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# TM-30, Color Preference, and More

**Lightfair**

April 27, 2016

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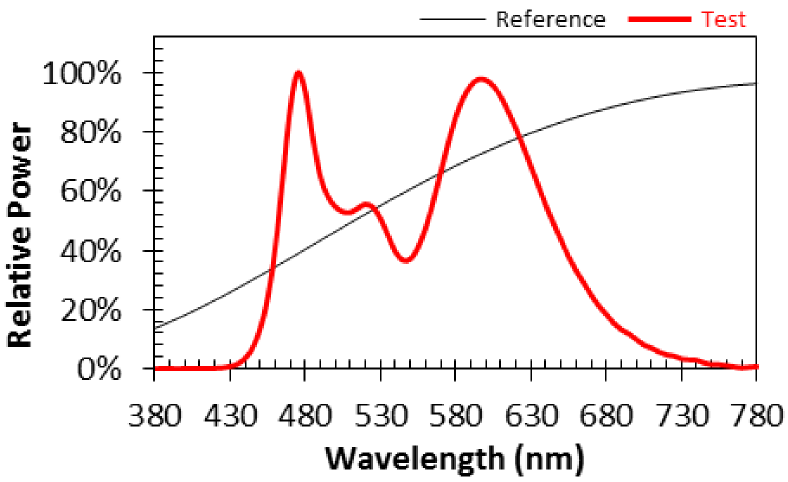
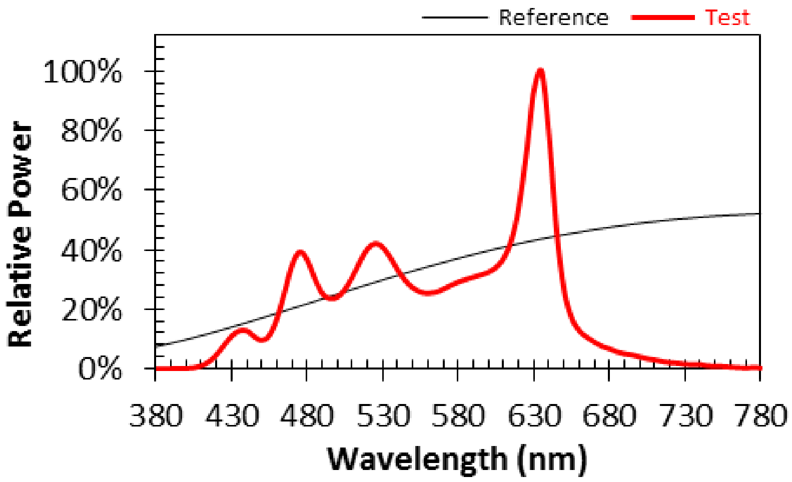
Lighting Engineer

Pacific Northwest National Laboratory



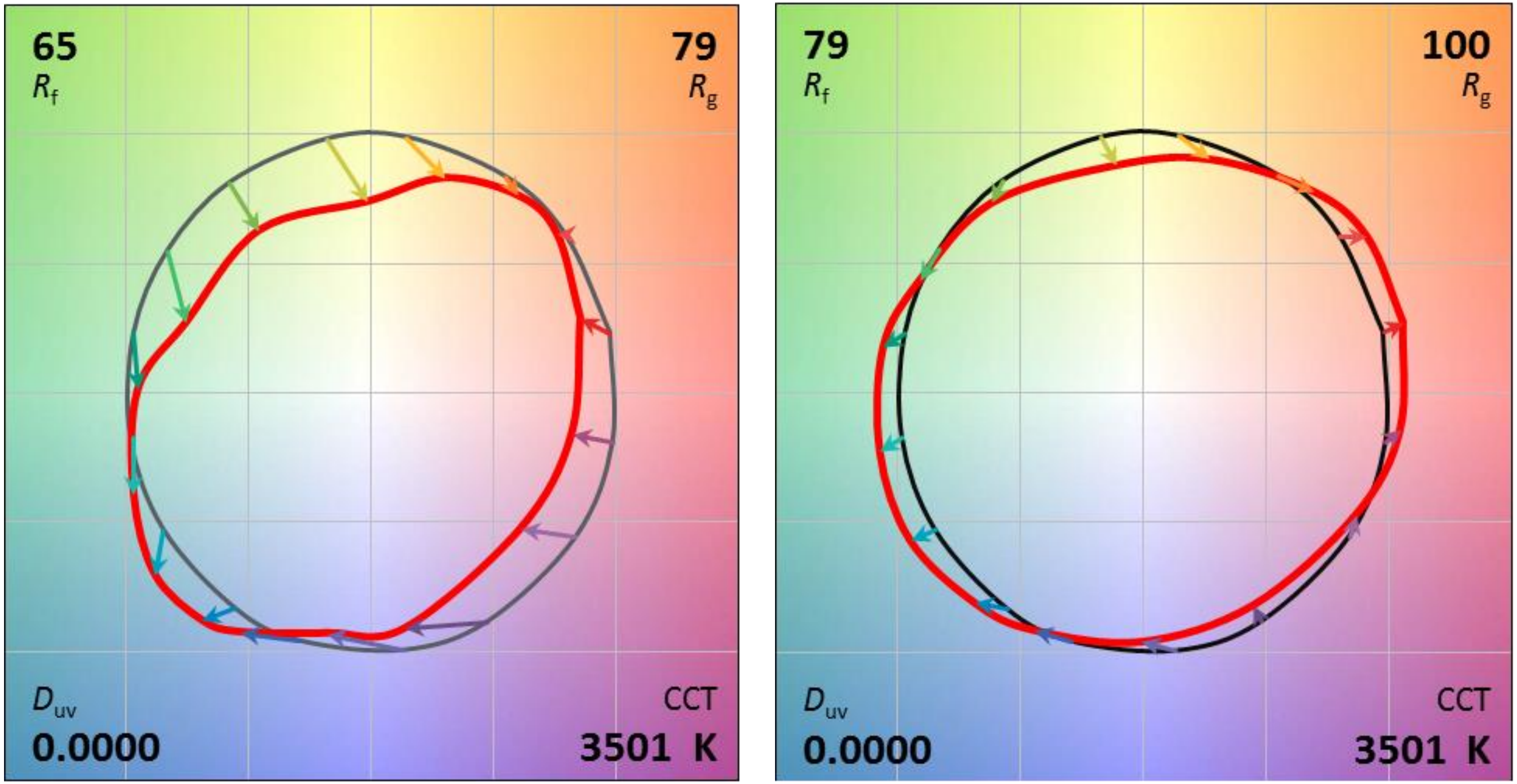

$R_a$ (CRI) = 75

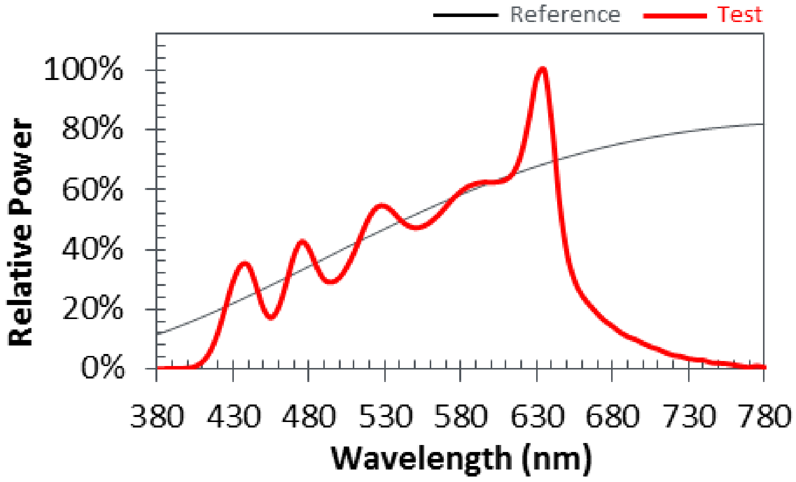
$R_9$ = 20




$R_a$ (CRI) = 77

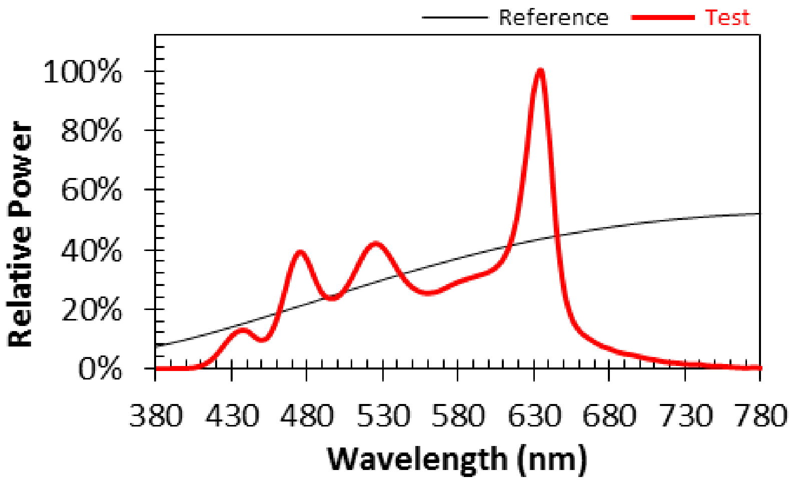
$R_9$ = 22


65
$R_f$
79
$R_g$
$D_{uv}$
0.0000
CCT
3501 K
79
$R_f$
100
$R_g$
$D_{uv}$
0.0000
CCT
3501 K



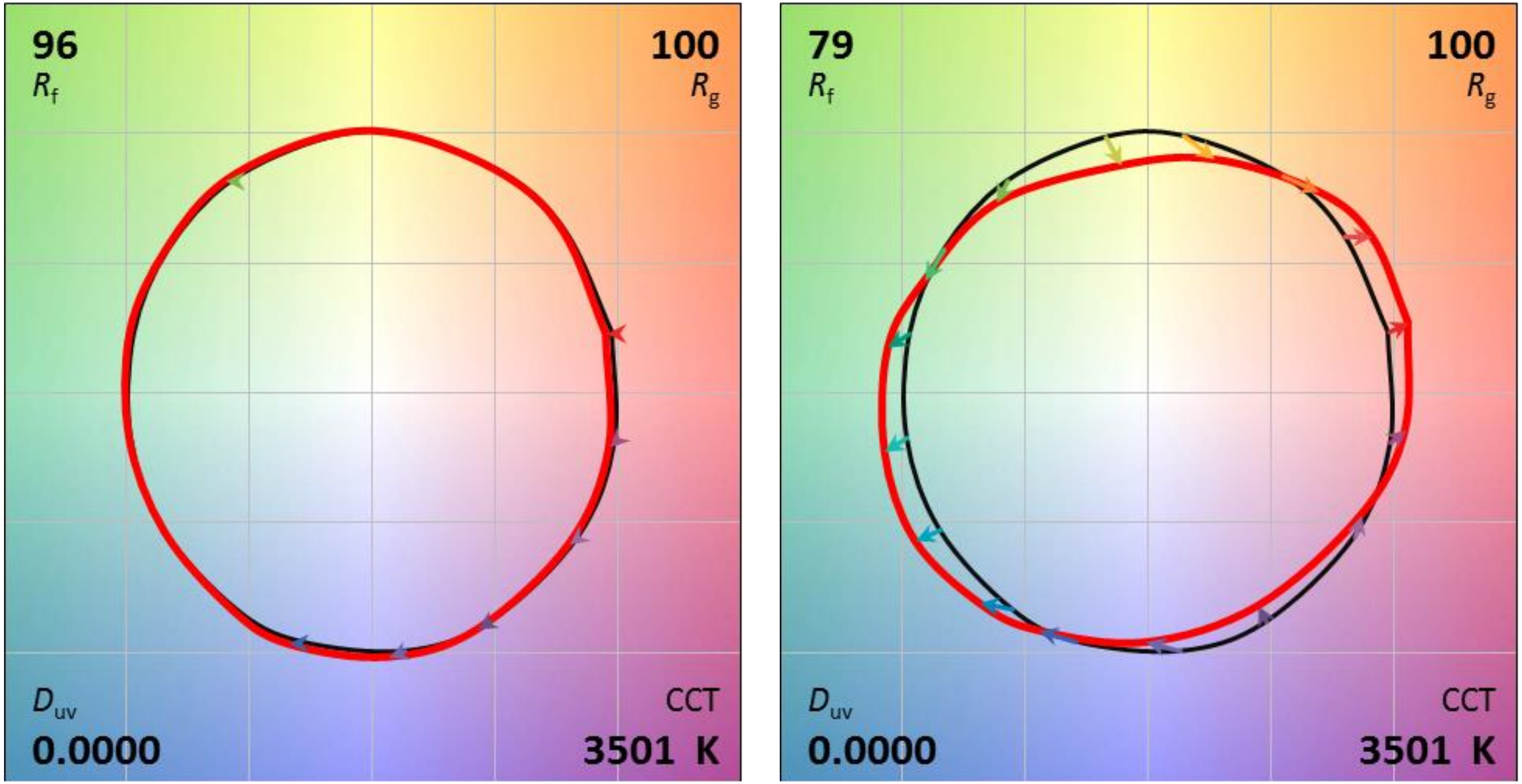

$R_a$ (CRI) = 98

$R_9$ = 83




$R_a$ (CRI) = 77

$R_9$ = 22



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# Topics

1. Can I accurately predict how the colors in a space will appear?
2. Will a given appearance be liked (or perceived as natural, saturated, etc.)?
3. How will color quality evolve in a changing lighting industry?

# Is TM-30 More Accurate?

| CRI Calculation Engine (1974) | TM-30 Calculation Engine (2015) | |
|---|---|---|
| Fidelity Only | Fidelity, Gamut, Graphical, Hues | Philosophical Change |
| CIE 1964 U*V*W* | CAM02-UCS (CIECAM02) | Technical Improvement |
| Von Kries CAT | CIE CAT02 | Technical Improvement |
| 8 color samples<br>Medium chroma/lightness<br>Spectral sensitivity varies<br>Munsell samples only | 99 color samples<br>Uniform color space coverage<br>Spectral sensitivity neutral<br>Variety of real objects | Technical Improvement |
| No lower limit for scores | 0 to 100 scale (fidelity) | Nice to Have |
| Ref Illuminant Step Function | Ref Illuminant Continuous<br>(Uses same reference sources, but blended between 4500 K and 5500 K) | Nice to Have |

# TM-30: A Set of Tools for Understanding Color Rendition

**CRI Calculation Engine**

Outdated Color Science
Limited Color Samples

**Average Fidelity**
$R_a$ (CRI)

**Specific Sample Fidelity**
$R_9$

**TM-30 Calculation Engine**

Modern Color Science
New Color Samples

**High Level Average Values**
Fidelity Index ($R_f$)
Gamut Index ($R_g$)

**Graphical Representations**
Color Vector Graphic
Color Distortion Graphic

**Detailed Values**
Skin Fidelity ($R_{f,skin}$)
Fidelity by Hue ($R_{f,h\#}$)
Chroma Shift by Hue ($R_{cs,h\#}$)
Fidelity by Sample ($R_{f,CES\#}$)

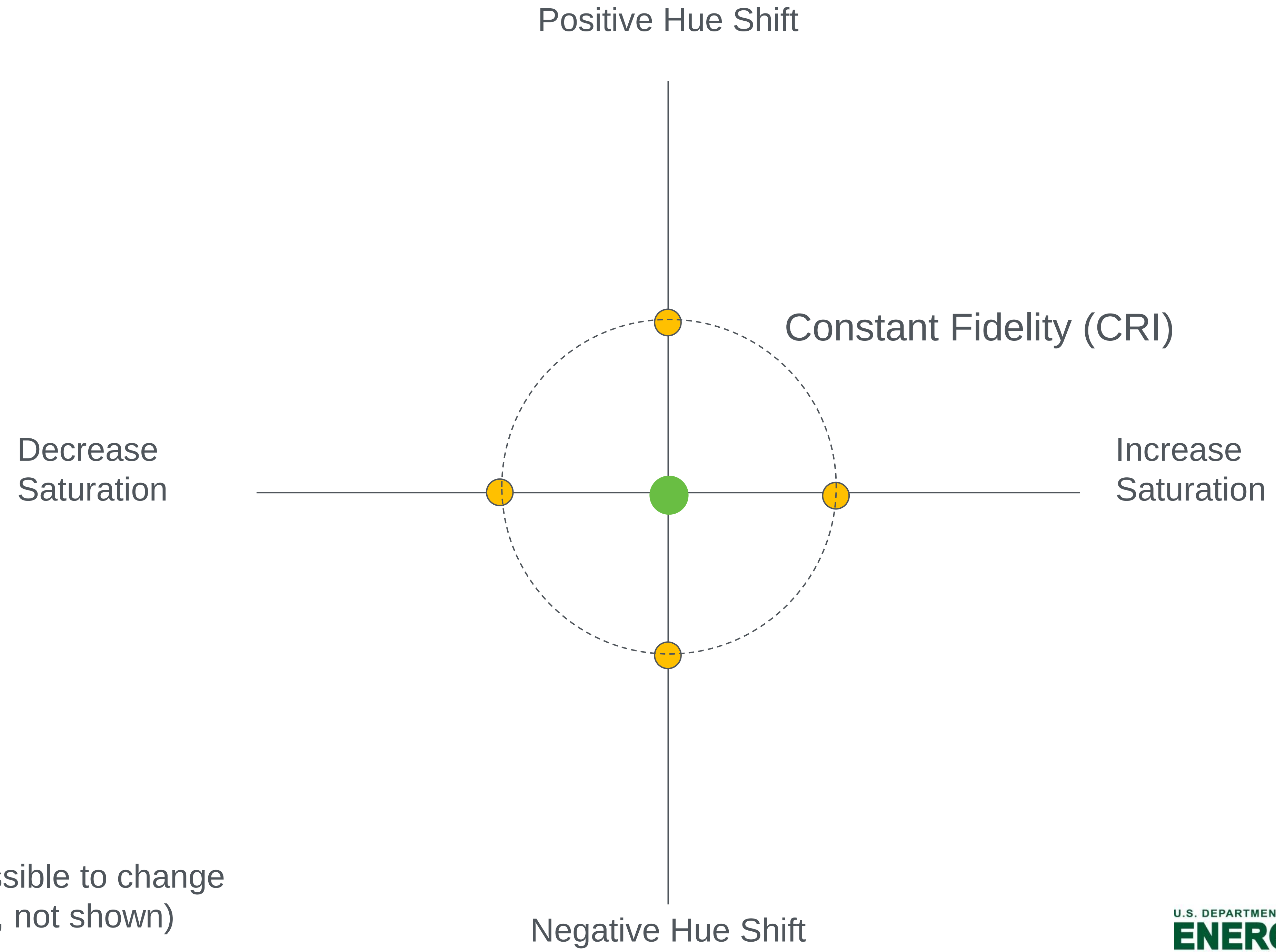
# TM-30 Method for Evaluating Color Rendition

