CORM 2008

CORM Council for Optical Radiation Measurements

# Color Rendering: A Tale of Two Metrics

Jean Paul Freyssinier, Mark S. Rea

Sponsor: US Environmental Protection Agency

Lighting Research Center



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# Basic issues

- Solid state lighting putting new demands on old metrics
- There are different dimensions of color rendering:
  - Naturalness, hue discrimination, vividness, preference, color naming accuracy
- CRI used exclusively by lighting industry
  - Known limitations
  - Poor predictor of preference and color naming accuracy
  - Implications for energy savings and standards

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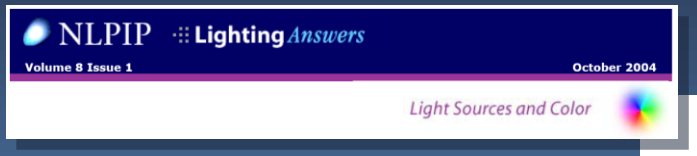
# Specifiers' views on color characteristics




www.lrc.rpi.edu/nlpip/publicationDetails.asp?id=901&type=2

**Table 1. Most useful light source color characteristics.**

| Characteristic | Average Usefulness Rating | Standard Deviation | Number of Responses |
|---|---|---|---|
| Color Rendering Index (CRI) | 3.5 | 0.7 | 237 |
| Correlated Color Temperature (CCT) | 3.2 | 1.0 | 233 |
| Color Stability | 3.2 | 1.0 | 232 |
| Lamp Type | 3.1 | 1.0 | 235 |
| Color Consistency | 3.1 | 1.0 | 228 |
| **Spectral Power Distribution (SPD)** | 2.4 | 1.2 | 226 |
| **Full-Spectrum Index (FSI)** | 2.0 | 1.3 | 204 |
| Brand Name | 1.9 | 1.2 | 226 |
| **Gamut Area** | 1.5 | 1.2 | 189 |

(Rating Key: 0 = Not useful; 4 = Very useful)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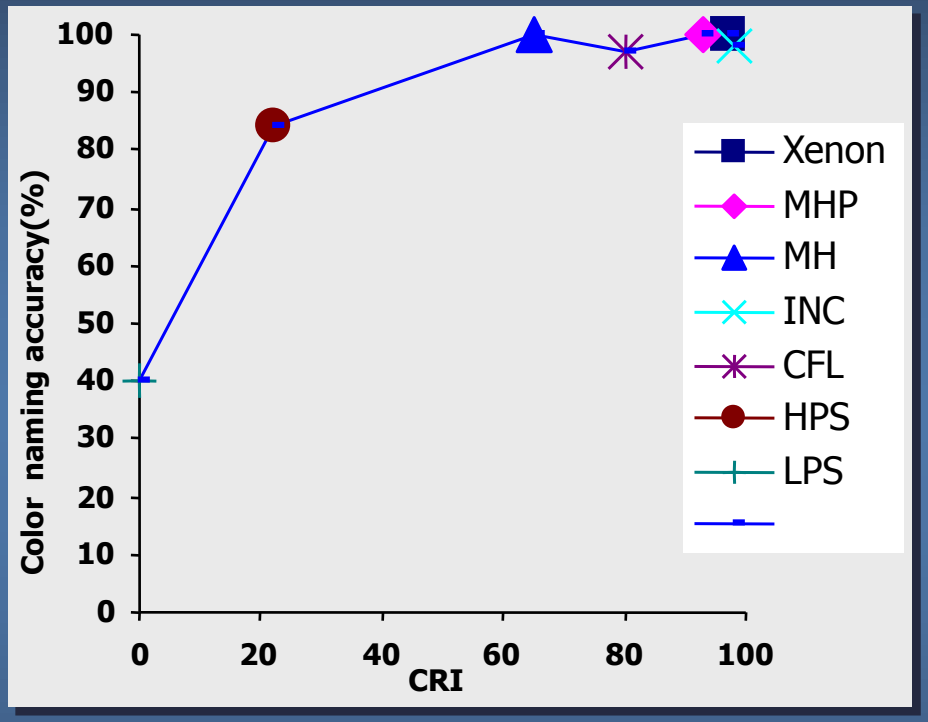
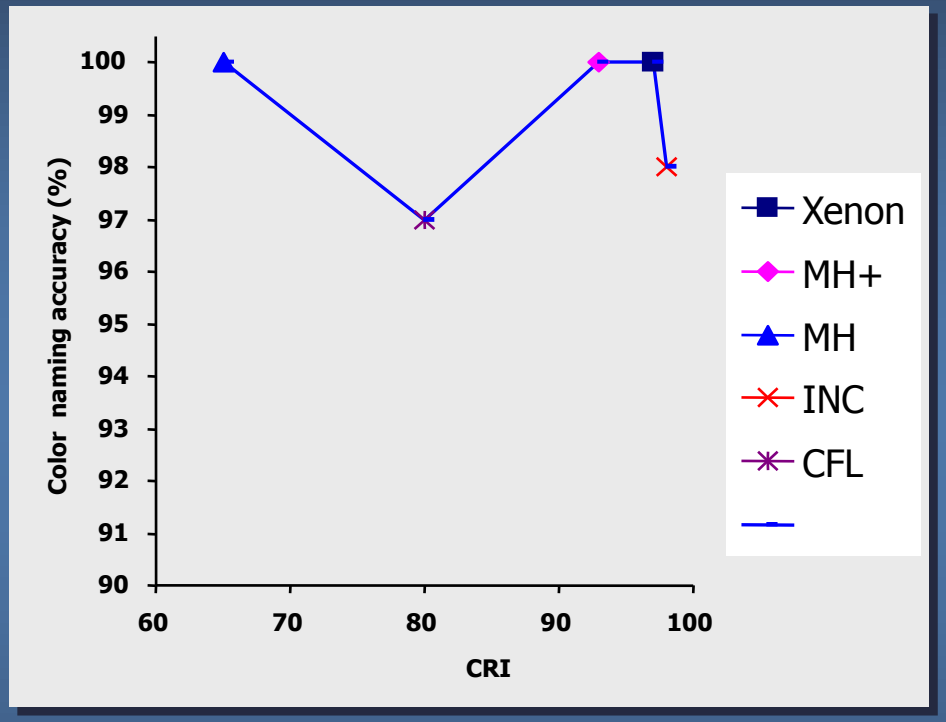
# CRI and Color Naming Accuracy




CRI is not a good predictor of color naming accuracy.

