Modeling Observer Metamerism through Monte Carlo Simulation

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Mark D. Fairchild, Ph.D.
Associate Professor
Director, Munsell Color Science Laboratory

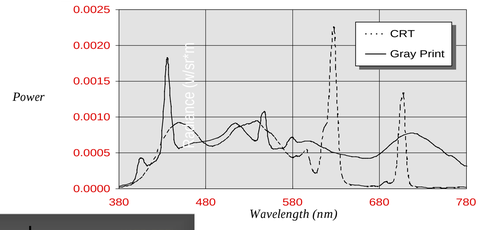
Rochester Institute of Technology

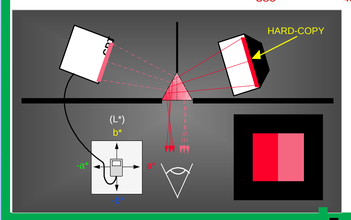
Chester F. Carlson Center for Imaging Science
54 Lomb Memorial Drive
Rochester, New York 14623-5604 USA
716-475-2784 • Fax: 716-475-5988
mdf@cis.rit.edu

Abstract:

Metameric color matches depend on the observer's color matching functions. Data were collected on observer variability in typical metameric matches. A Monte Carlo simulation, using a model of color matching functions and physiological data, was performed to derive a complete colorimetric system capable of predicting inter-observer variability in addition to mean color matches.

Visual Experiment:

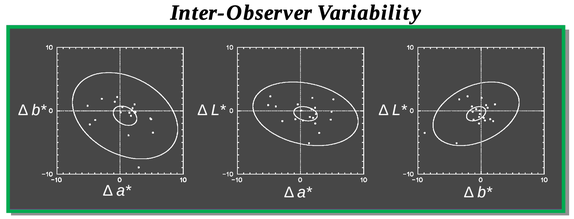


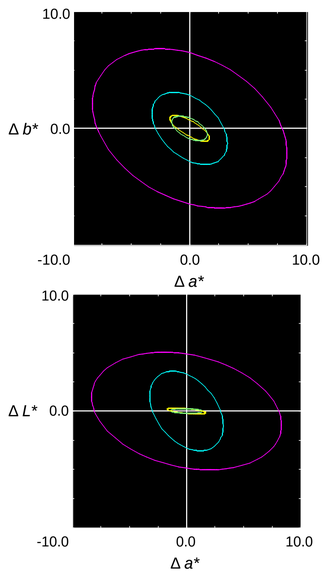


- **Metameric Matching**
- **Color Reproduction Media**
- **20 Observers**
- **7 Colors (CMYKRGB)**
- **2 Media (Print, Transparency)**

Typical Results:

Inter-Observer Variability





Nimeroff *et al.*
CIE Pub. 80
Intra-observer
Inter-observer

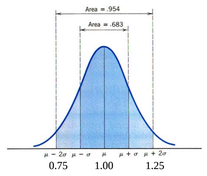
Sample:
Cyan Transparency

Observed and predicted (previously published models) covariance ellipses.

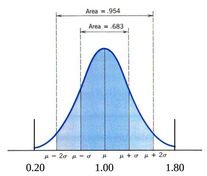
Predictions are inadequate.

Monte Carlo Model:

k Coefficeints Fitted to CIE 1931 Standard Colorimetric Observer



Lens Peak Density

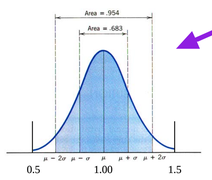


Macula Peak Density

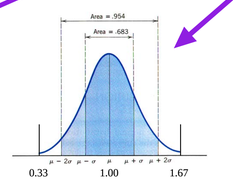
$$\overline{x}'(\lambda) = 10^{-k_{1x}\alpha_{lens}(\lambda)}10^{-k_{2x}\alpha_{macula}(\lambda)}\left[k_{3x}L(\lambda) + k_{4x}M(\lambda) + k_{5x}S(\lambda)\right]$$

$$\overline{y}'(\lambda) = 10^{-k_{1y}\alpha_{lens}(\lambda)}10^{-k_{2y}\alpha_{macula}(\lambda)}\left[k_{3y}L(\lambda) + k_{4y}M(\lambda) + k_{5y}S(\lambda)\right]$$