## Color Fidelity

The accurate rendition of color so that they appear as they would under familiar (reference) illuminants

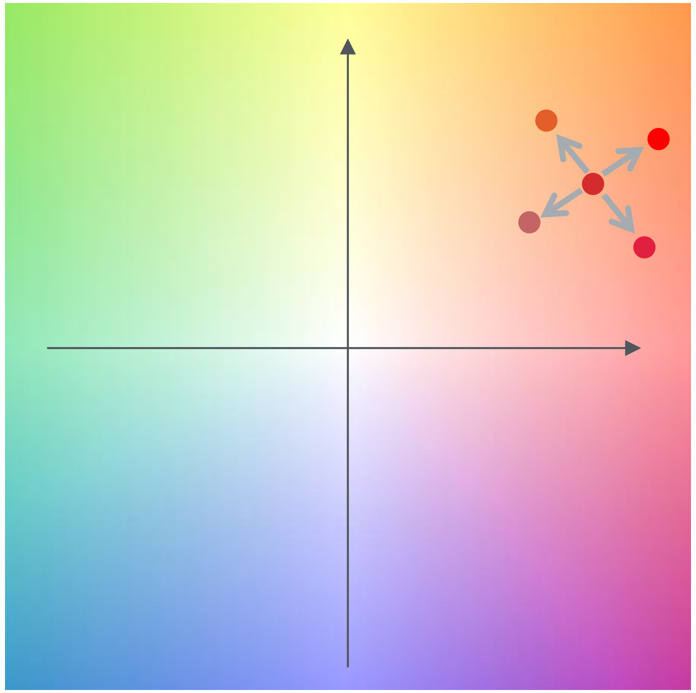
**Fidelity Index (*$R_f$*)**

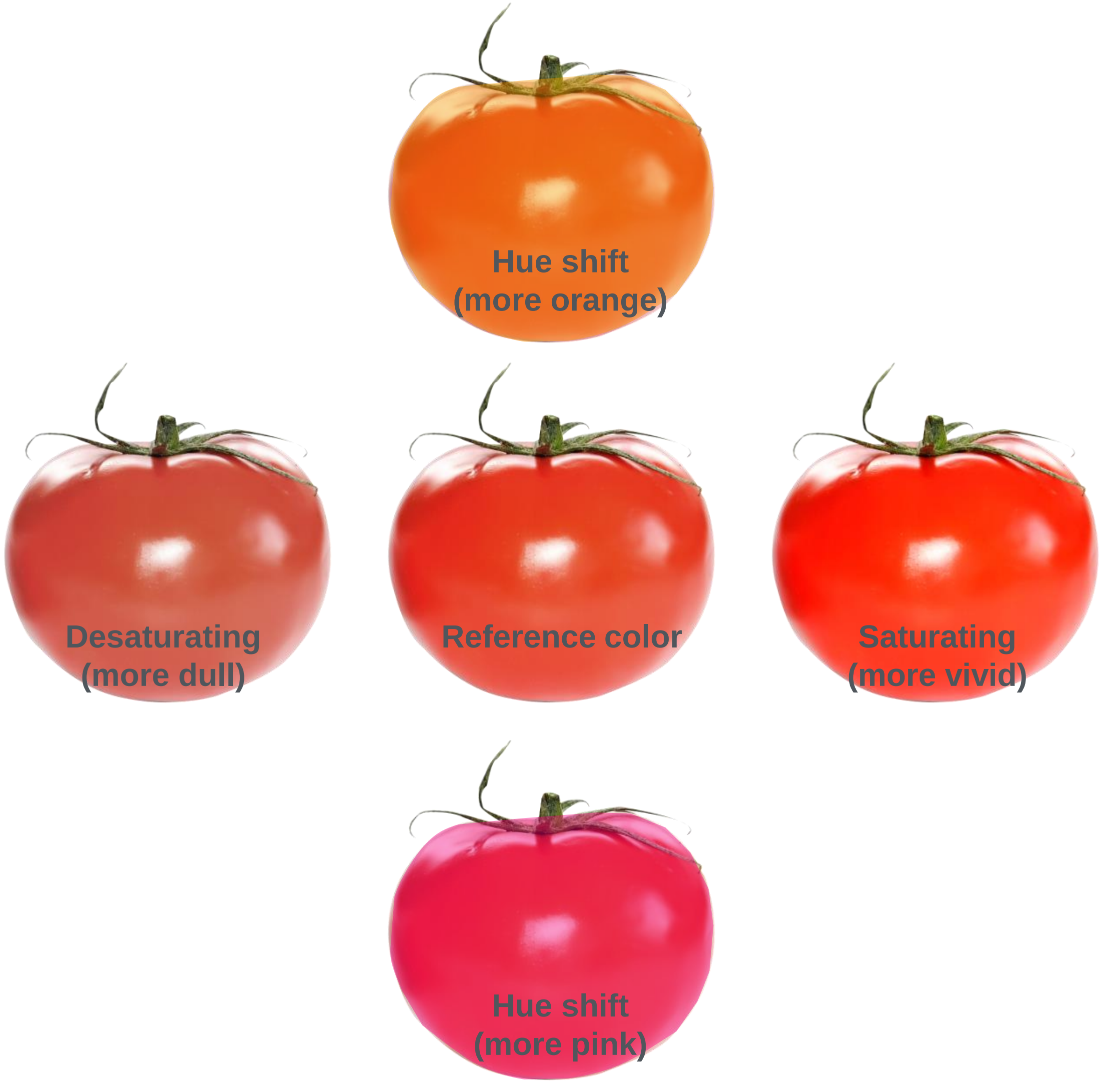
(0-100)




(Also possible to change lightness, not shown)

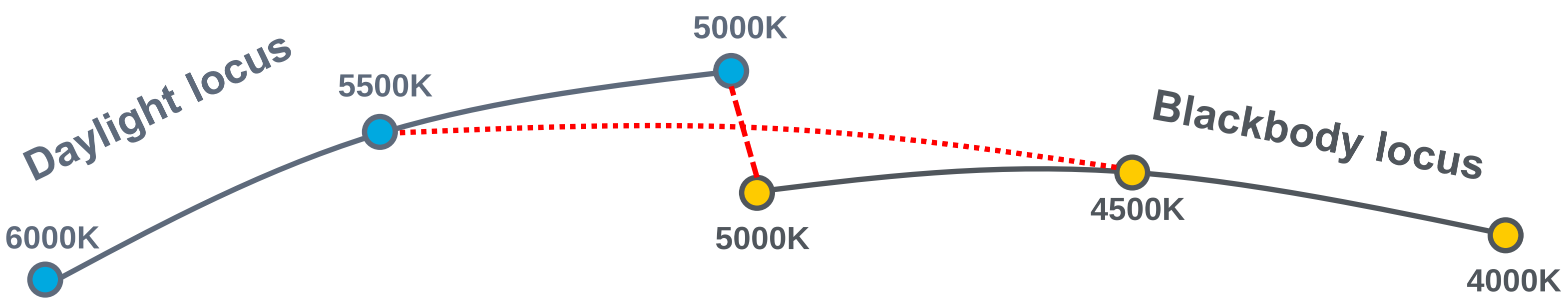
# Color Shifts





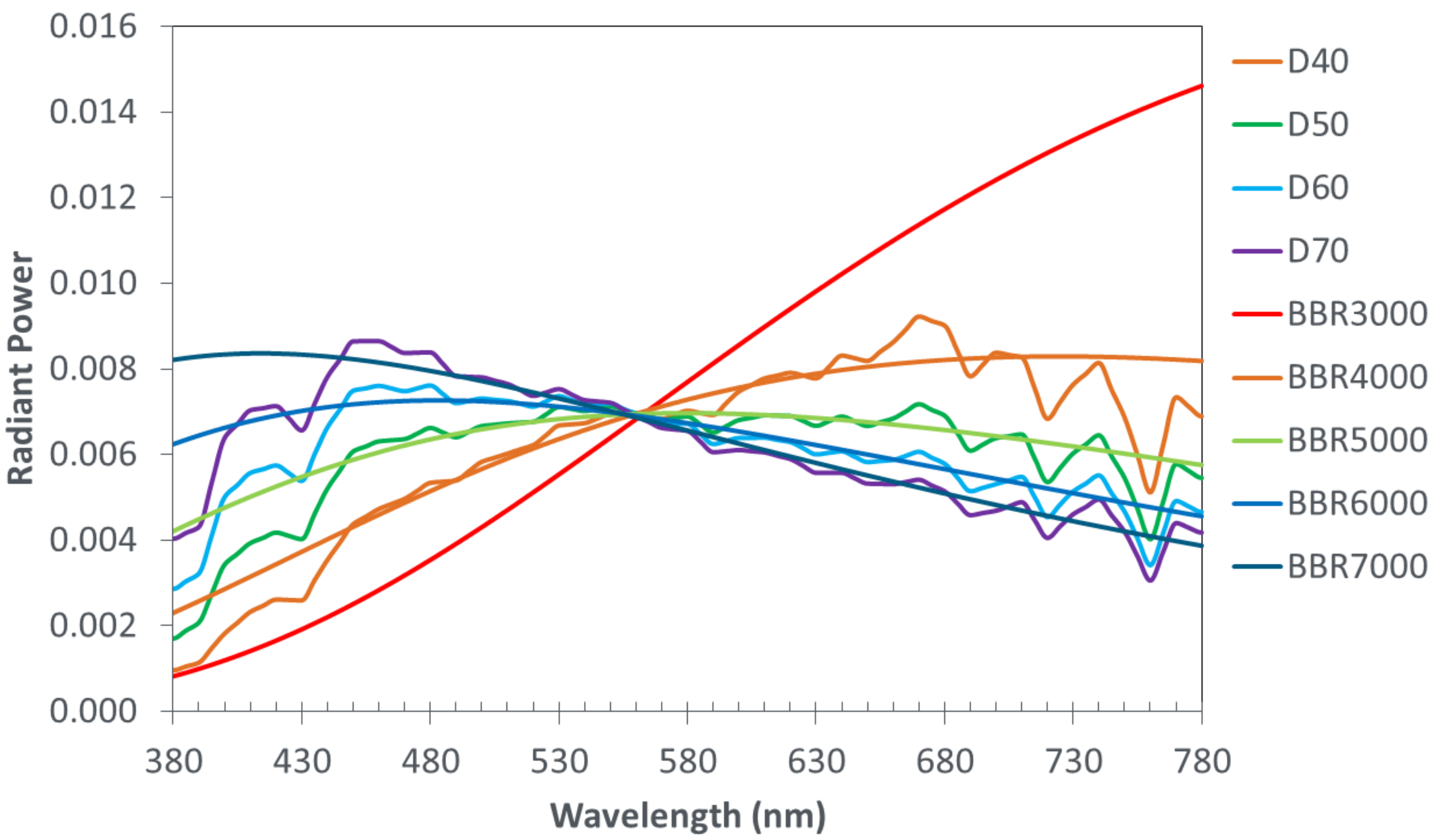
# What's the reference?

| CRI: | CCT ≥ 5000 K | CCT < 5000 K |
|---|---|---|
| | CIE D Series<br>(Model of Daylight) | Planckian Radiation<br>(Think Incandescent) |



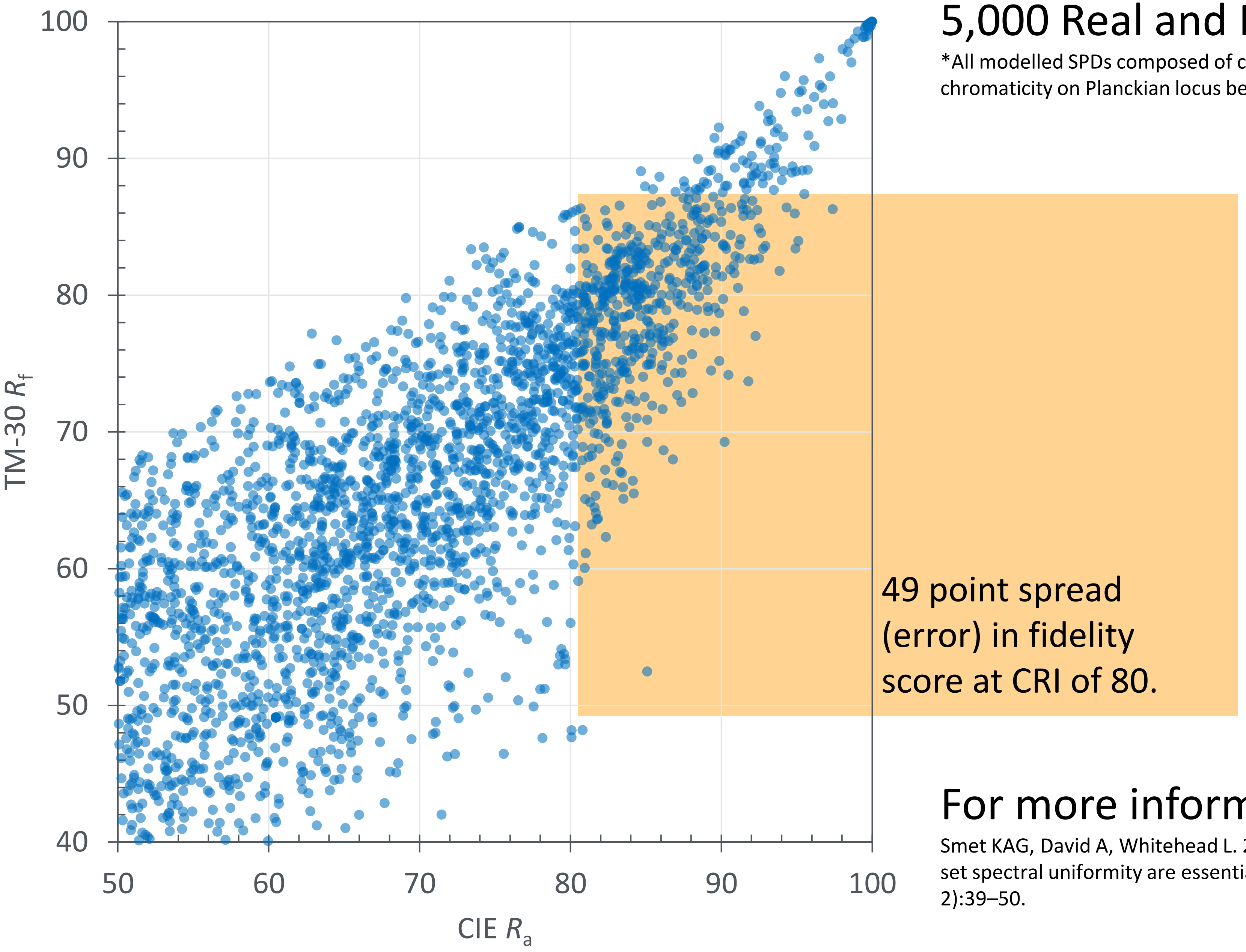

| TM-30: | CCT ≥ 5500 K | 5500 K > CCT > 4500 K | CCT ≤ 4500 K |
|---|---|---|---|
| | CIE D Series<br>(Model of Daylight) | Proportional blend of<br>D Series and Planckian | Planckian Radiation<br>(Think Incandescent) |

# Reference Sources



# 5,000 Real and Modelled* SPDs

*All modelled SPDs composed of combinations of Gaussian primaries; chromaticity on Planckian locus between 2700 K and 7000 K




## For more information:


Smet KAG, David A, Whitehead L. 2015. Why color space uniformity and sample set spectral uniformity are essential for color rendering measures. Leukos 12(1–2):39–50.