**An evaluation of the Hunt94 color appearance model under different light sources at low photopic to low mesopic light levels**
Lei Deng, Linsheng Chen, Mark S. Rea. 2005. ***Color Research & Application***; Volume 30, Issue 2, Date: April 2005, Pages: 107-117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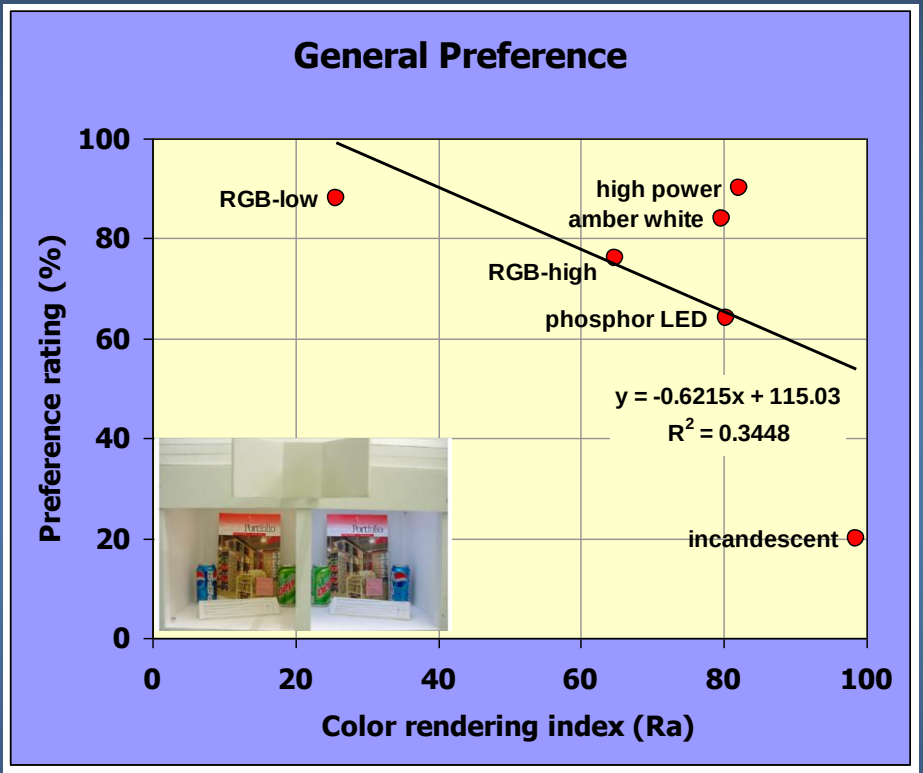
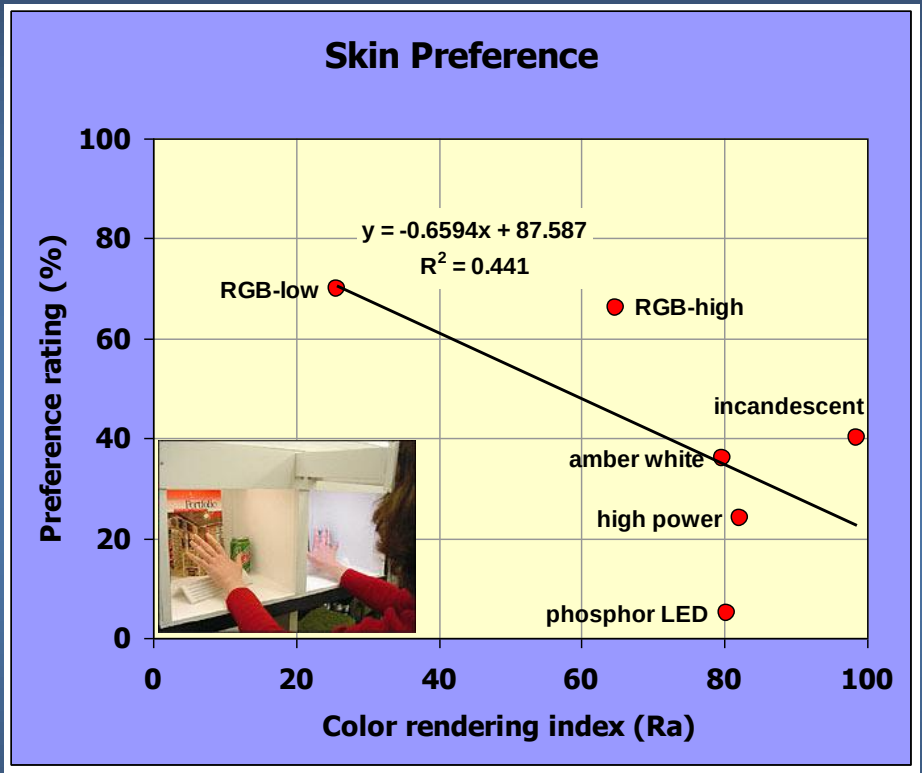
# CRI and Color Preference




CRI is not a good predictor of color preference.

**Color Rendering Properties of LED Light Sources**
Nadarajah Narendran and Lei Deng. 2002. *Solid State Lighting II: Proceedings of SPIE*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# Basic issues

- Not clear what "color rendering" means
- Bouma (1947): suggested that daylight is the best source because
  - can tell differences among colors (hue, lightness, and saturation)
  - can discriminate among subtle shades
  - can make objects appear natural


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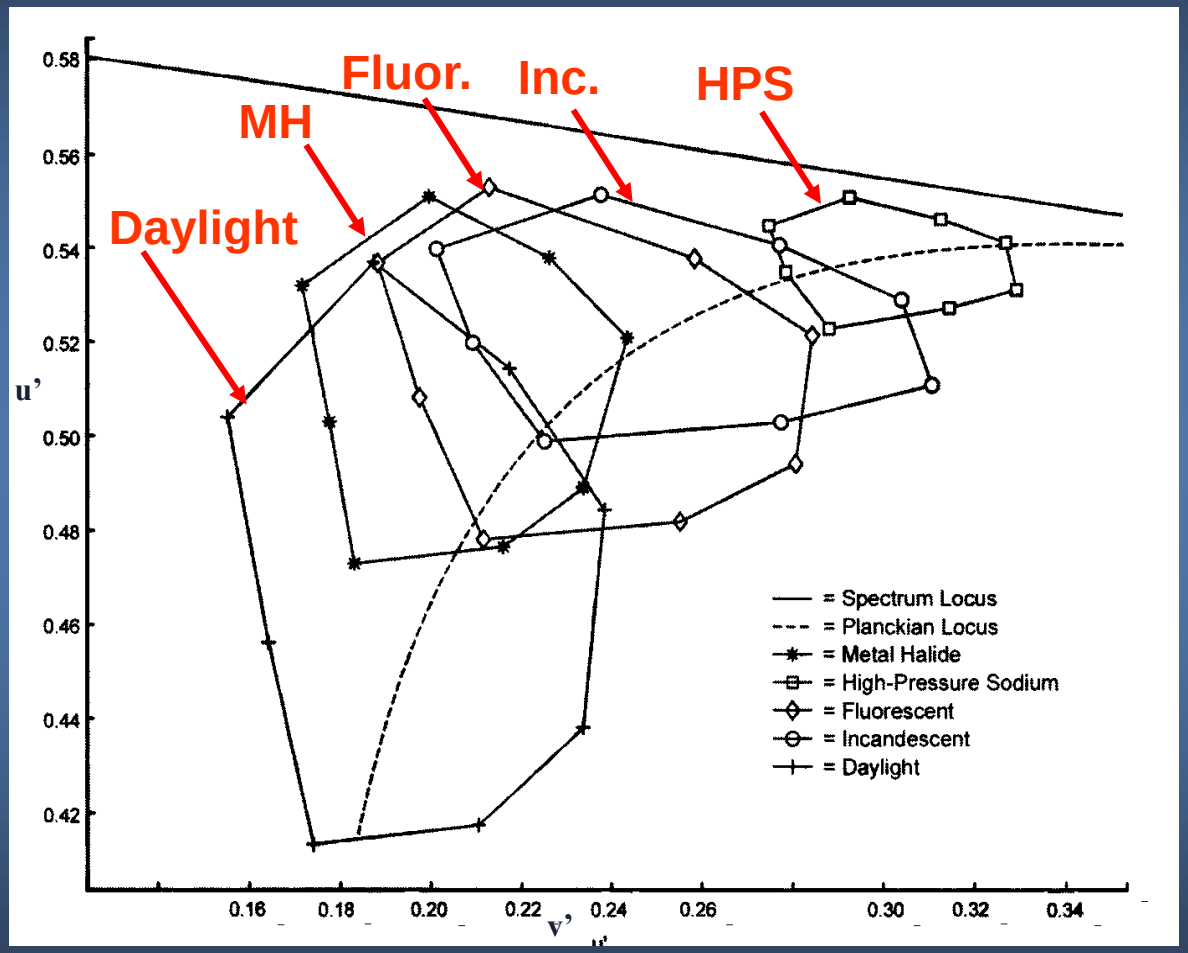
# Color Gamut Area

- In general, the larger the gamut area, the more saturated the color samples are, and the easier it is to discriminate between them.