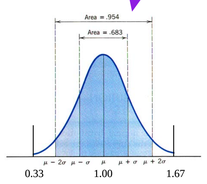
$$\overline{z}'(\lambda) = 10^{-k_{1z}\alpha_{lens}(\lambda)}10^{-k_{2z}\alpha_{macula}(\lambda)}\left[k_{3z}L(\lambda) + k_{4z}M(\lambda) + k_{5z}S(\lambda)\right]$$



L-Cone Peak Density



M-Cone Peak Density



Lens Peak Density

L-Cones:
60% Smith & Pokorny
40% Shifted -4nm (In Wave#)

M-Cones:
88% Smith & Pokorny
12% Shifted +4nm (In Wave#)

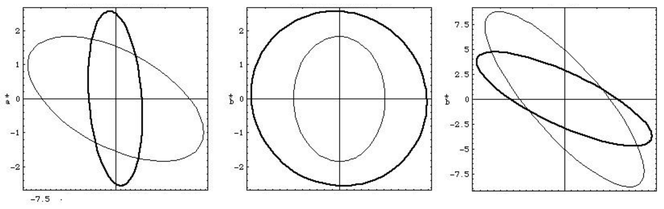
S-Cones:
100% Smith & Pokorny

Monte Carlo Experiment:

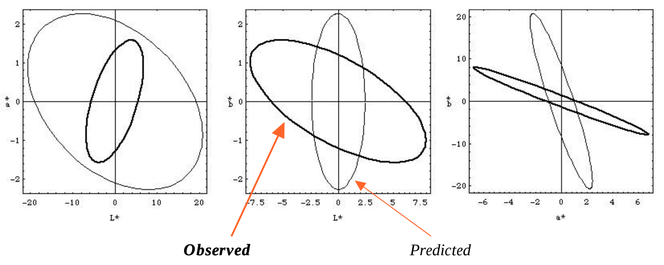
- **10,000 Sets of Color Matching Functions Generated**
- **Mean and Covariance Functions Established**
- **Standard Error Propoagation to CIELAB Covariance Matrices for Observed Metamers**
- **Predicted Covariance Dependent upon Metemeric Properties**

Monte Carlo Results:

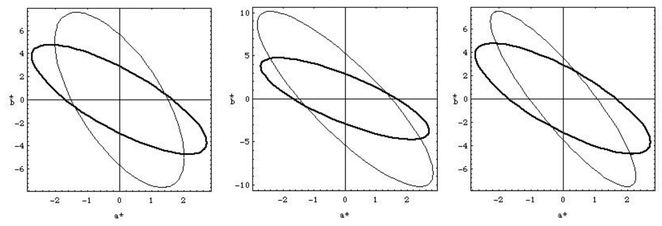
Gray Print: 10,000 Color Matching Functions



Blue Transparency: 10,000 Color Matching Functions



Gray Print: 3 Sets of 20 Color Matching Functions



Conclusions:

- **Observer Variability in Practical Color Matching is Significant**
- **Previously Published Techniques Underpredict Variability**
- **A Monte Carlo Model Produced Better Results**
- **Further Data and Model Refinement are Required**

Acknowledgements / References:

Funding: NSF-NYS / IUCRC & NYSSTF CAT CEIS
Visual Experiment: Rick Alfvin and Jason Gibson

Experimental Results:
R.L. Alfvin and M.D. Fairchild, Observer Variability in Metameric Color Matches using Color Reproduction Media, *Color Res. Appl.* **22,** in press (1997).

CMF Model:
A.D. North and M.D. Fairchild, Measuring Color Matching Functions Part I, *Color Res. Appl.* **18**, 155-162 (1993).

Visual Data Starting Point:
V.C. Smith and J. Pokorny, Chromatic Discrimination Axes, CRT Phosphor Spectra, and Individual Variation in Color Vision, *J. Opt. Soc. Am.* **12**, 27-35 (1995).