# TM-30 Method for Evaluating Color Rendition

## Color Fidelity

The accurate rendition of color so that they appear as they would under familiar (reference) illuminants

**Fidelity Index (*$R_f$*)**

(0-100)

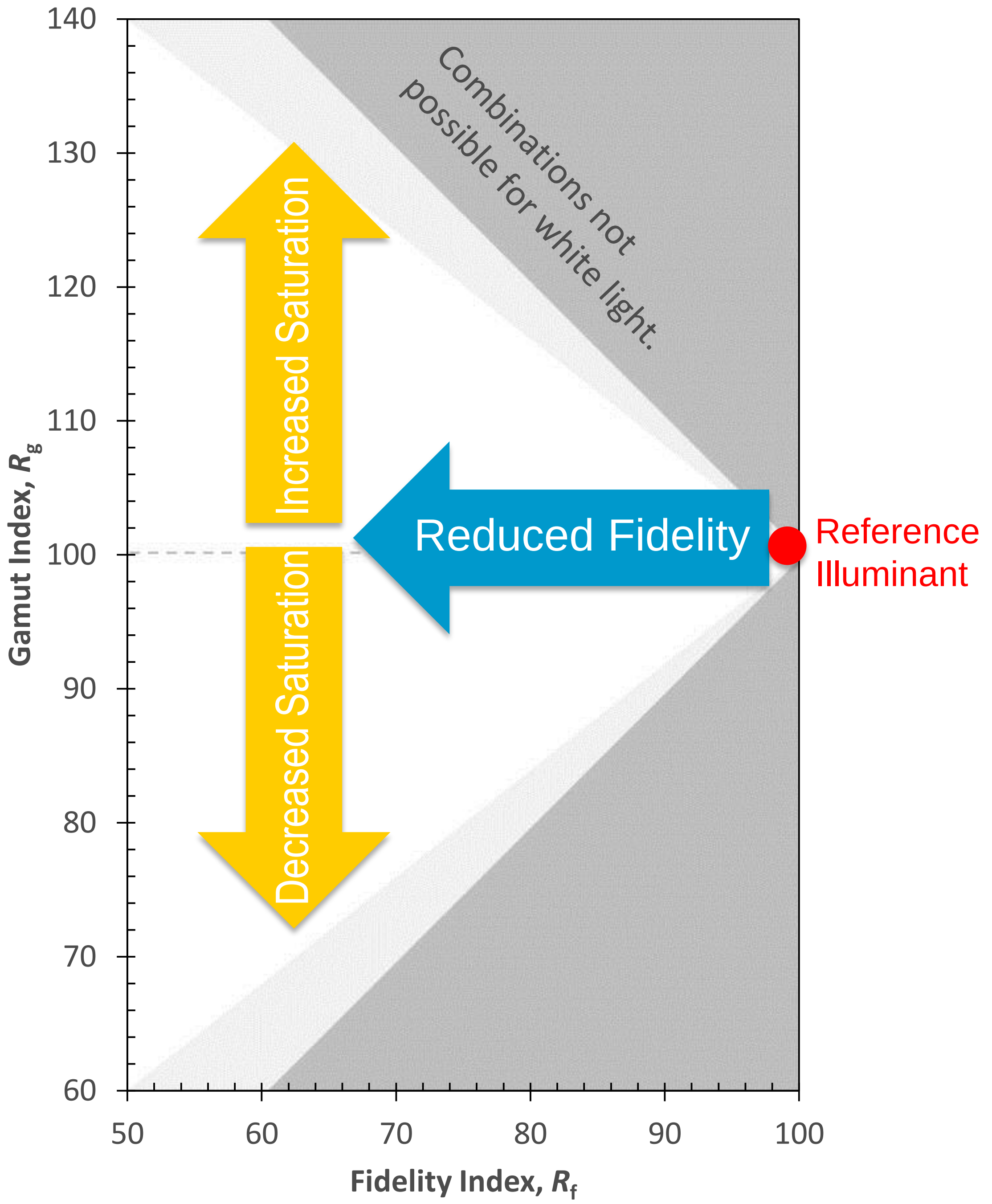
## Color Gamut

The average level of saturation relative to familiar (reference) illuminants.

**Gamut Index (*$R_g$*)**

~60-140 when $R_f > 60$

- Evaluate tradeoffs between fidelity and saturation.
- Cohesive system from the same calculation engine.
- **But average values don't tell the whole story…**



# TM-30 Method for Evaluating Color Rendition

## Color Fidelity

The accurate rendition of color so that they appear as they would under familiar (reference) illuminants

**Fidelity Index ($R_f$)**

(0-100)

## Color Gamut

The average level of saturation relative to familiar (reference) illuminants.

**Gamut Index ($R_g$)**

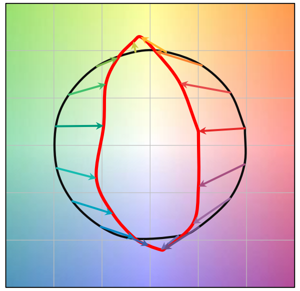
~60-140 when $R_f$ > 60

## Gamut Shape

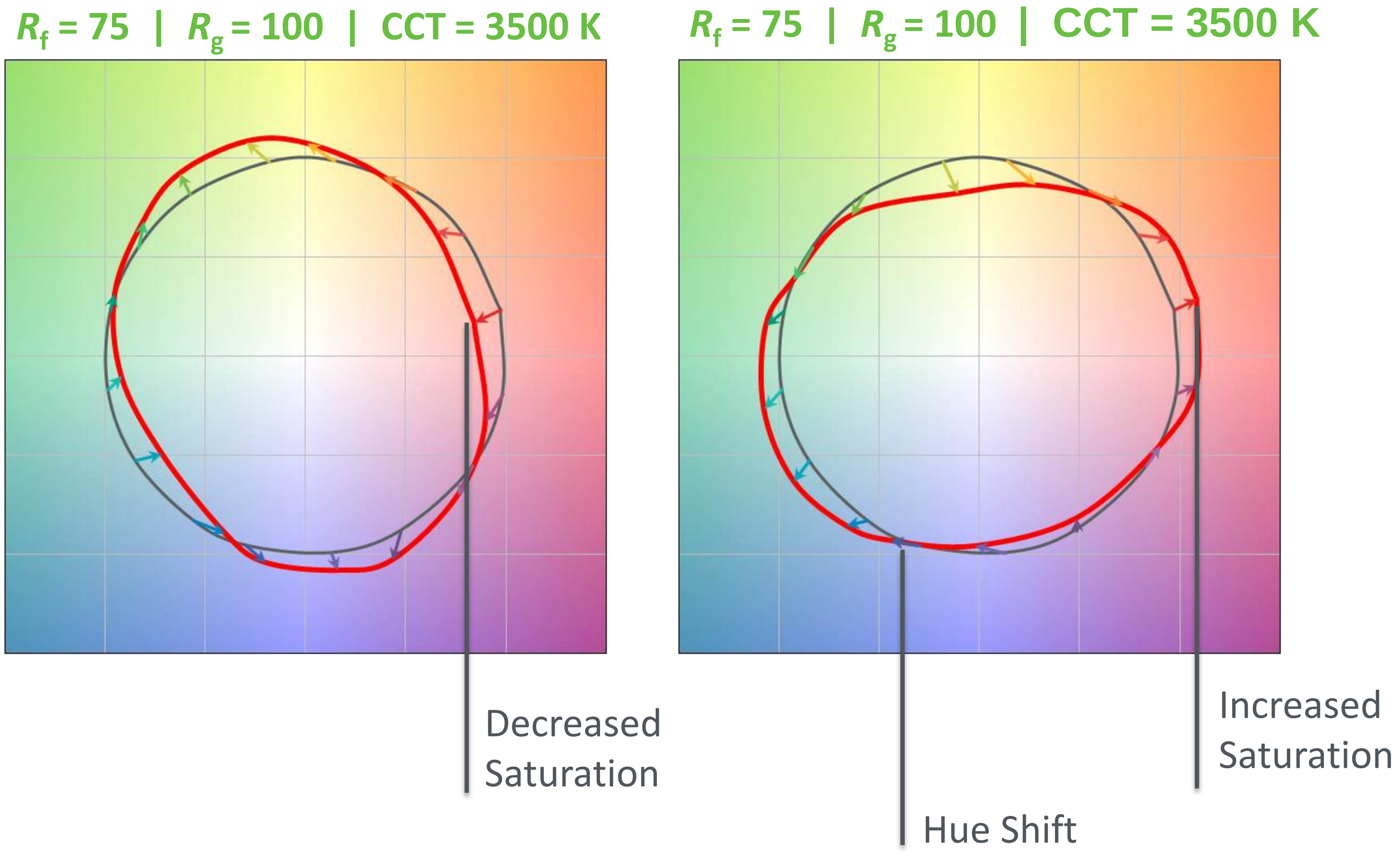
Changes over different hues

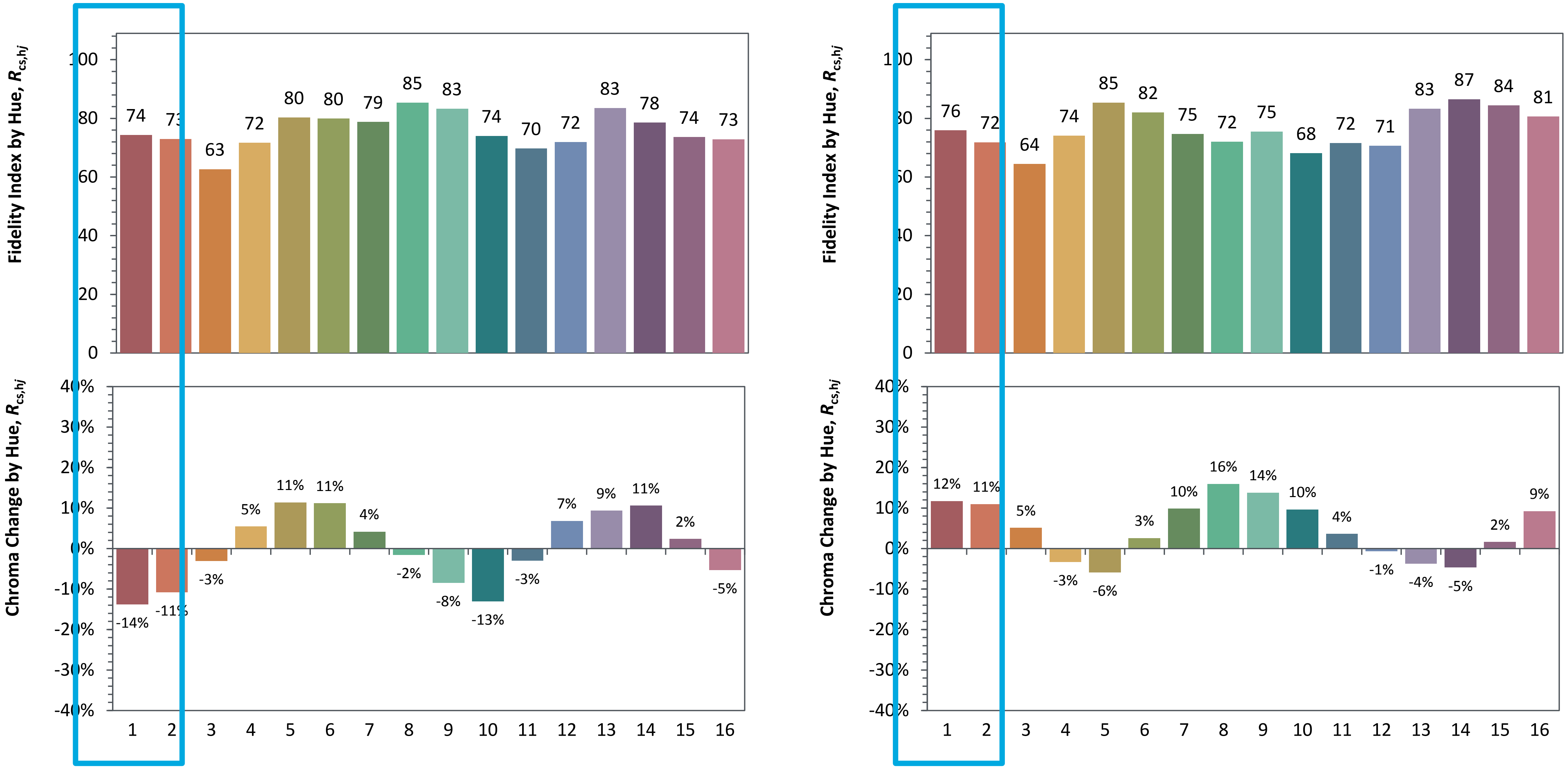
**Hue Bin Fidelity**
**Hue Bin Chroma Shift**

**Color Vector Graphic**



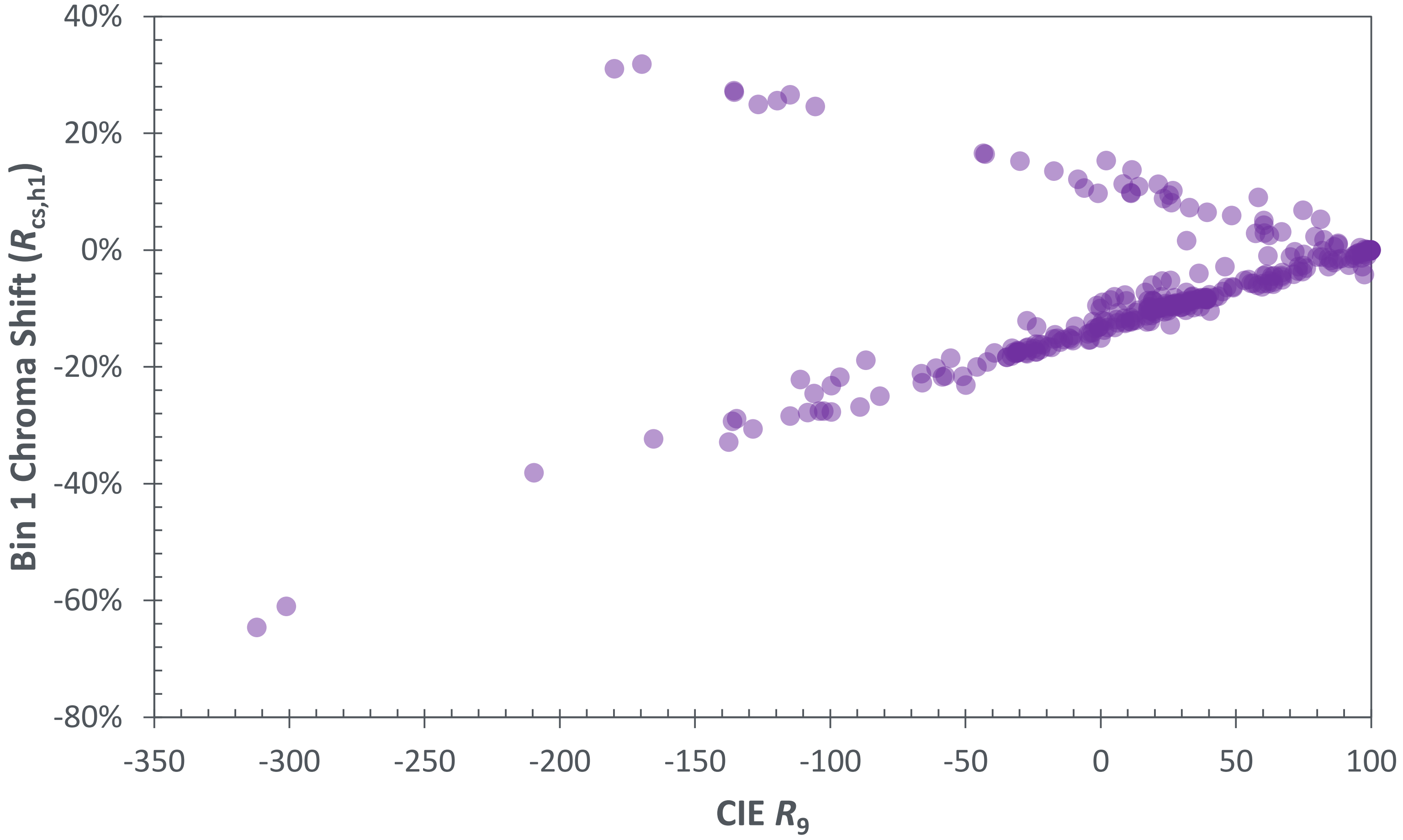
# Color Vector Graphics and Gamut Shape






**Same red fidelity, shift in opposite directions.**

# Red Fidelity vs. Red Chroma Shift




(All TM-30 Library)