Adapted from ***Human Factors in Lighting* - 2nd Edition**
Boyce, P. R. 2003. London; New York: Taylor & Francis.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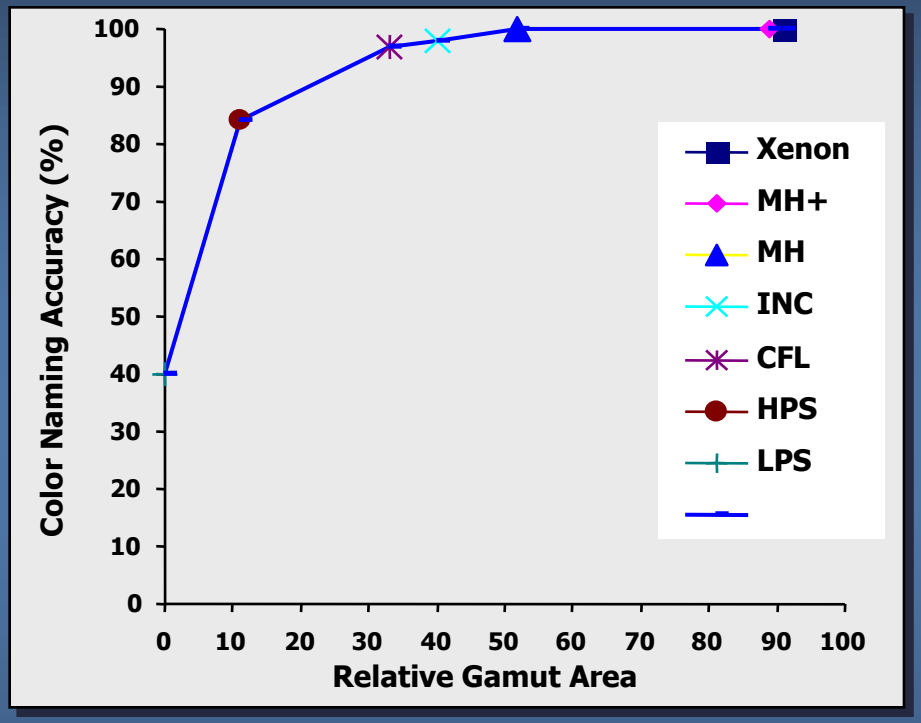
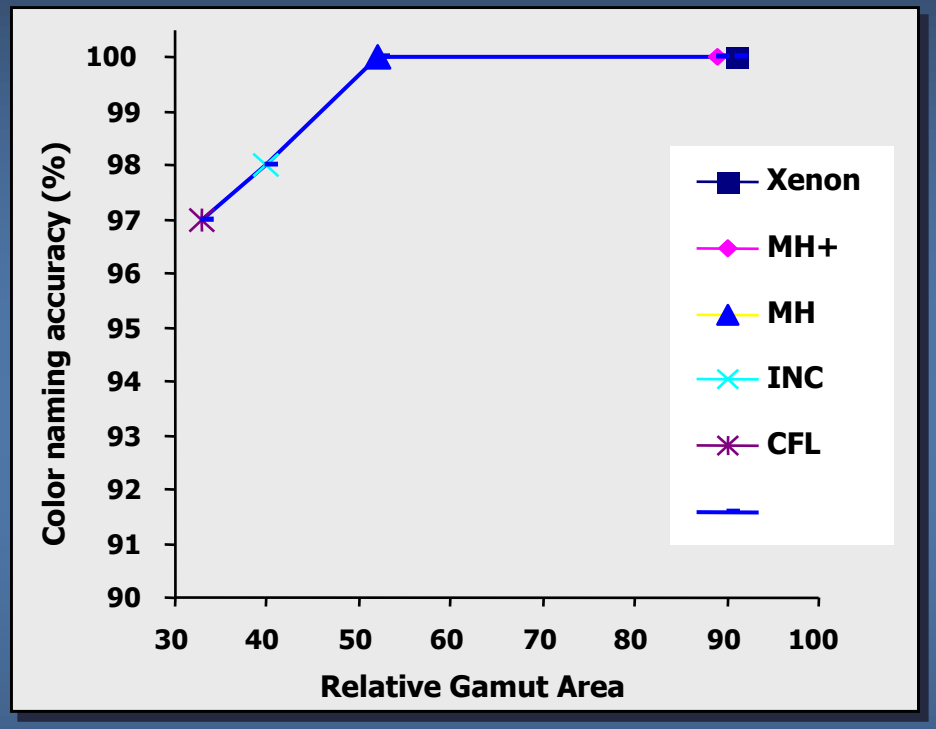
# Gamut Area and Color Naming Accuracy




