEST: A Bayesian adaptive psychometric method. *Perception & psychophysics*, *33*(2), 113-120.

[4] Watson, A. B., & Ahumada, A. J. (2005). A standard model for foveal detection of spatial contrast. *Journal of vision*, *5*(9), 6-6.

[5] Kim, Y. J., Reynaud, A., Hess, R. F., & Mullen, K. T. (2017). A normative data set for the clinical assessment of achromatic and chromatic contrast sensitivity using a qCSF approach. *Investigative ophthalmology & visual science*, *58*(9), 3628-3636.

[6] Stockman, A., Langendörfer, M., Smithson, H. E., & Sharpe, L. T. (2006). Human cone light adaptation: From behavioral measurements to molecular mechanisms. *Journal of Vision*, *6*(11), 5-5.