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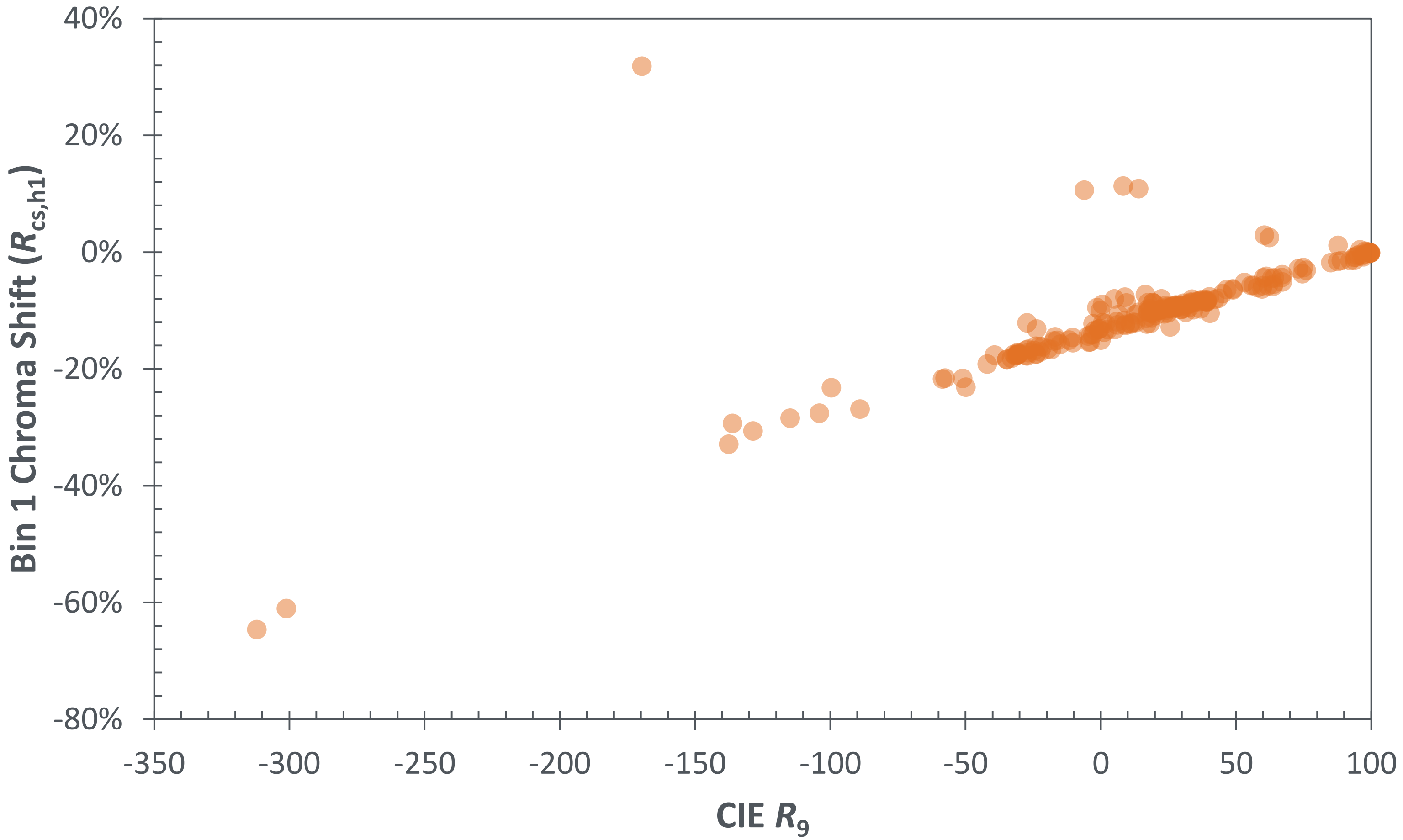
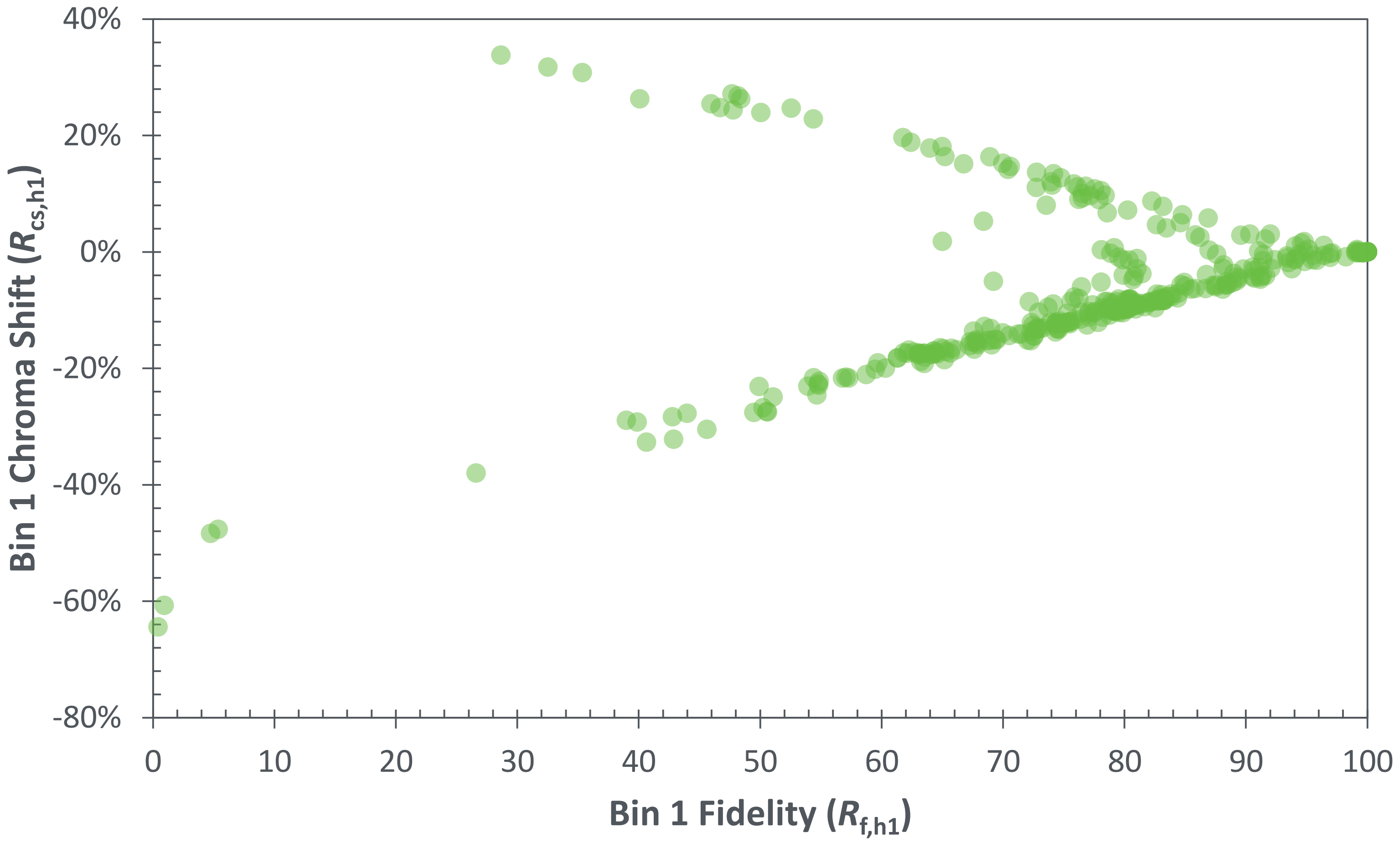
# Red Fidelity vs. Red Chroma Shift




(Existing Commercial Sources)

# Red Fidelity vs. Red Chroma Shift



# Linguistic Relativity Applied to TM-30

A study by British researchers suggests that color words in a given language shape human perception of color, perhaps explaining why some native English-speaking **children, familiar with the rainbow of colors in the Crayola 64-pack, actually can tell "rust" from "brick" and "moss" from "sage," while children who grow up speaking languages with fewer color names lump such hues together**. The research on English children and children in seminomadic Namibian tribes appeared in the December issue of the *Journal of Experimental Psychology: General* (Vol. 133, No. 4). Cognitive psychologist Akira Miyake, PhD, of the University of Toronto, says that the study "addresses an age-old question: To what extent does language shape or even determine the way we think?"

**TM-30 provides a new language to communicate color rendering. To truly be beneficial, the lighting industry will have to change its thinking on color rendering.**

# Halogen (MR16)

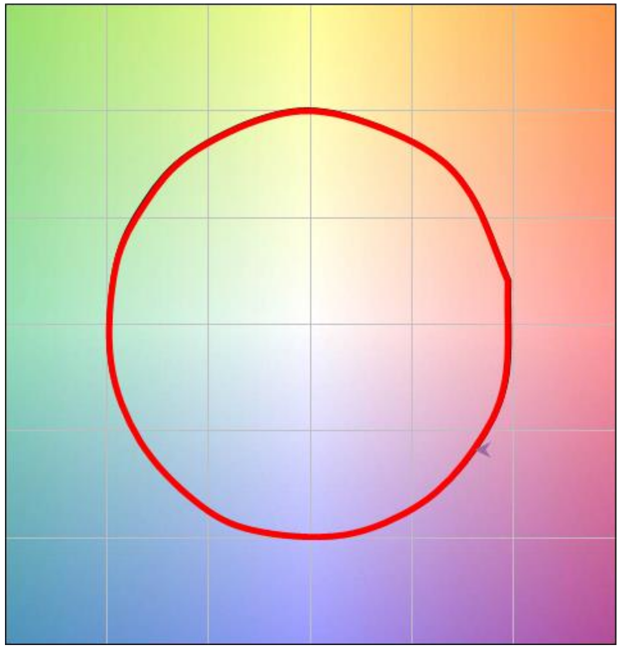
TM-30 Library Source No. 80

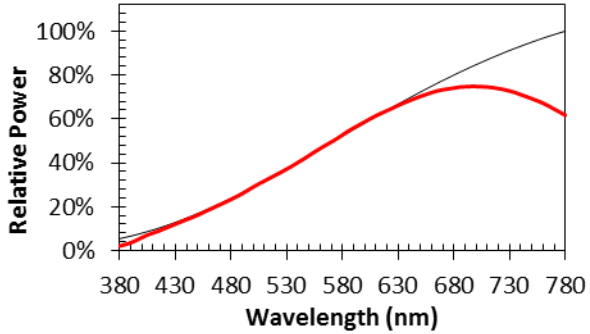
$R_f$ = 99
$R_g$ = 99
$R_{f,skin}$ = 99
$R_{f,h1}$ = 98
$R_{cs,h1}$ = -1%

