Luminance-dependent spatio-chromatic sensitivity: from detection to appearance

Maliha Ashraf[1], Sophie Wuerger[1], Rafał Mantiuk[2], Minjung Kim[2], Jasna Martinović[3]
[1]University of Liverpool, [2]University of Cambridge, [3]University of Aberdeen

EPSRC Engineering and Physical Sciences Research Council

Aim

To predict suprathreshold appearance from contrast threshold measurements for a wide range of luminances

Kulikowski's Model[1]

- Perceived apparent contrast is proportional to the difference between physical and threshold contrast
- Hence, difference between test contrast and test threshold contrast matches the difference between reference contrast and reference threshold contrast

$$C_T' - C_T \approx C_R' - C_R$$

$C_T' = Test\ suprathreshold\ contrast$
$C_T = Test\ threshold\ contrast$
$C_R' = Reference\ suprathreshold\ contrast$
$C_R = Reference\ threshold\ contrast$

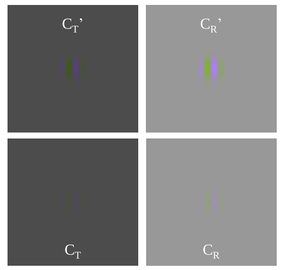


Figure 1 (right): Reference and test stimuli at 200 and 2 cd/m² luminance levels respectively. Top row: matched contrasts at suprathreshold levels. Bottom row: both stimuli at their contrast thresholds

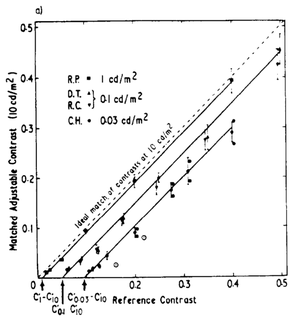


Figure 2 (left): Reference and test contrast matching results from Kulikowski[1]

Experiment

- Colour directions: Black-White (C1), Red-green (C2), and Lime-Violet (C3)
- Spatial Frequencies: 0.5, 2, 4 cpd
- Test luminances: 0.02, 0.2, 2, 20, 200, and 2000 cd/m²
- Reference luminance: 200 cd/m²
- Haploscopic matching method (each eye adapted to a different luminance level)
- Task: "Adjust the contrast on the test display such that it matches the contrast on the reference display"

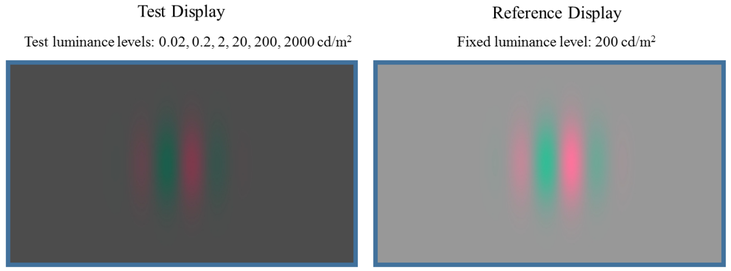


Figure 3: Reference and test stimuli displayed on reference and test displays respectively at different luminance levels

Table 1: Fixed suprathreshold contrast values for the three colour channels

Colour Directions		**Reference suprathreshold cone contrast levels**		
	Name	*Level 1*	*Level 2*	*Level 3*
L+M	Black and white	0.1495	0.2719	0.4943
L-M	Red-Green	0.0246	0.0416	0.0704
S-(L+M)	Lime-Violet	0.1939	0.3449	0.6138