Color gamut area is a good predictor of color naming accuracy.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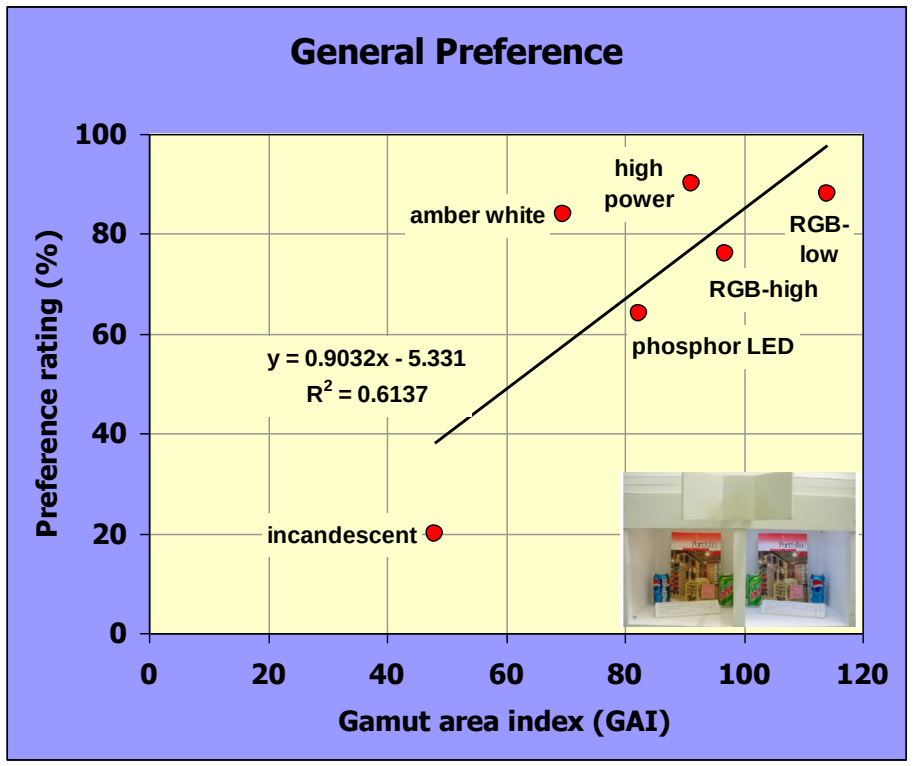
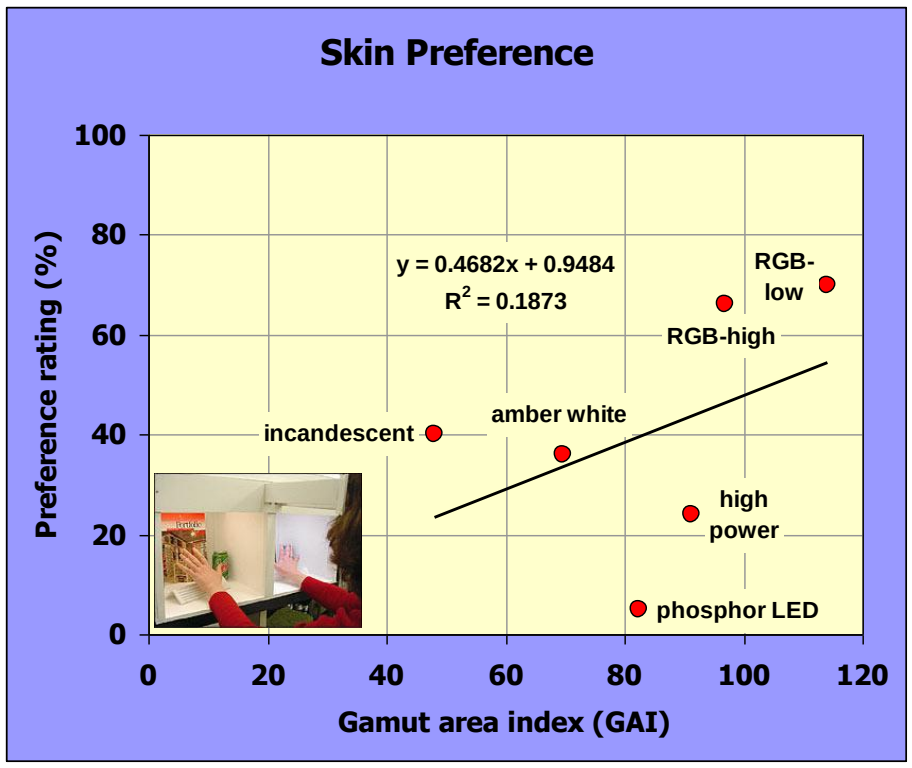
# Gamut Area and Color Preference




Color gamut area can be a better predictor of color preference than CRI.

**Color Rendering Properties of LED Light Sources**
Nadarajah Narendran and Lei Deng. 2002. *Solid State Lighting II: Proceedings of SPIE*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# Experimental Approach

- Objective evaluation
  - Farnsworth-Munsell 100 hue test
- Subjective evaluation
  - Restrict colors to red and blue
  - Restrict subjective responses to *vividness* and *naturalness*
  - Paired comparisons (sequential) for *vividness* and *naturalness*
- Compare different light levels
- Examine correlations of subjective and objective evaluations to CRI and GA


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# Apparatus

- Farnsworth-Munsell 100-hue color vision test
- Collage of Cardinals and Blue Jays pictures

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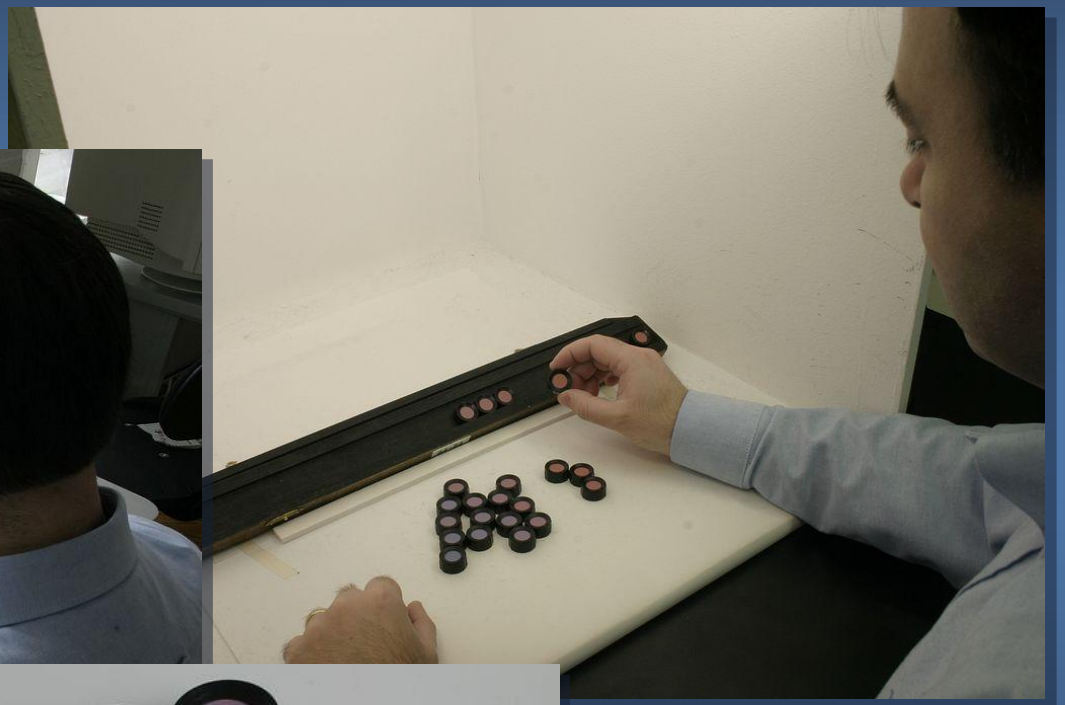
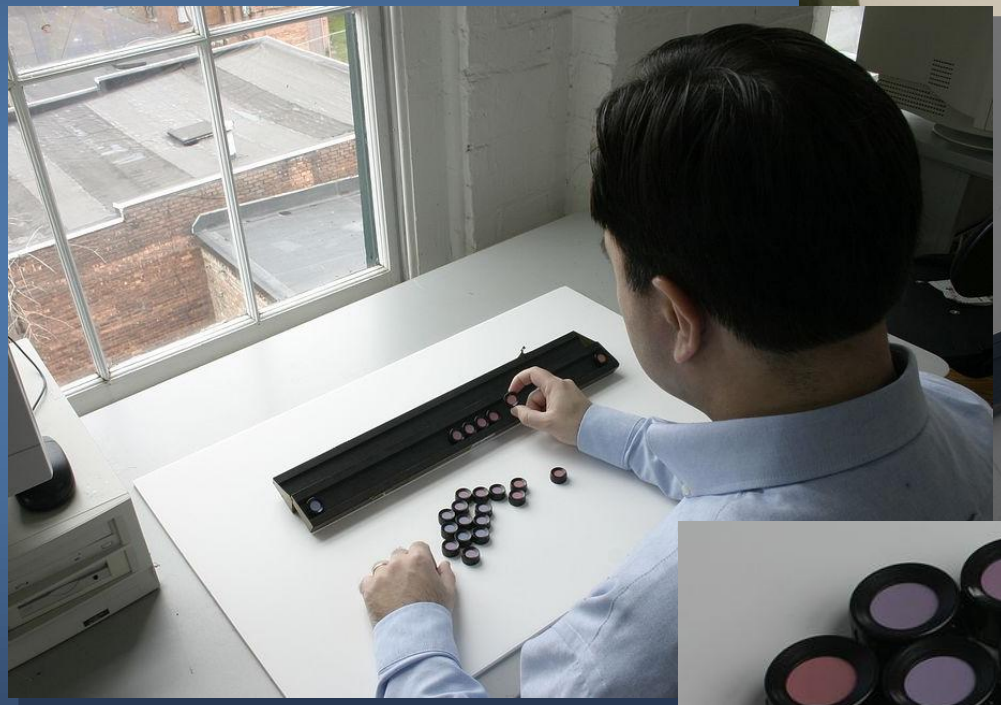
# Experiment setup