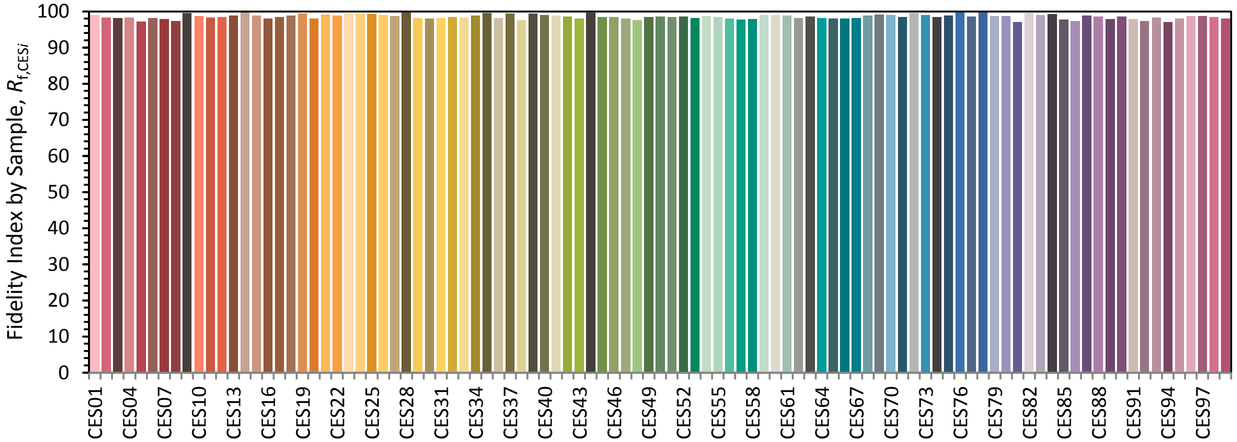
$R_a$ = 99
$R_9$ = 93

CCT = 2988 K
$D_{uv}$ = 0.0010

LER = 180





# High Pressure Sodium

TM-30 Library Source No. 56

$R_f$ = 32

$R_g$ = 61

$R_{f,skin}$ = 34

$R_{f,h1}$ = 5

$R_{cs,h1}$ = -48%

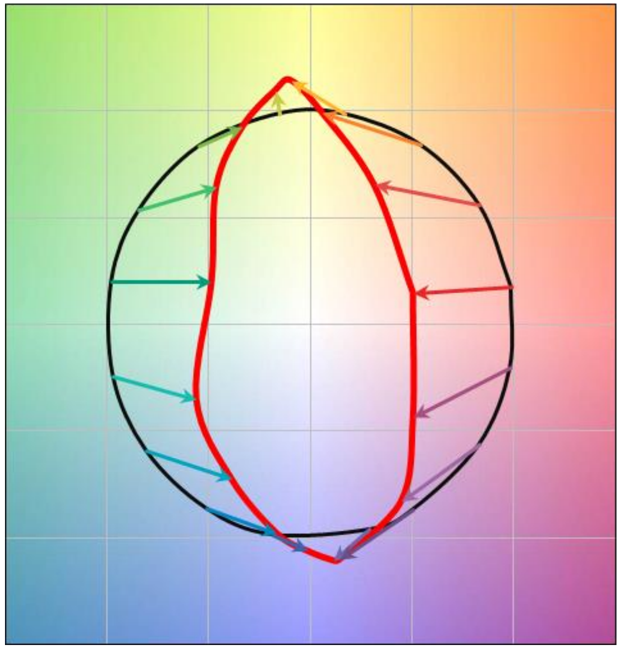
$R_a$ = 17

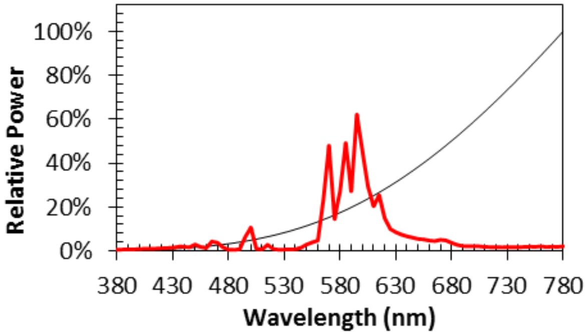
$R_9$ = -225

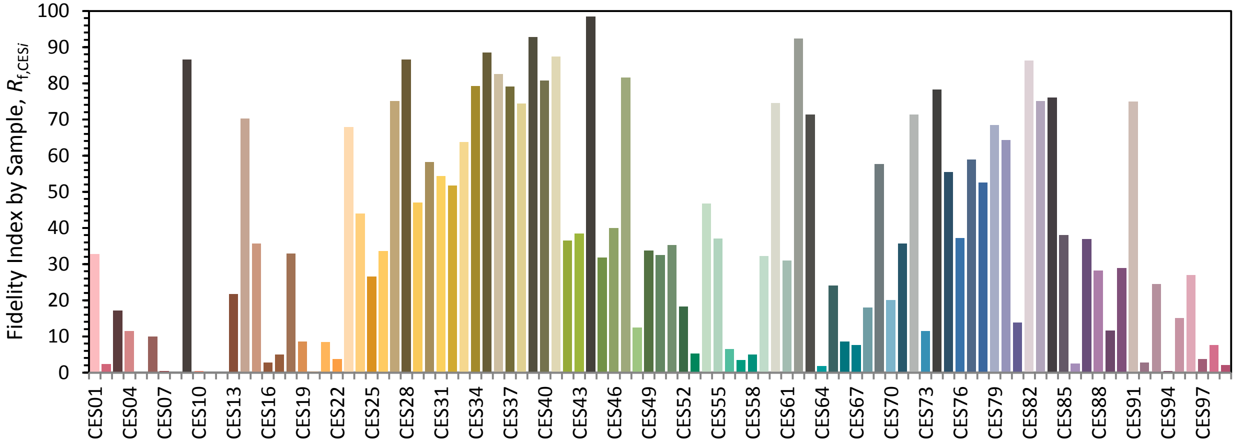
CCT = 1971 K

$D_{uv}$ = -0.0001

LER = 382





# Neodymium Incandescent

TM-30 Library Source No. 88

$R_f$ = 86

$R_g$ = 109

$R_{f,skin}$ = 84

$R_{f,h1}$ = 78

$R_{cs,h1}$ = 11%

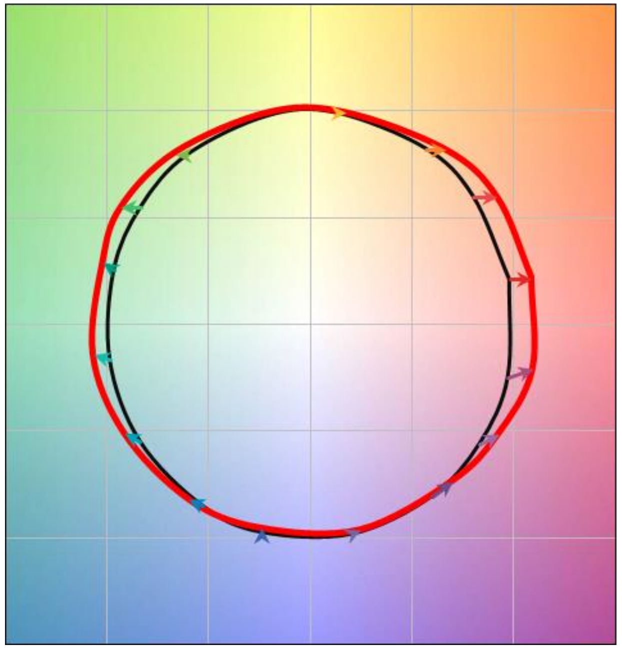
$R_a$ = 77

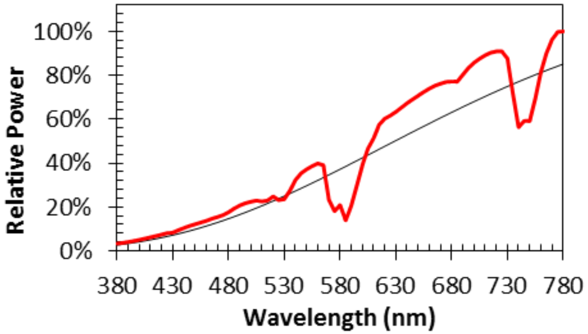
$R_9$ = 15

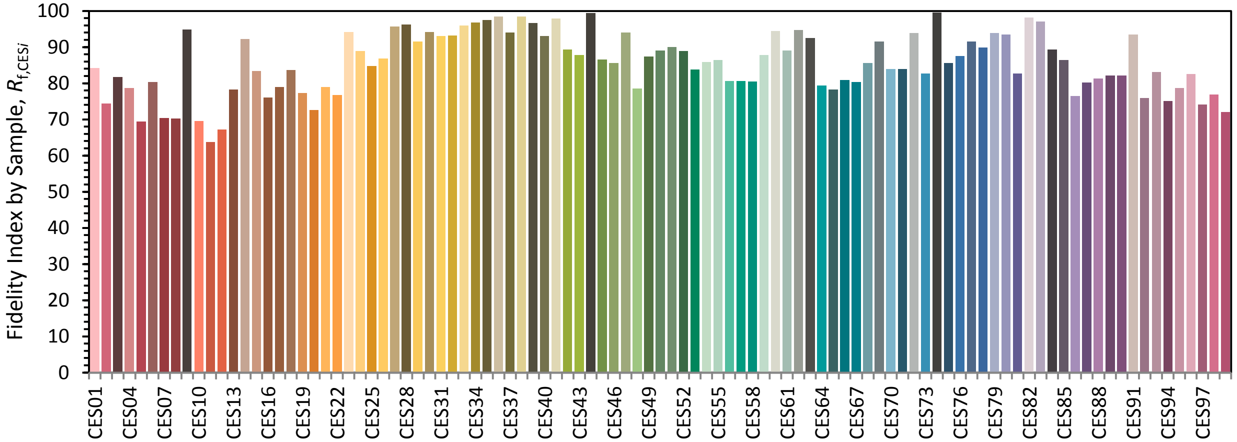
CCT = 2756 K

$D_{uv}$ = -0.0048

LER = 136





# Linear Fluorescent F32T8/835

TM-30 Library Source No. 38

$R_f$ = 75

$R_g$ = 99

$R_{f,skin}$ = 84

$R_{f,h1}$ = 74

$R_{cs,h1}$ = -12%

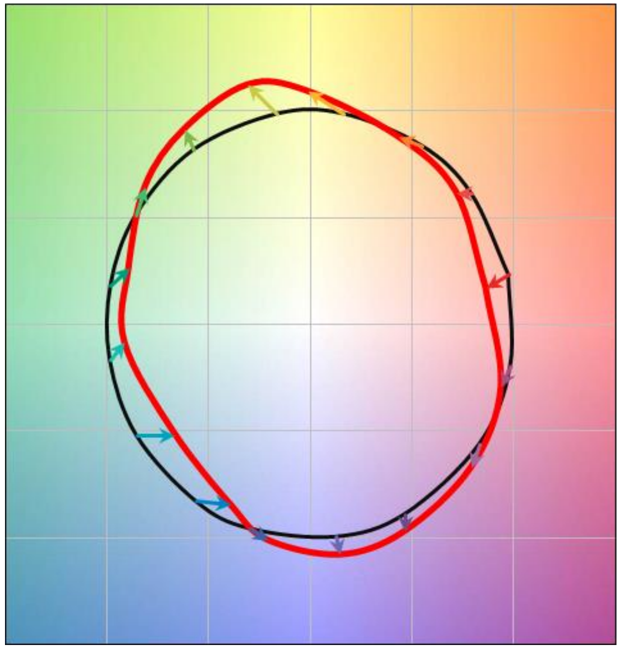
$R_a$ = 79

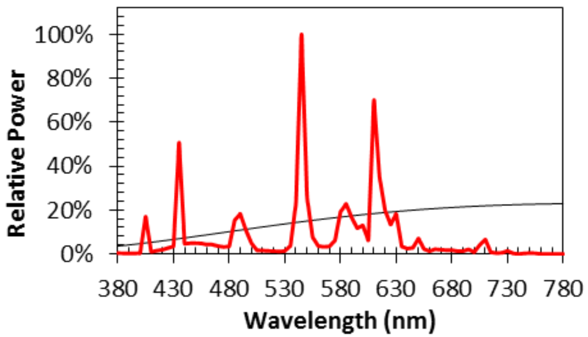
$R_9$ = -5

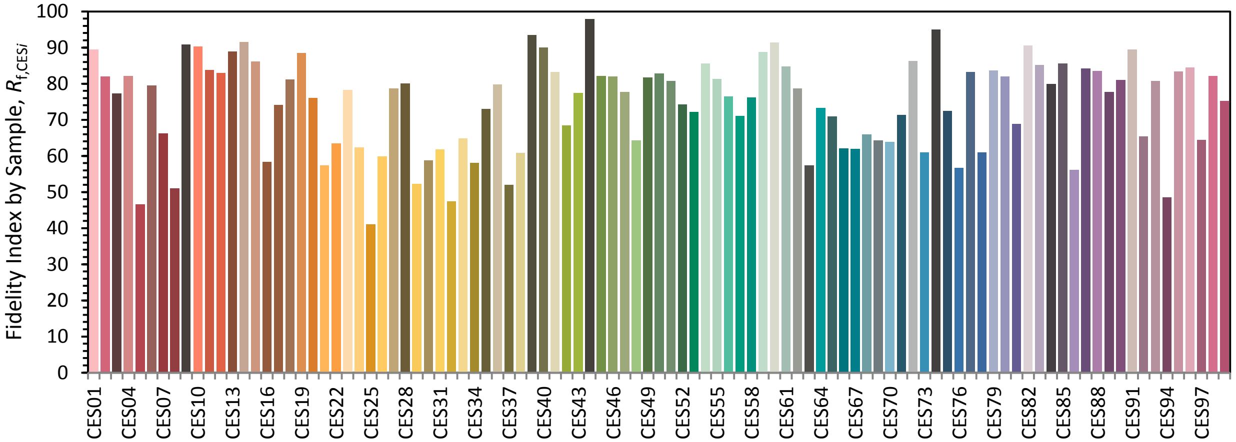
CCT = 3563 K

$D_{uv}$ = -0.0002

LER = 349





# Linear Fluorescent F32T8/835

TM-30 Library Source No. 37

$R_f$ = 81

$R_g$ = 102

$R_{f,skin}$ = 90

$R_{f,h1}$ = 79

$R_{cs,h1}$ = -8%

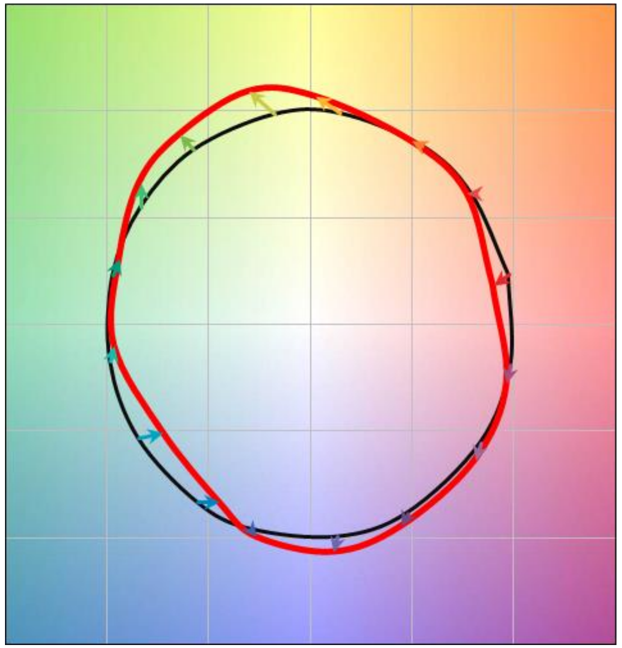
$R_a$ = 86

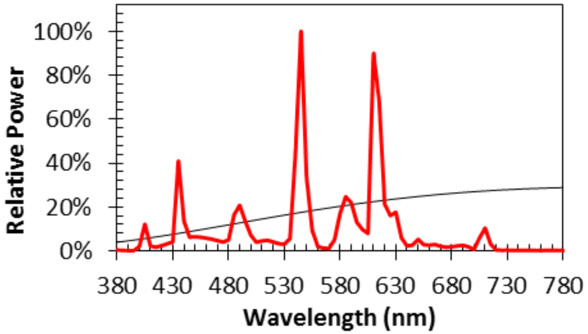
$R_9$ = 15

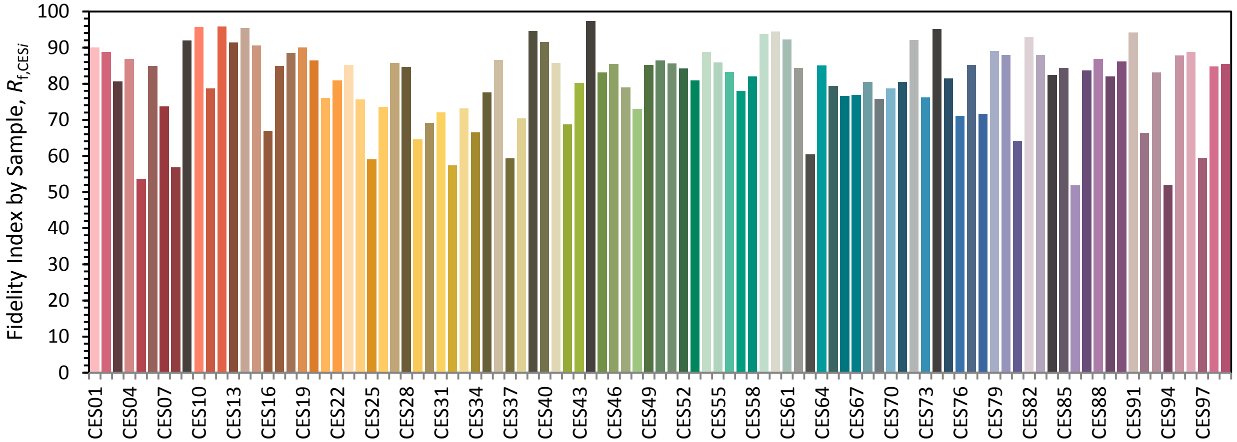
CCT = 3483 K

$D_{uv}$ = 0.0008

LER = 348





# Ceramic Metal Halide 835

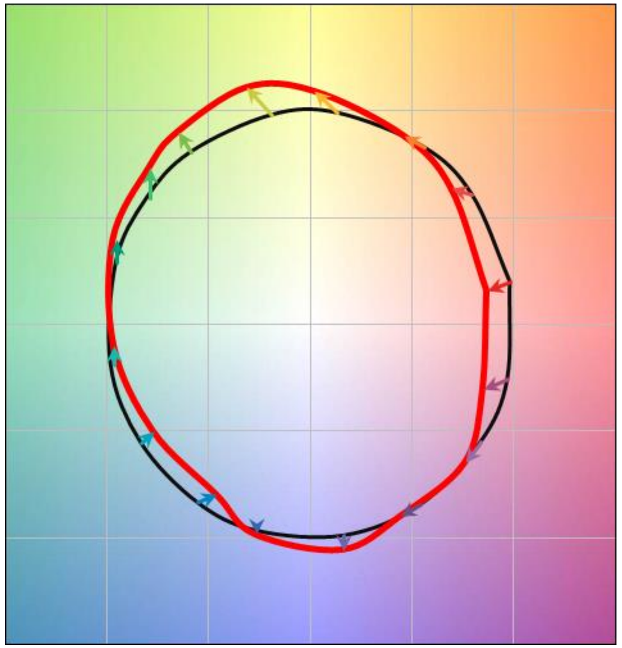
TM-30 Library Source No. 62

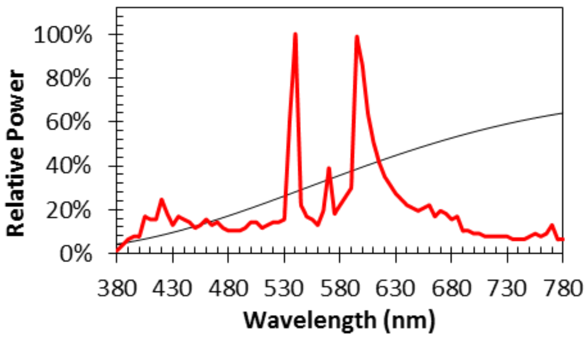
$R_f$ = 79
$R_g$ = 100
$R_{f,skin}$ = 78
$R_{f,h1}$ = 74
$R_{cs,h1}$ = -12%

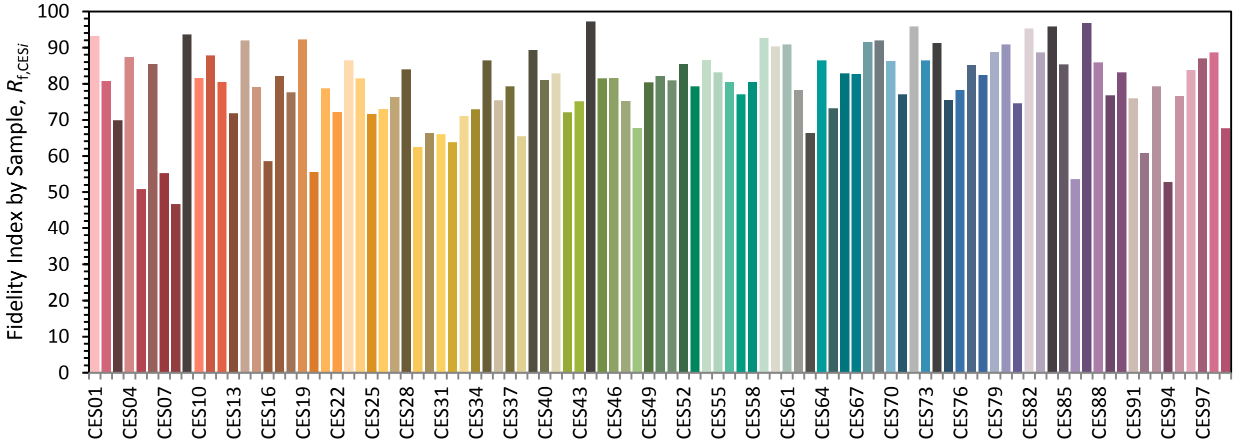
$R_a$ = 84
$R_9$ = -29

CCT = 3083 K
$D_{uv}$ = -0.0024

LER = 294





# PC White LED

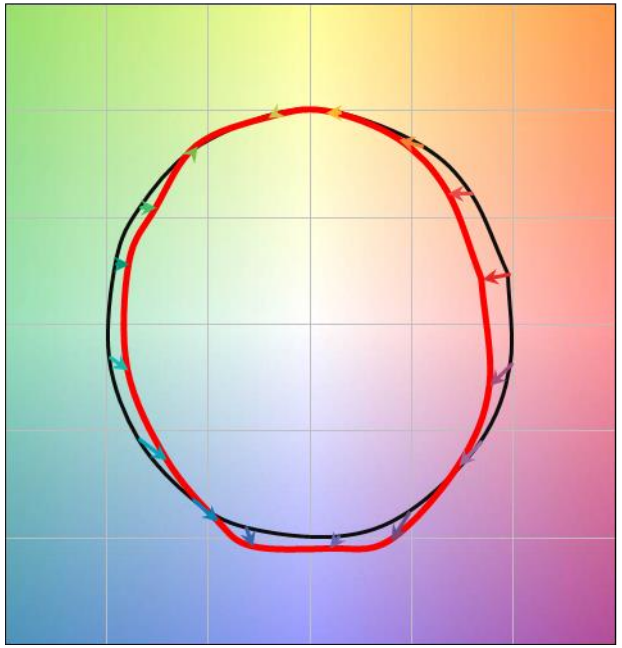
TM-30 Library Source No. 184

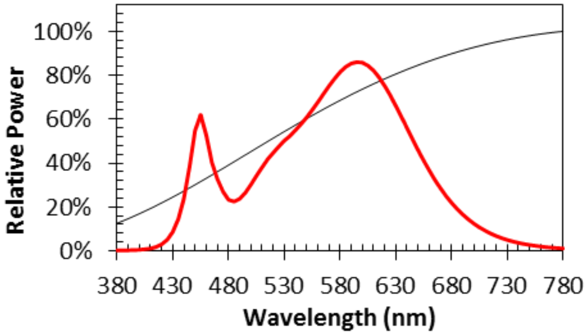
$R_f$ = 81
$R_g$ = 94
$R_{f,skin}$ = 86
$R_{f,h1}$ = 75
$R_{cs,h1}$ = -13%