Results

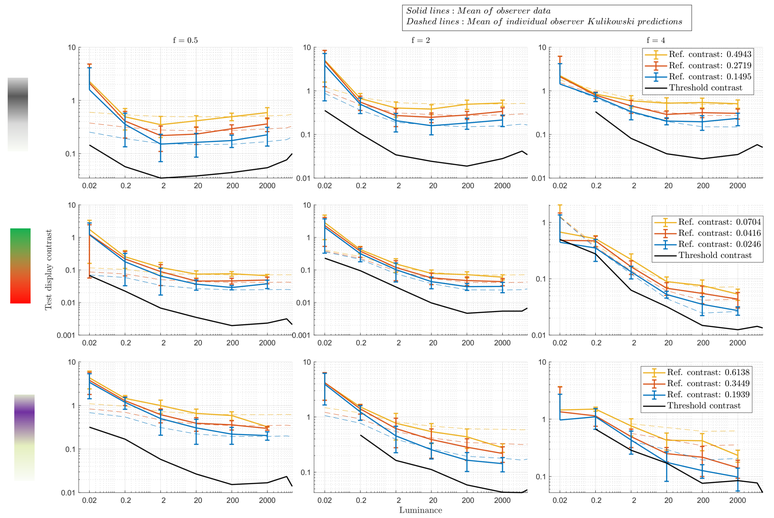
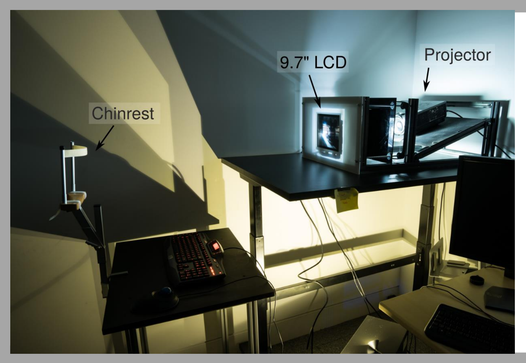


Figure 4: Matched contrasts for three colour channels and three frequencies at three different reference contrast levels

- For both luminance and chromatic contrast matches, Kulikowski's model predicts the contrast appearance well for mid to high luminance levels (> 2 cd/m²)
- The predictions are more consistent for luminance and red-green channel compared to lime-violet
- For low luminance levels (< 2 cd/m²), the matched contrasts from the observers is much higher than predicted by the model
- Individuals' threshold contrast sensitivity has a significant impact on their respective contrast matching results



Apparatus (left): high-dynamic range (HDR) display capable of displaying up to 15,000 cd/m² viewed from 91cm in a dark room[2]

Psychophysical tasks (10 observers)

Contrast sensitivity thresholds
- Task: 4AFC detection
- Thresholds obtained using QUEST

Suprathreshold contrast matching
- Task: Method of adjustment
- Physical contrasts recorded as mean of 5 observations

Conclusions and future work

- We have extended Kulikowski's model to chromatic directions and wider range of luminances
- For low luminance levels, Kulikowki's model predictions are not consistent with our data. Contrast appearance matching for mesopic and scotopic levels to be further investigated
- Effect of stimuli size on contrast appearance matching to be investigated
- We intend to verify our suprathreshold contrast matches using complex images

References

[1] Kulikowski, J. J. "Effective contrast constancy and linearity of contrast sensation." *Vision research* 16.12 (1976): 1419-1431.

[2] Kim, Kil Joong, Rafal Mantiuk, and Kyoung Ho Lee. "Measurements of achromatic and chromatic contrast sensitivity functions for an extended range of adaptation luminance." *Human Vision and Electronic Imaging XVIII.* Vol. 8651. International Society for Optics and Photonics, 2013.

[4] Georgeson, M. A., and G. D. Sullivan. "Contrast constancy: deblurring in human vision by spatial frequency channels." *The Journal of Physiology* 252.3 (1975): 627-656.

[5] Wanat, R., & Mantiuk, R. K. (2014). Simulating and compensating changes in appearance between day and night vision. *ACM Transactions on Graphics* (TOG), 33(4), 147.

[6] Pattanaik, Sumanta N., et al. "A multiscale model of adaptation and spatial vision for realistic image display." *Proceedings of the 25th annual conference on Computer graphics and interactive techniques*. ACM, 1998.

Acknowledgements

Special thanks to Kristof Santa and Olivia Kingston for collecting valuable data for our experiments
This research has been supported by:
- EPSRC EP/P007503
- Apple Inc
- Summer vacation bursary program