**Electric light sources conditions**



**Daylight conditions**



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# Apparatus

- Eight phosphor-based light sources
- Two light levels: 5 fc and 50 fc

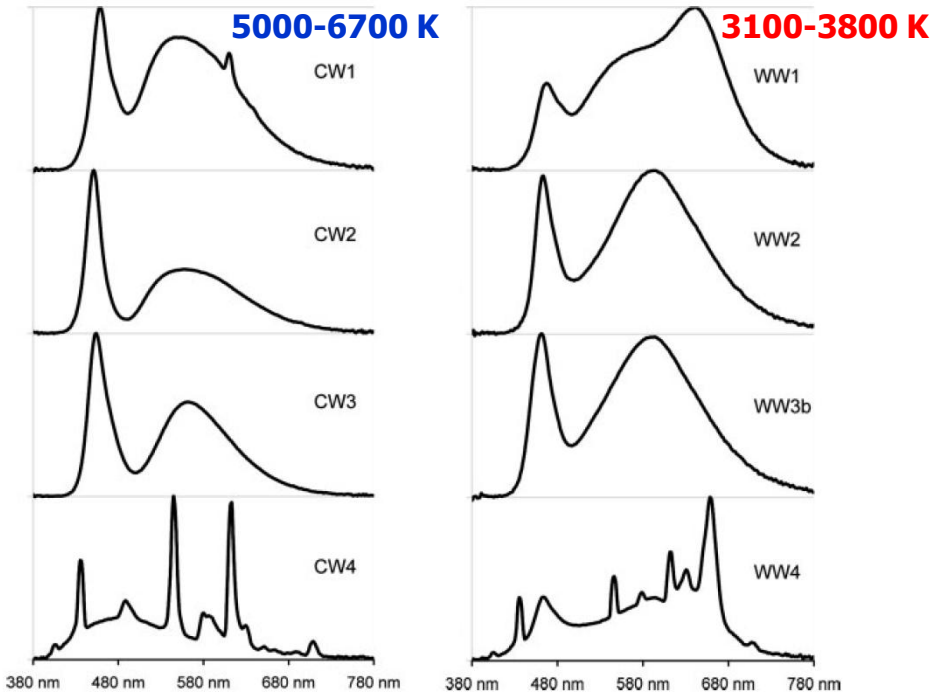


FIG. 2. Normalized spectral power distributions of the illuminants used in this study at 50 fc. Color characteristics or each illuminant are summarized in Table I.

Farnsworth-Munsell 100-hue test



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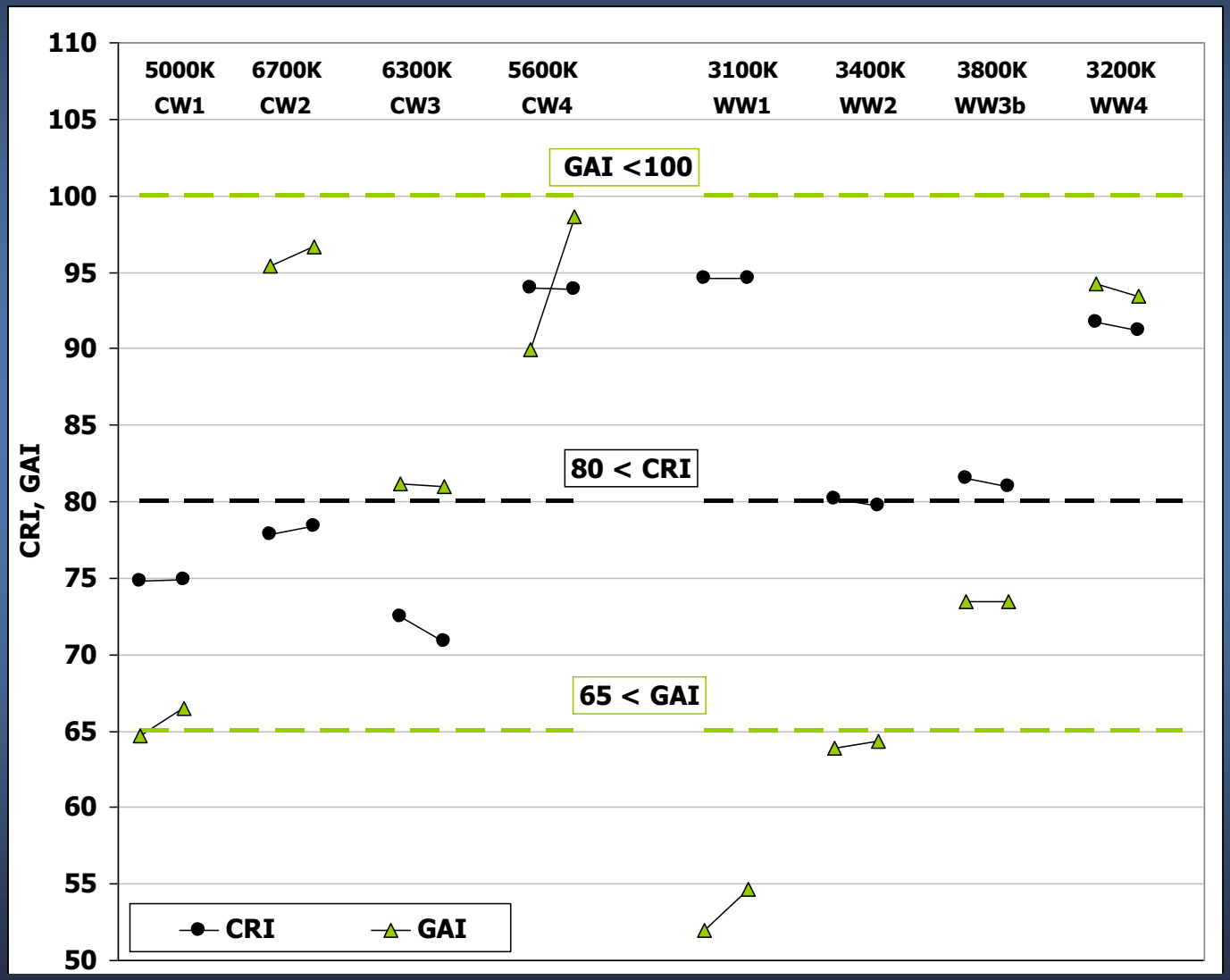
# Apparatus

- CRI and GAI of the 8 light sources used in the experiments at 5 fc (left) and 50 fc (right).