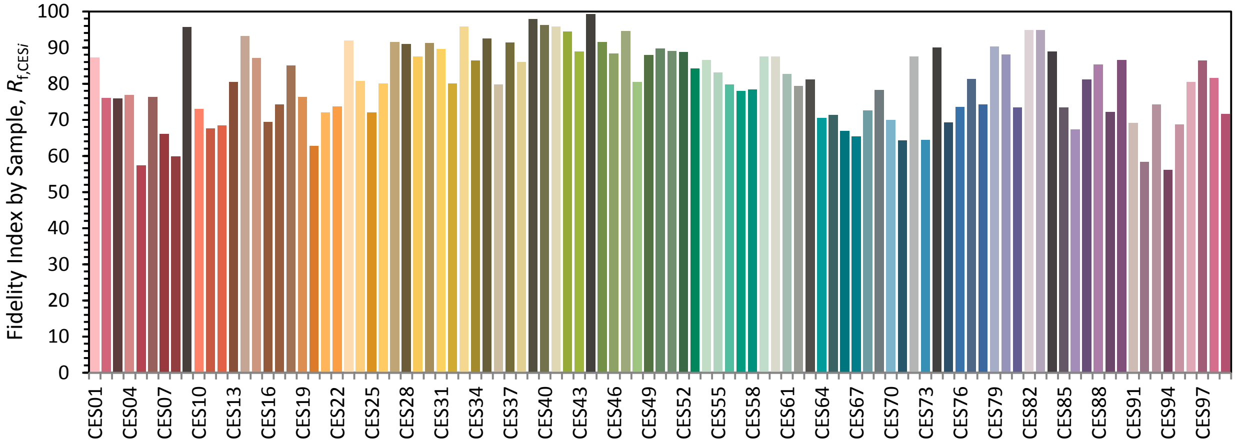
$R_a$ = 81
$R_9$ = 0

CCT = 3429 K
$D_{uv}$ = 0.0001

LER = 332





# Hybrid LED (PC+Red)

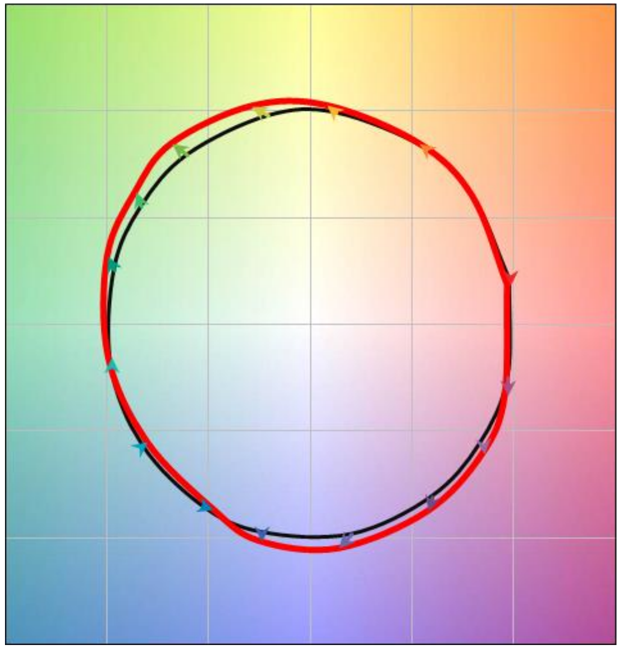
TM-30 Library Source No. 92

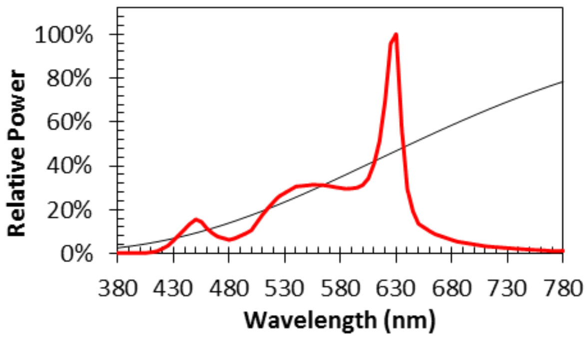
$R_f$ = 89
$R_g$ = 105
$R_{f,skin}$ = 97
$R_{f,h1}$ = 91
$R_{cs,h1}$ = -1%

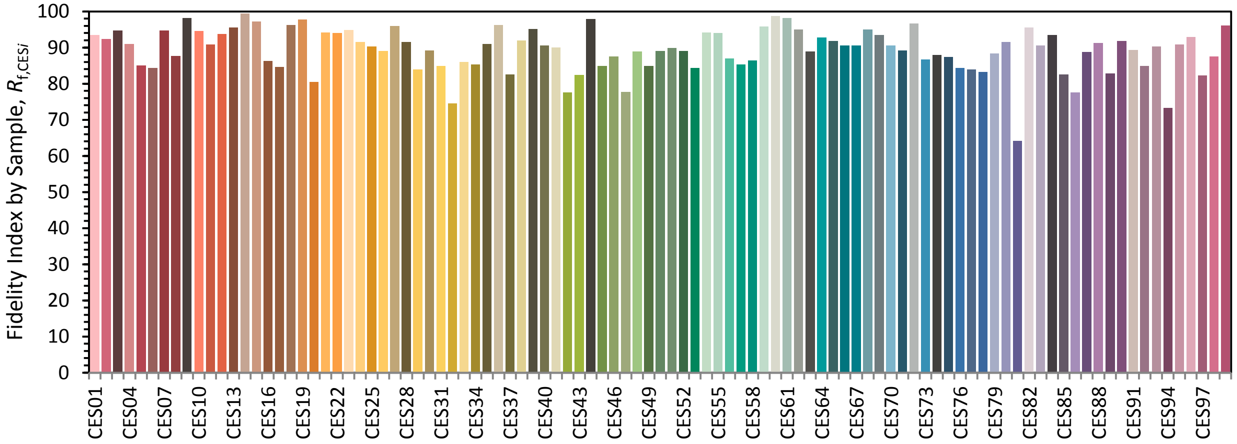
$R_a$ = 94
$R_9$ = 89

CCT = 2776 K
$D_{uv}$ = 0.0011

LER = 336





# RGB LED

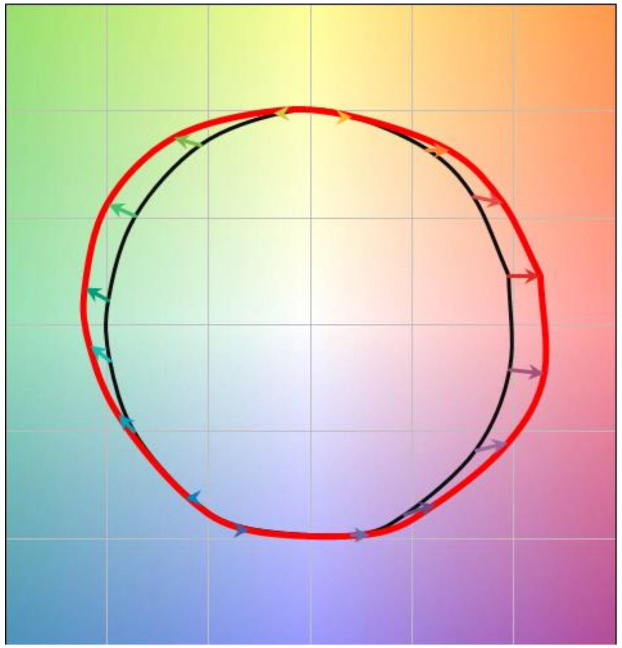
TM-30 Library Source No. 108

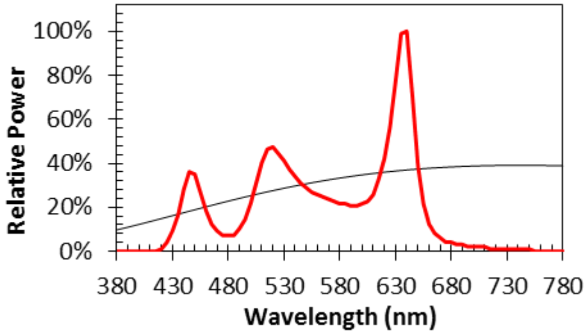
$R_f$ = 80
$R_g$ = 114
$R_{f,skin}$ = 81
$R_{f,h1}$ = 70
$R_{cs,h1}$ = 15%