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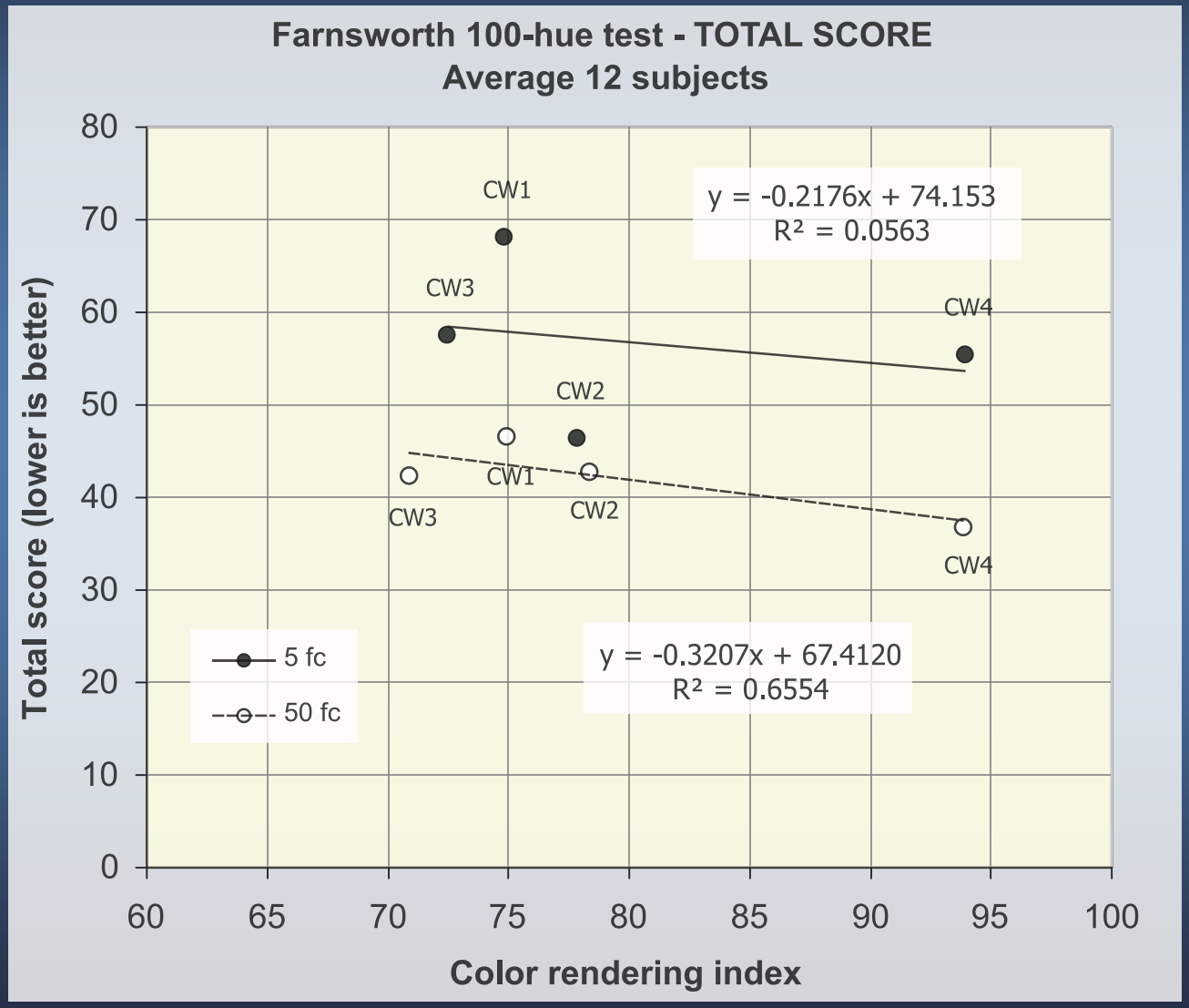
# Farnsworth test results



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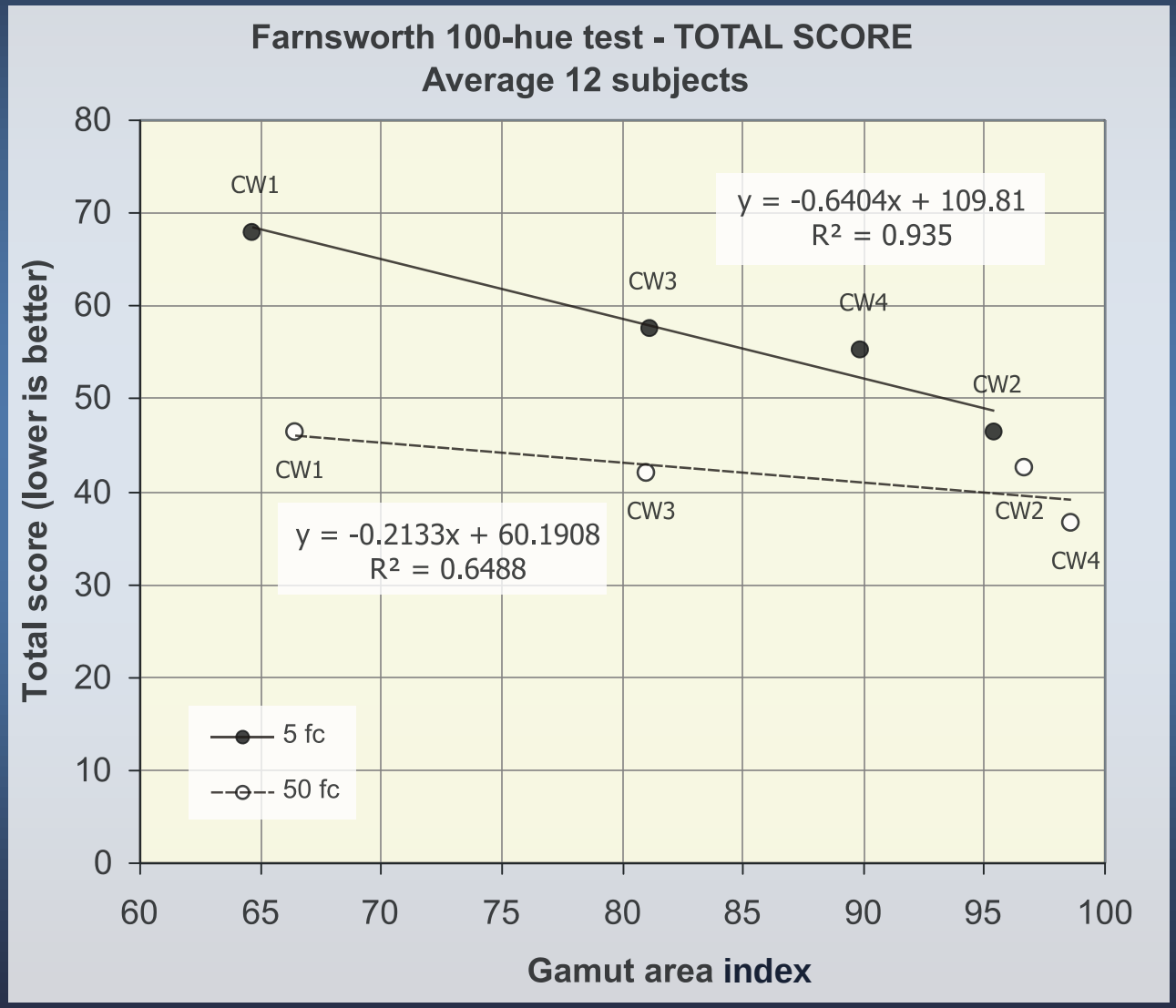
# Farnsworth test results