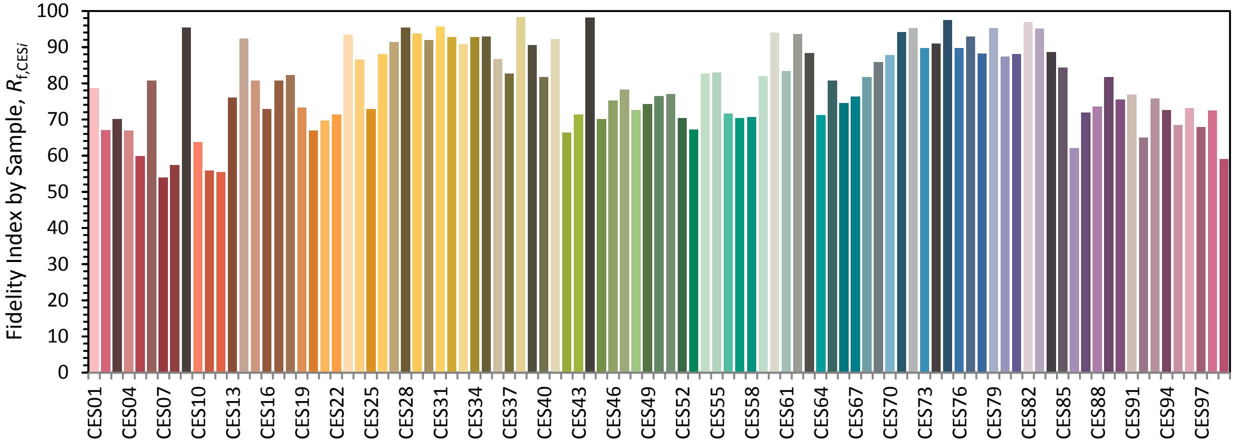
$R_a$ = 71
$R_9$ = -27

CCT = 3906 K
$D_{uv}$ = 0.0027

LER = 299





# PC White LED

TM-30 Library Source No. 175

$R_f$ = 95

$R_g$ = 103

$R_{f,skin}$ = 98

$R_{f,h1}$ = 97

$R_{cs,h1}$ = 0%

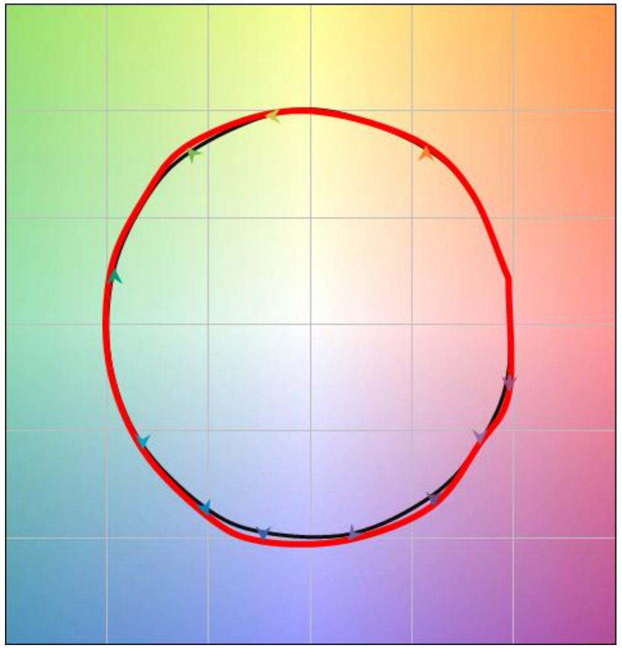
$R_a$ = 97

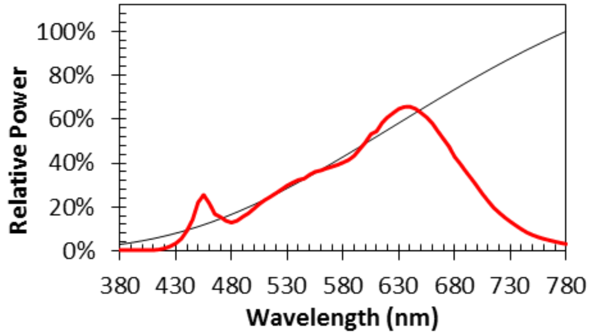
$R_9$ = 98

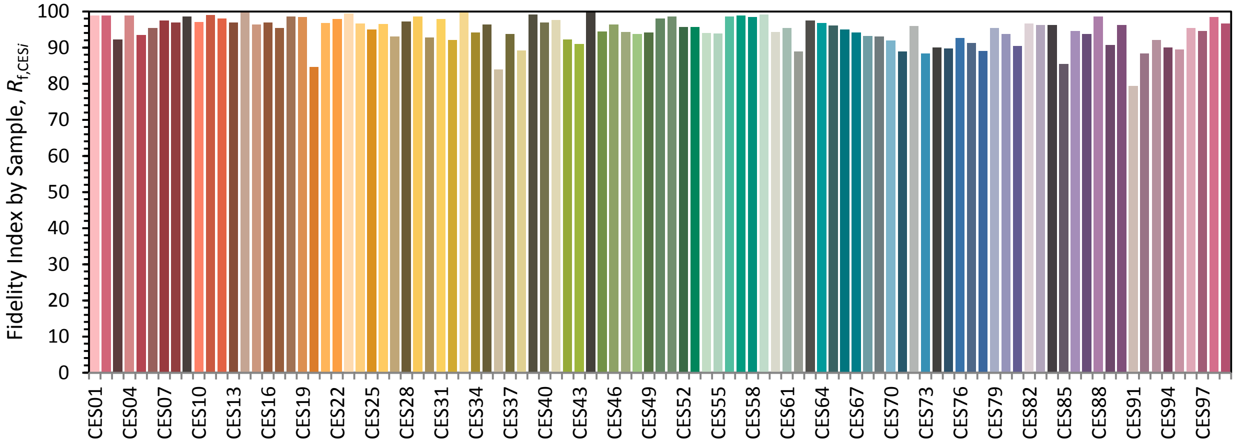
CCT = 2733 K

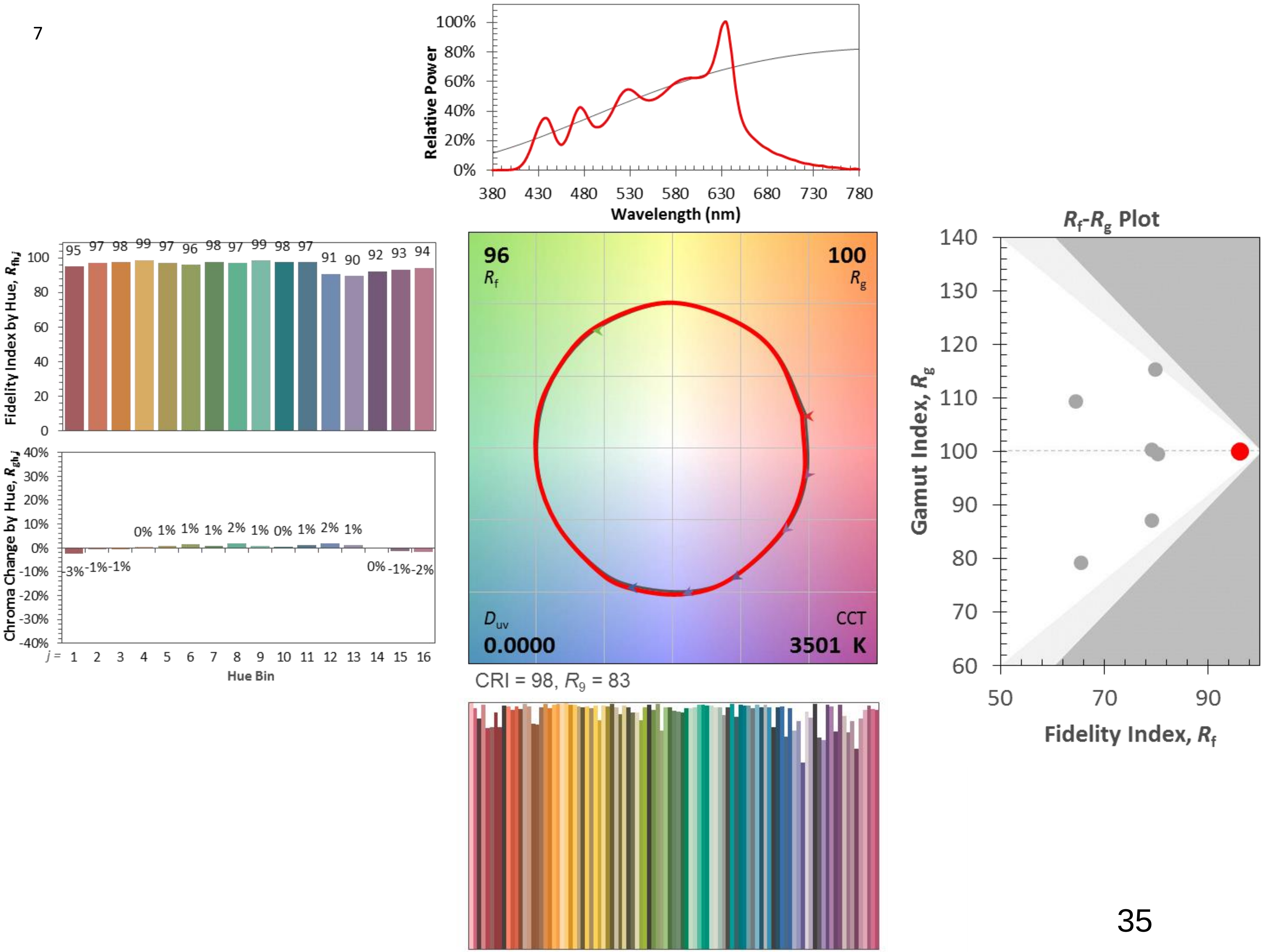
$D_{uv}$ = -0.0031

LER = 252

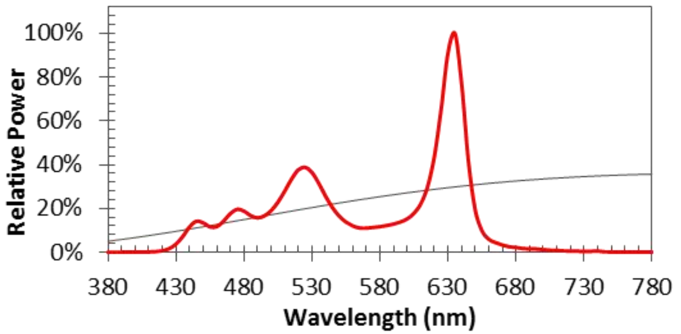


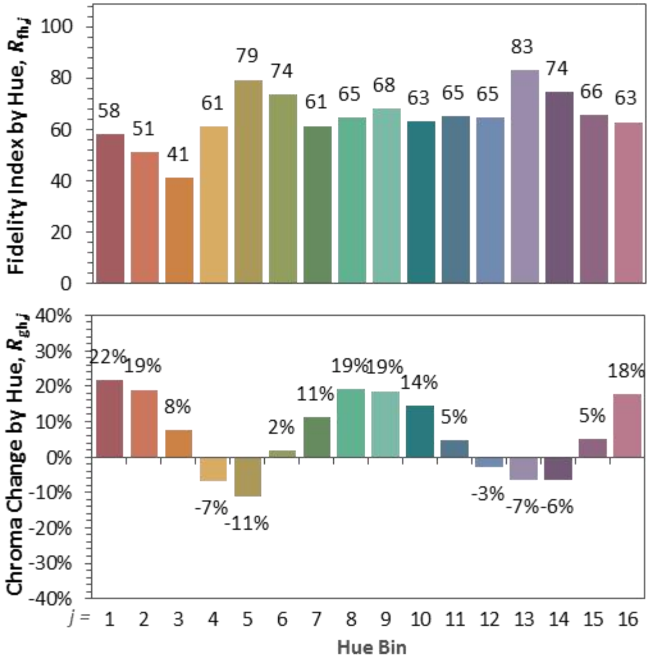


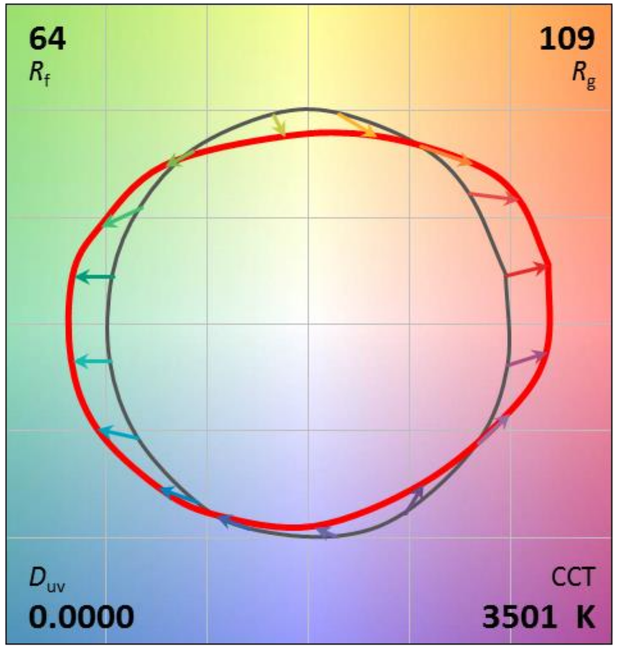





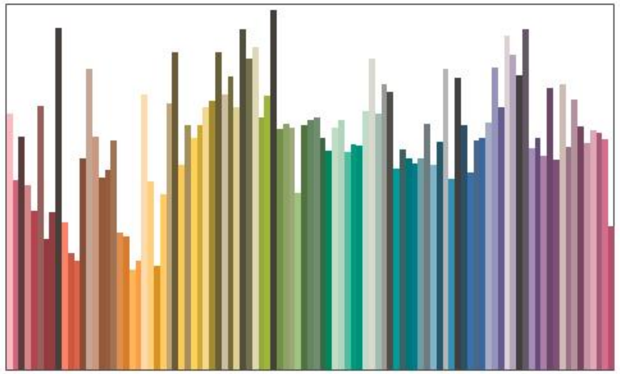
100%
80%
60%
40%
20%
0%
Relative Power
380 430 480 530 580 630 680 730 780
Wavelength (nm)
95 97 98 99 97 96 98 97 99 98 97 91 90 92 93 94
Fidelity Index by Hue, $R_{f,h,j}$
100 80 60 40 20 0
40% 30% 20% 10% 0% -10% -20% -30% -40%
Chroma Change by Hue, $R_{cs,h,j}$
0% 1% 1% 1% 2% 1% 0% 1% 2% 1%
-3% -1% -1% 0% -1% -2%
j = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Hue Bin
96
$R_f$
100
$R_g$
$D_{uv}$
0.0000
CCT
3501 K
CRI = 98, $R_9$ = 83
$R_f$-$R_g$ Plot
140 130 120 110 100 90 80 70 60
Gamut Index, $R_g$
50 70 90
Fidelity Index, $R_f$

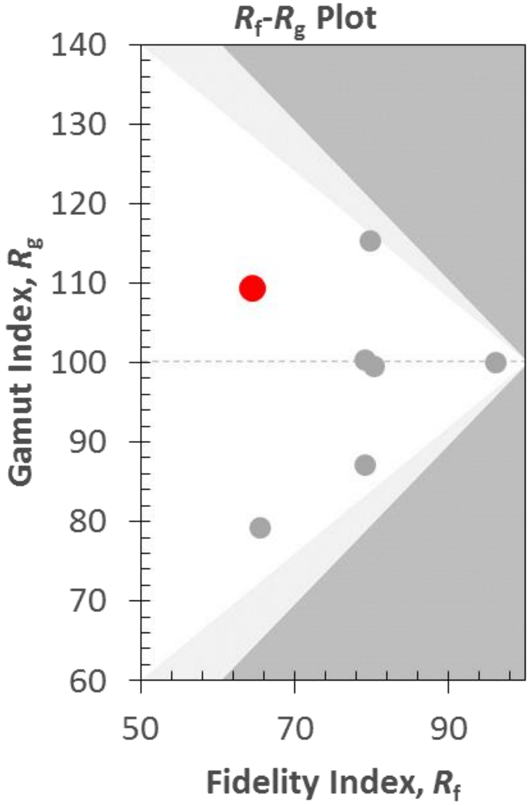

100%
80%
60%
40%
20%
0%
Relative Power
380 430 480 530 580 630 680 730 780
Wavelength (nm)


Fidelity Index by Hue, $R_{f,h,j}$
58 51 41 61 79 74 61 65 68 63 65 65 83 74 66 63
Chroma Change by Hue, $R_{cs,h,j}$
22% 19% 8% -7% -11% 2% 11% 19% 19% 14% 5% -3% -7% -6% 5% 18%
j = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Hue Bin

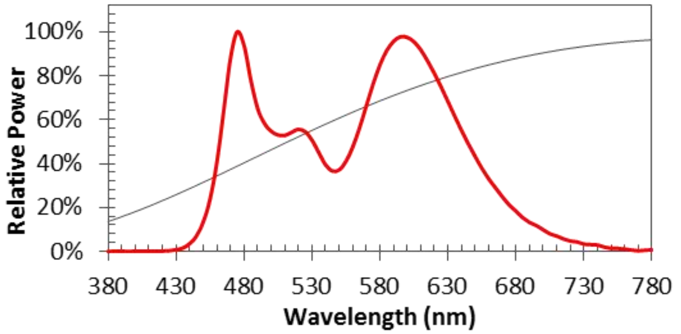

64
$R_f$
109
$R_g$
$D_{uv}$
0.0000
CCT
3501 K

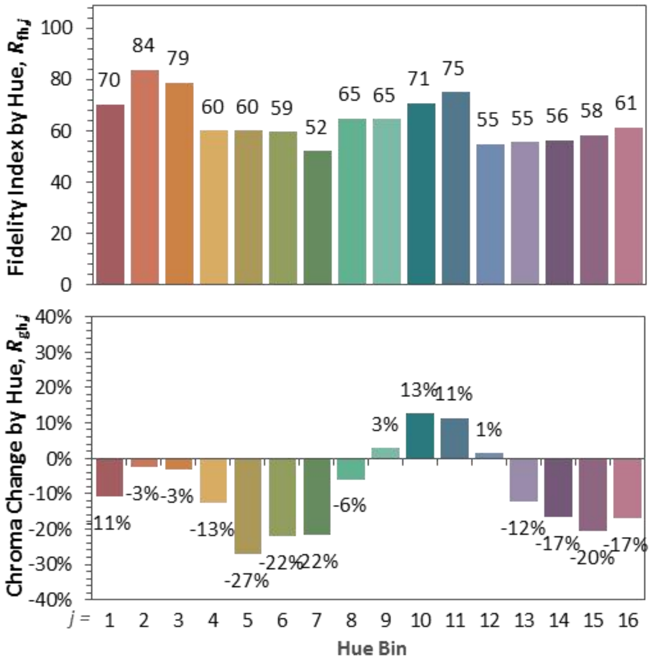
CRI = 50, $R_9$ = -80

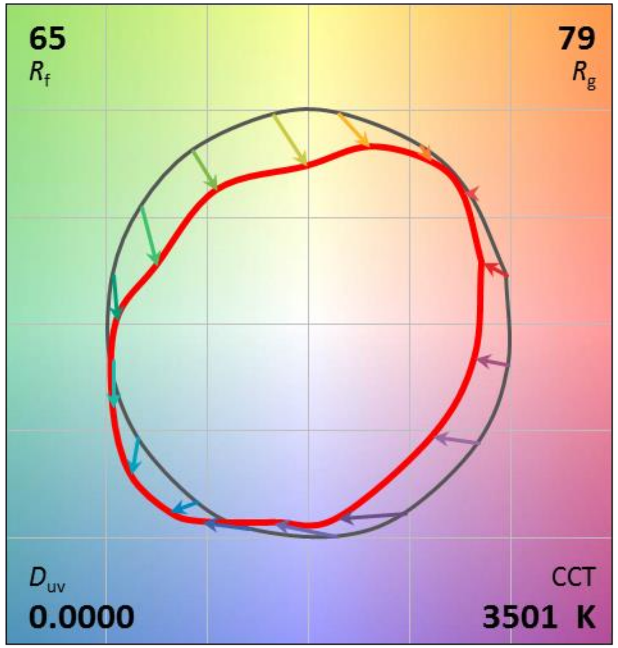



$R_f$-$R_g$ Plot
Gamut Index, $R_g$
140 130 120 110 100 90 80 70 60
50 70 90
Fidelity Index, $R_f$

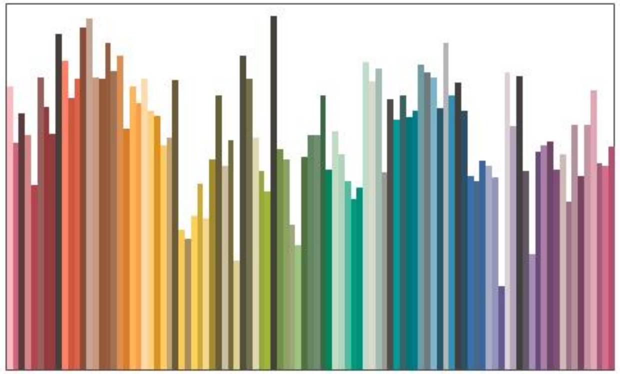
2

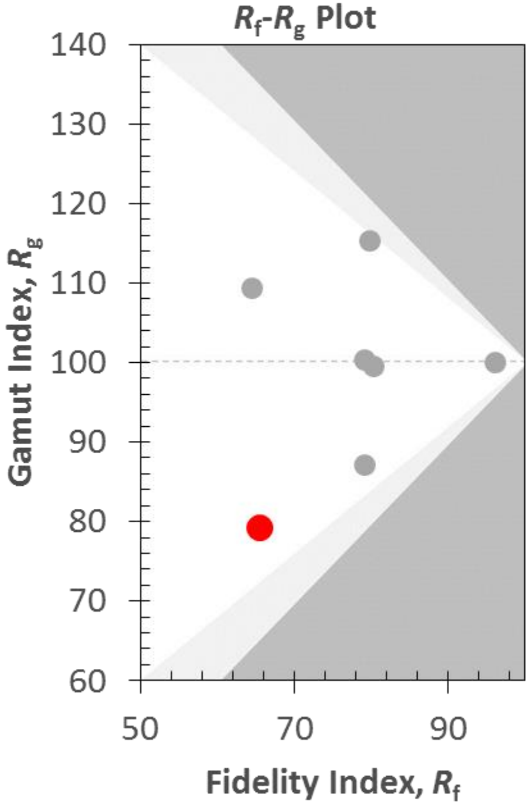

100%
80%
60%
40%
20%
0%
Relative Power
380 430 480 530 580 630 680 730 780
Wavelength (nm)


Fidelity Index by Hue, $R_{f,h,j}$
100
80
60
40
20
0
70 84 79 60 60 59 52 65 65 71 75 55 55 56 58 61
Chroma Change by Hue, $R_{cs,h,j}$
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
-11% -3% -3% -13% -27% -22% -22% -6% 3% 13% 11% 1% -12% -17% -20% -17%
j = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Hue Bin

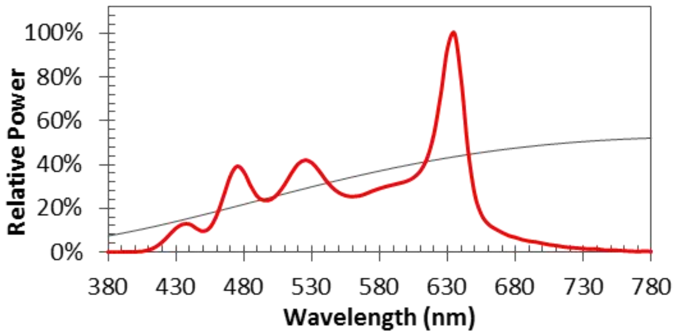

65
$R_f$
79
$R_g$
$D_{uv}$
0.0000
CCT
3501 K

CRI = 75, $R_9$ = 20

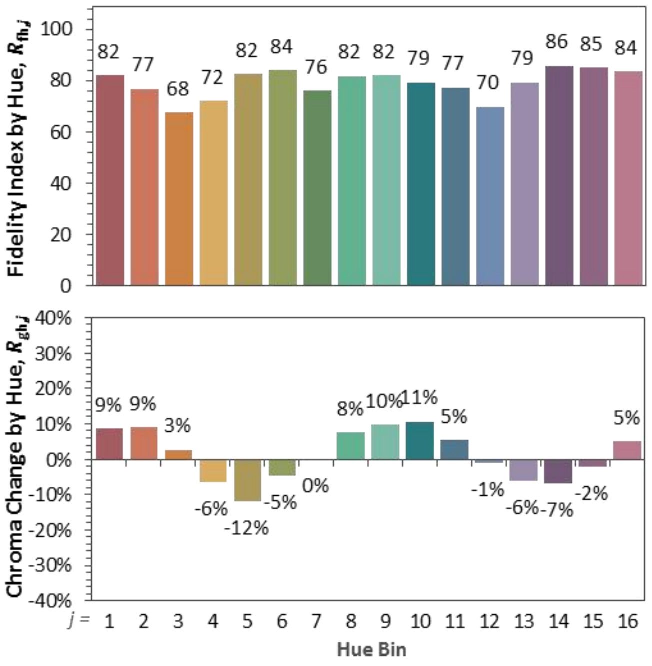



$R_f$-$R_g$ Plot
140
130
120
110
100
90
80
70
60
Gamut Index, $R_g$
50
70
90
Fidelity Index, $R_f$