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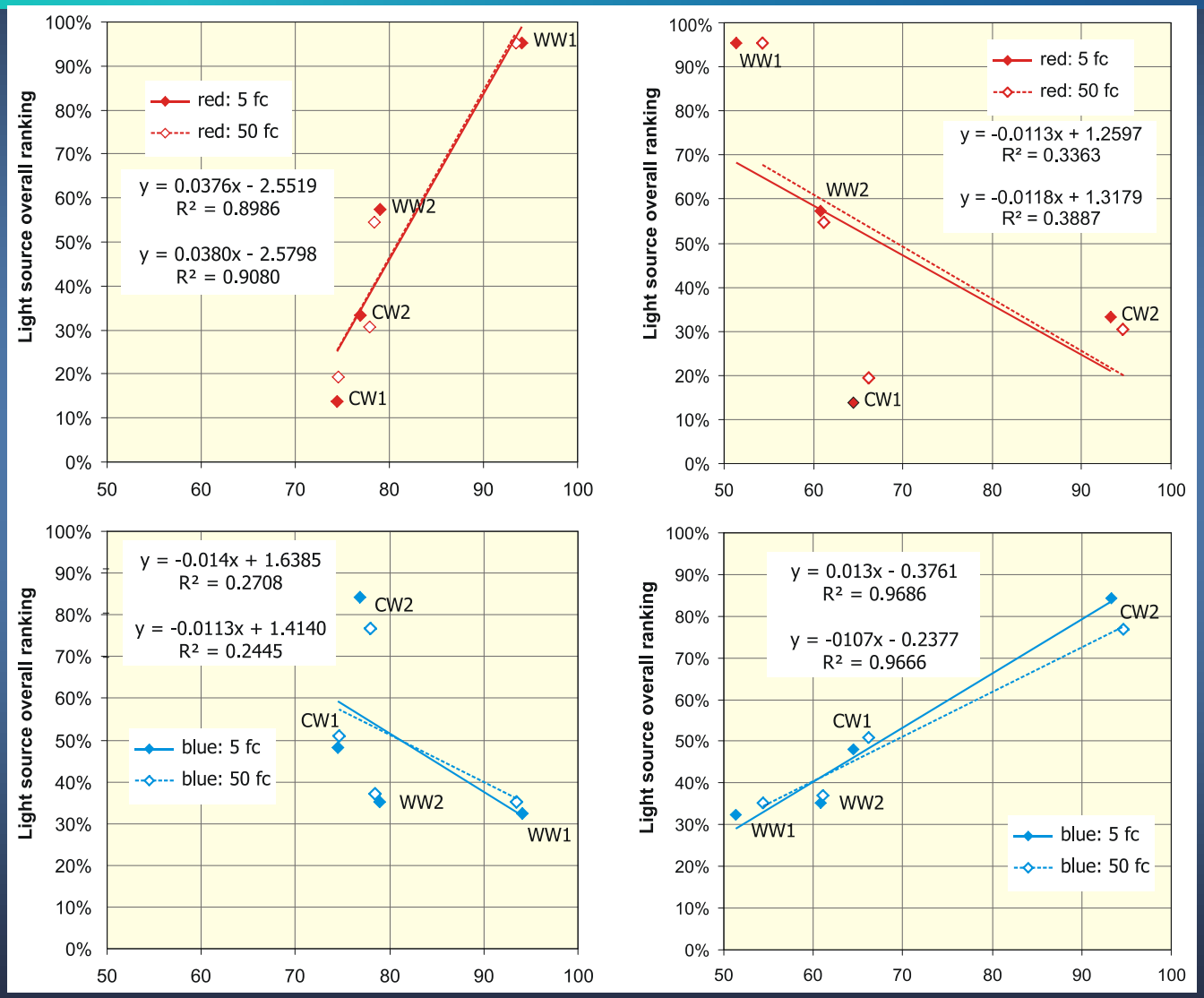
# Paired comparisons mixed CCTs: Vividness

CRI GAI

red

blue



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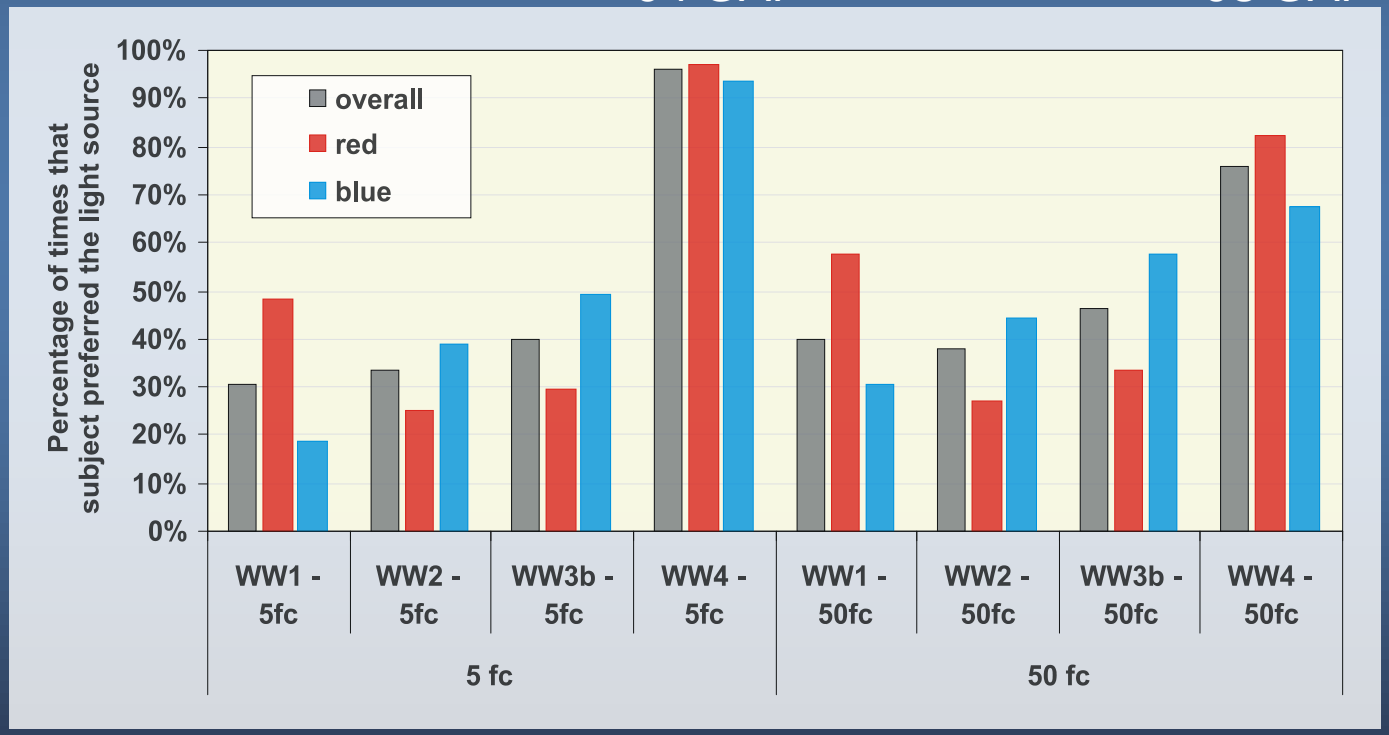
# Paired comparisons: Vividness

- Warm CCTs (3100-3800 K)

92 CRI
94 GAI

91 CRI
93 GAI





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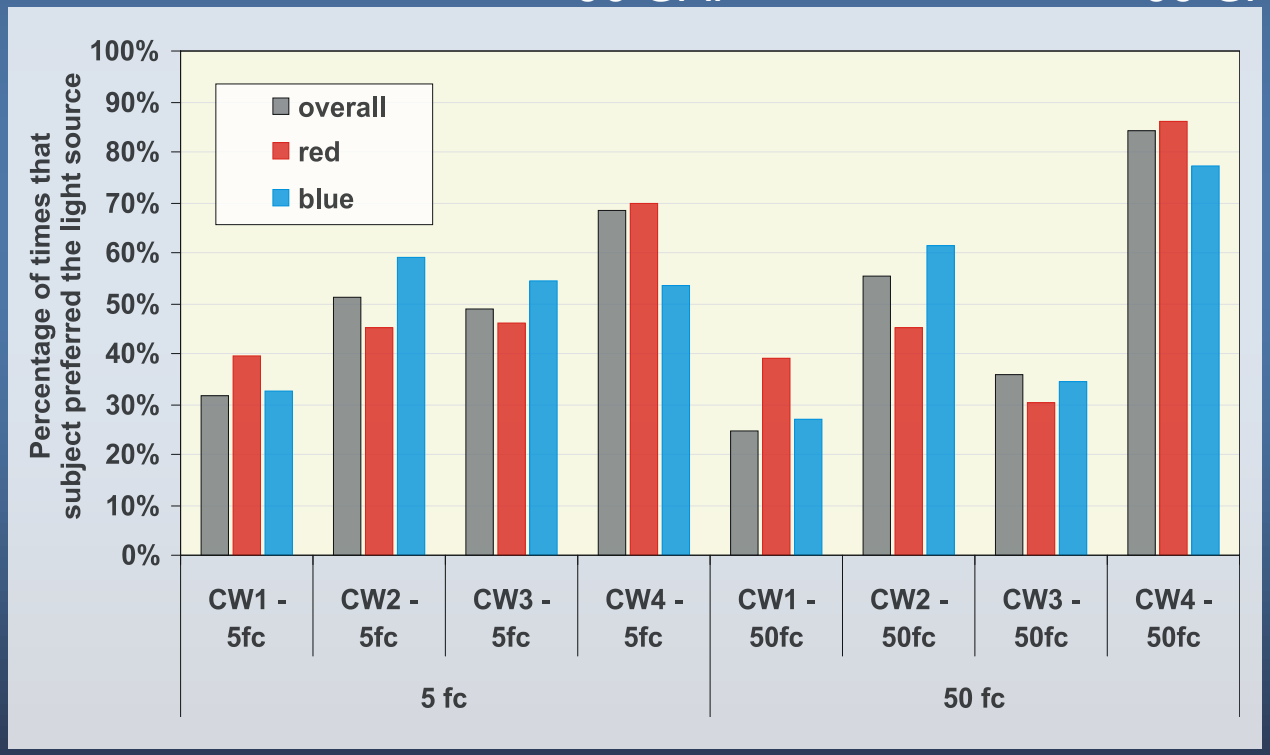
# Paired comparisons: Vividness

- Cool CCTs (5000-6700 K)

94 CRI
90 GAI

94 CRI
99 GAI





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# Summary

- Light level is important for color rendering.
- Color rendering encompasses many dimensions. One can be fooled by using just one metric, even with GAI.
- These results are not a complete test of the two-metric hypothesis, but the evidence to date indicates that using CRI and GAI together can ensure good color rendering.


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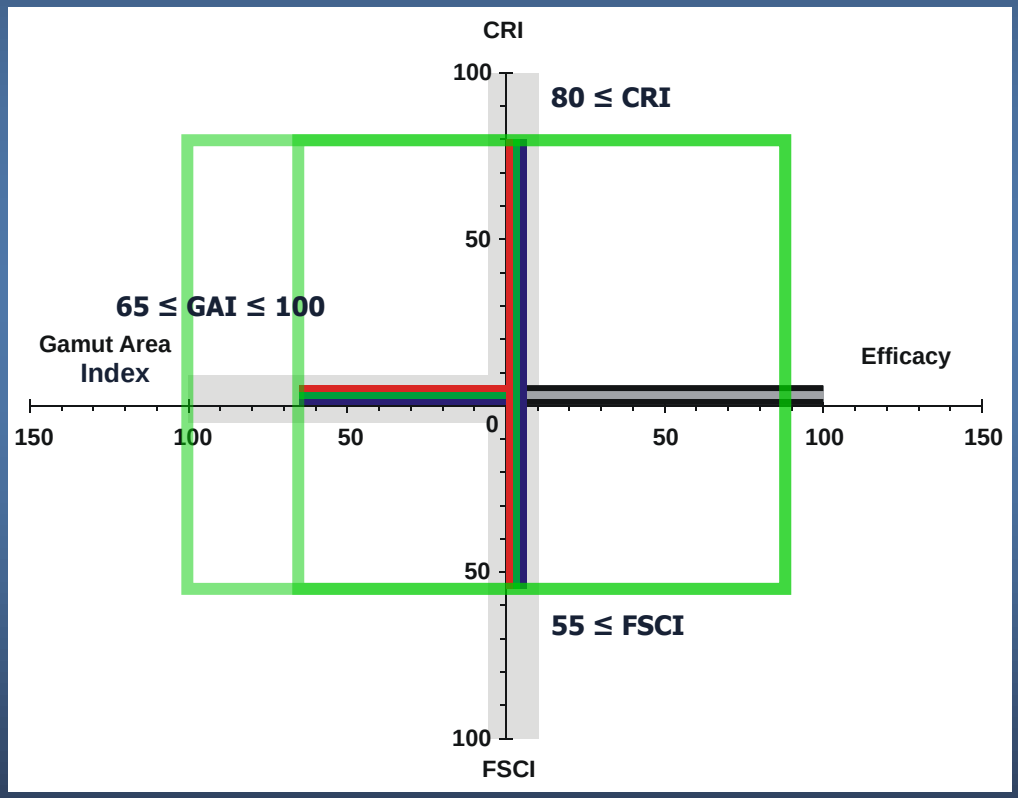
# Summary

- Current recommendation based on NICU+ standards:

**80 ≤ CRI**
**<u>and</u>**
**65 ≤ GAI ≤ 100**




+A Discussion of Recommended Standards for Lighting in the NICU
Figueiro MG, Appleman K, Bullough JD, Rea MS. 2006. *Journal of Perinatology*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# Thank you!

**Acknowledgements:**

Peter Banwell, EPA

Yukio Akashi, University of Fukui

Andrew Bierman, LRC

John Bullough, LRC

Mariana Figueiro, LRC

Dennis Guyon, LRC

Russ Leslie, LRC

Rui Qi, LRC

Robert Wolsey, LRC



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