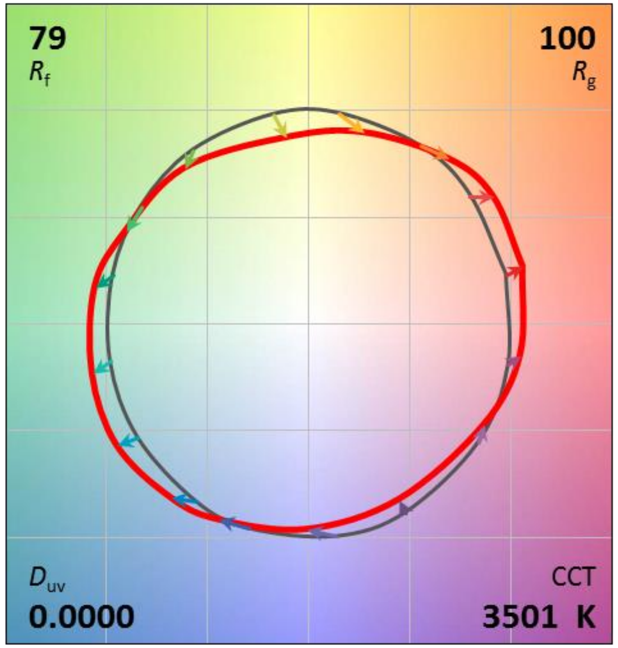
3



100%
80%
60%
40%
20%
0%
Relative Power
380 430 480 530 580 630 680 730 780
Wavelength (nm)

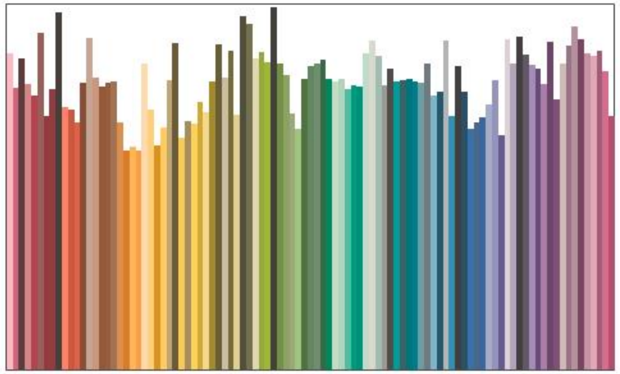



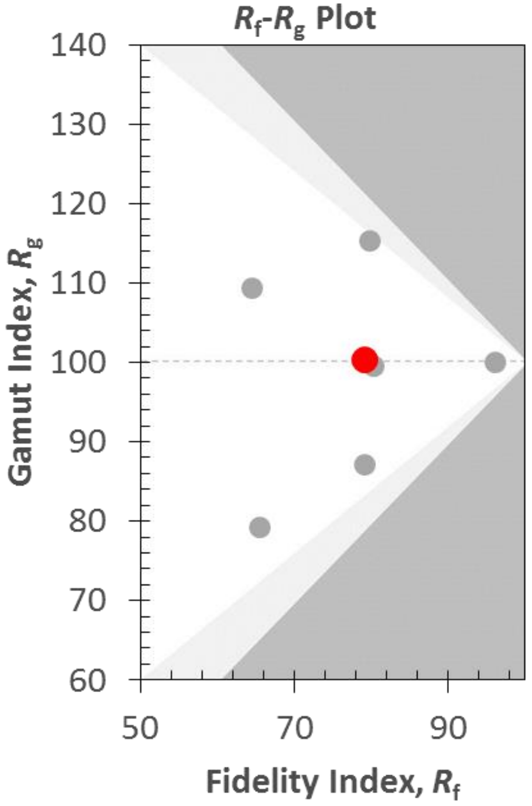
Fidelity Index by Hue, $R_{f,h,j}$
100
80
60
40
20
0
82 77 68 72 82 84 76 82 82 79 77 70 79 86 85 84
Chroma Change by Hue, $R_{cs,h,j}$
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
9% 9% 3% -6% -12% -5% 0% 8% 10% 11% 5% -1% -6% -7% -2% 5%
j = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Hue Bin

79
$R_f$
100
$R_g$
$D_{uv}$
0.0000
CCT
3501 K

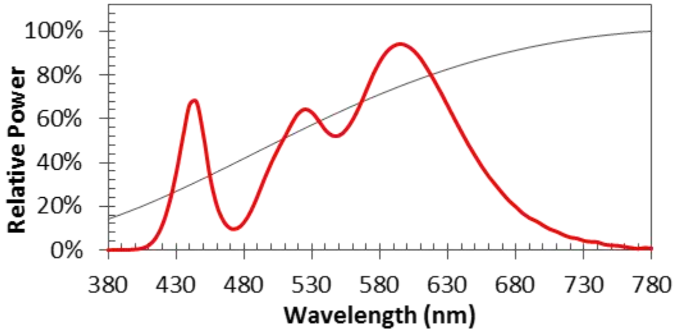

CRI = 77, $R_9$ = 22



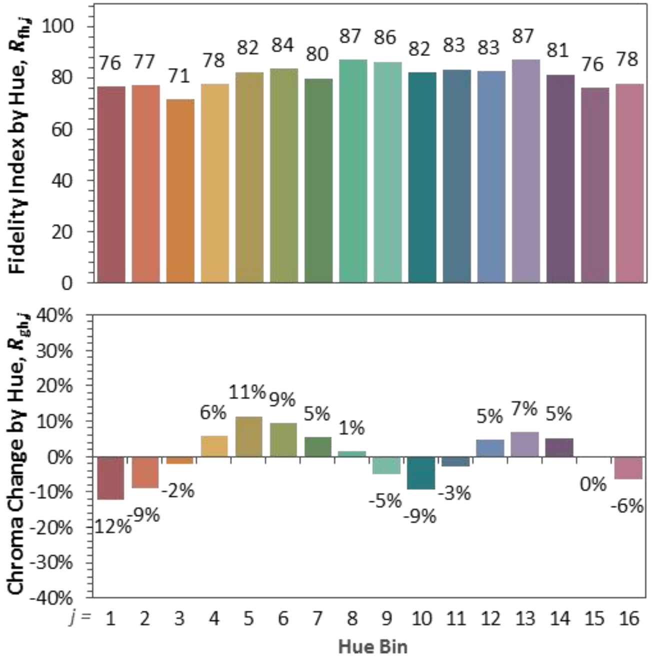


$R_f$-$R_g$ Plot
140
130
120
110
100
90
80
70
60
Gamut Index, $R_g$
50 70 90
Fidelity Index, $R_f$

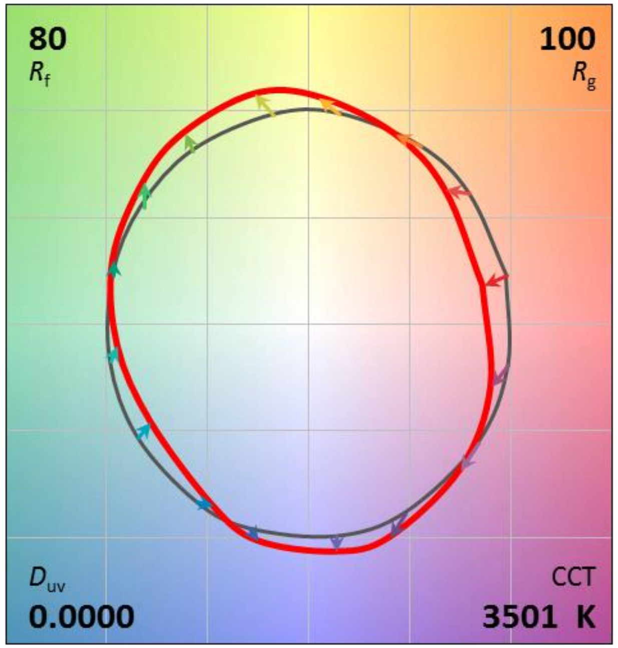
4



100%
80%
60%
40%
20%
0%
Relative Power
380 430 480 530 580 630 680 730 780
Wavelength (nm)

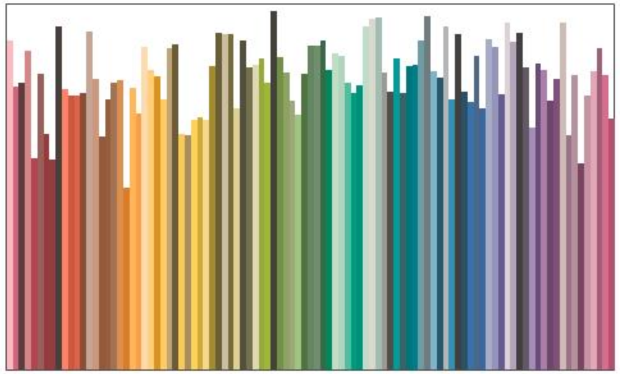



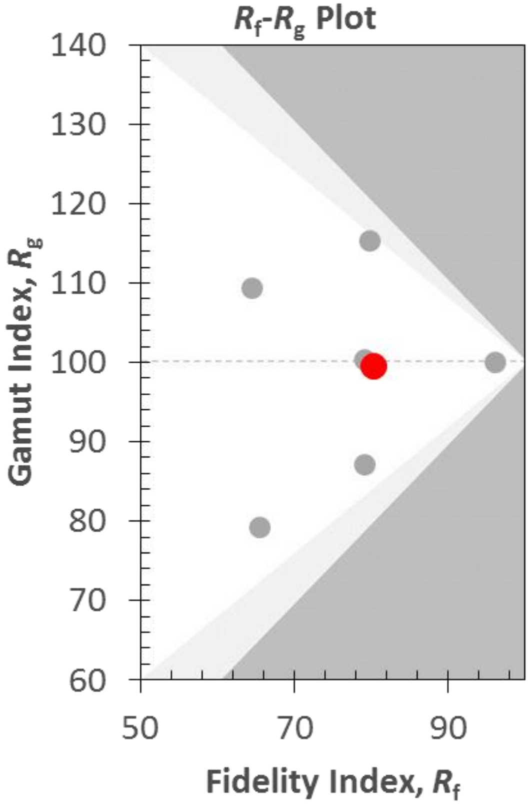
Fidelity Index by Hue, $R_{f,hj}$
100
80
60
40
20
0
76 77 71 78 82 84 80 87 86 82 83 83 87 81 76 78
Chroma Change by Hue, $R_{cs,hj}$
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
-12% -9% -2% 6% 11% 9% 5% 1% -5% -9% -3% 5% 7% 5% 0% -6%
j = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Hue Bin

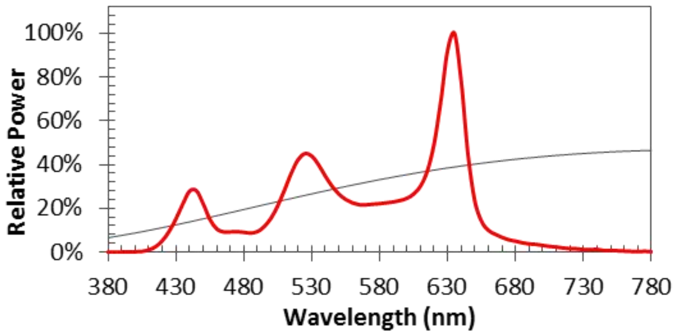
80
$R_f$
100
$R_g$
$D_{uv}$
0.0000
CCT
3501 K

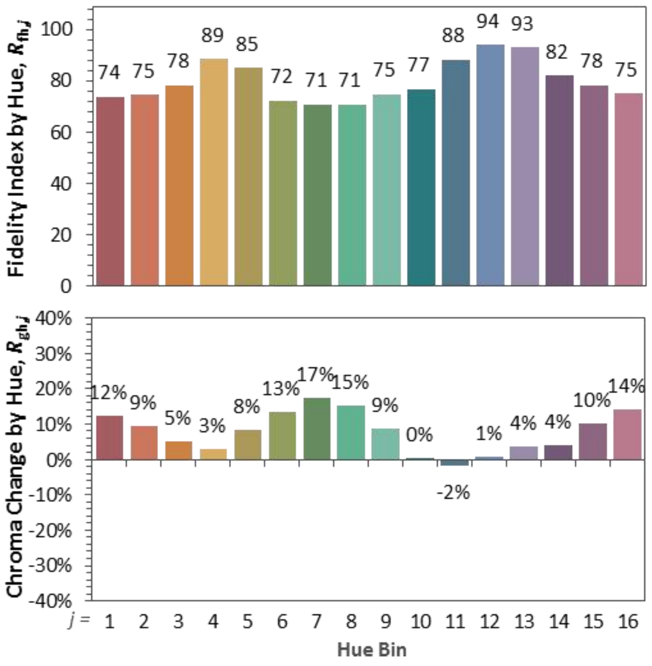

CRI = 83, $R_9$ = -5

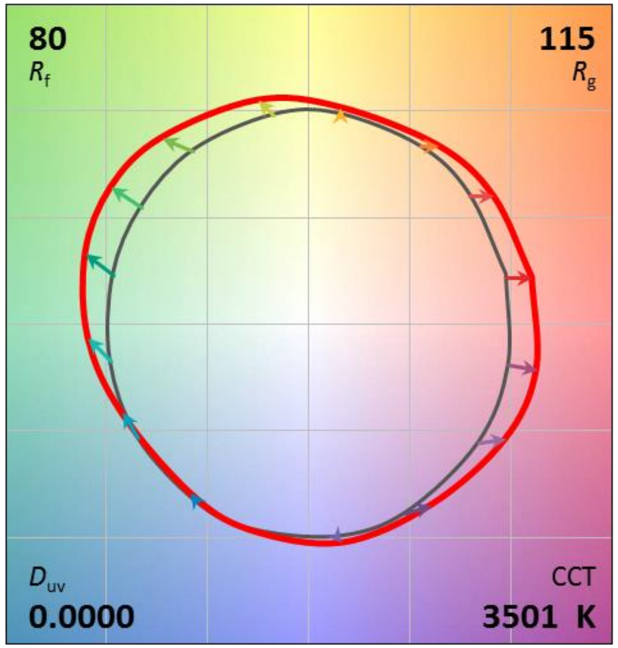




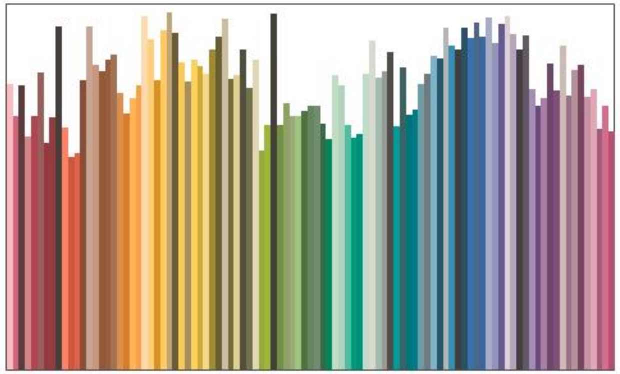
$R_f$-$R_g$ Plot
140
130
120
110
100
90
80
70
60
Gamut Index, $R_g$
50 70 90
Fidelity Index, $R_f$

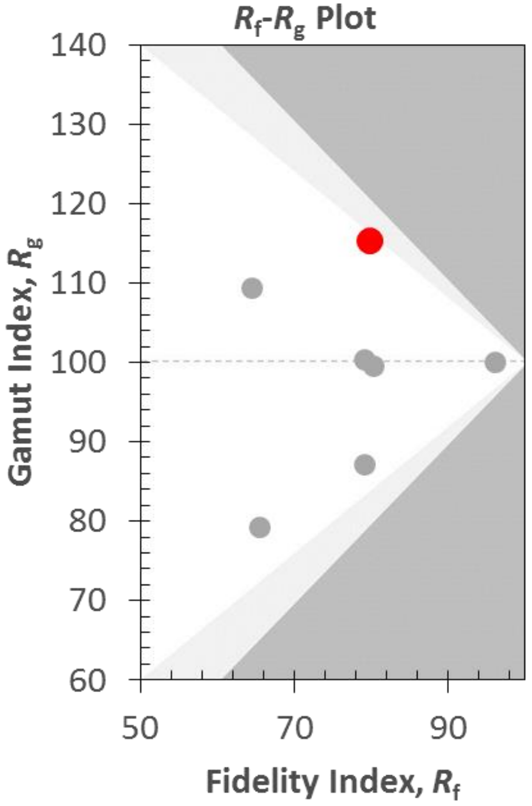

100%
80%
60%
40%
20%
0%
Relative Power
380
430
480
530
580
630
680
730
780
Wavelength (nm)


Fidelity Index by Hue, $R_{f,h,j}$
100
80
60
40
20
0
74 75 78 89 85 72 71 71 75 77 88 94 93 82 78 75
Chroma Change by Hue, $R_{cs,h,j}$
40%
30%
20%
10%
0%
-10%
-20%
-30%
-40%
12% 9% 5% 3% 8% 13% 17% 15% 9% 0% -2% 1% 4% 4% 10% 14%
j = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Hue Bin


80
$R_f$
115
$R_g$
$D_{uv}$
0.0000
CCT
3501 K

CRI = 72, $R_9$ = 1




$R_f$-$R_g$ Plot
140
130
120
110
100
90
80
70
60
Gamut Index, $R_g$
50
70
90
Fidelity Index, $R_f$

# TM-30 Experiment at PNNL

Illuminance: ~20 fc
CCT: 3500 K
Lighting Conditions: 26
Objects: Generic Consumer, balanced hues
Application: Undefined
Participants (28): 18-65, 16 females 12 males
Rating Questions: Normal-Shifted, Saturated-Dull, Like-Dislike


Dr Pepper
93
$R_f$
101
$R_g$
$D_{uv}$
-0.0001
CCT
3502 K


64
$R_f$
120
$R_g$
$D_{uv}$
0.0000
CCT
3511 K

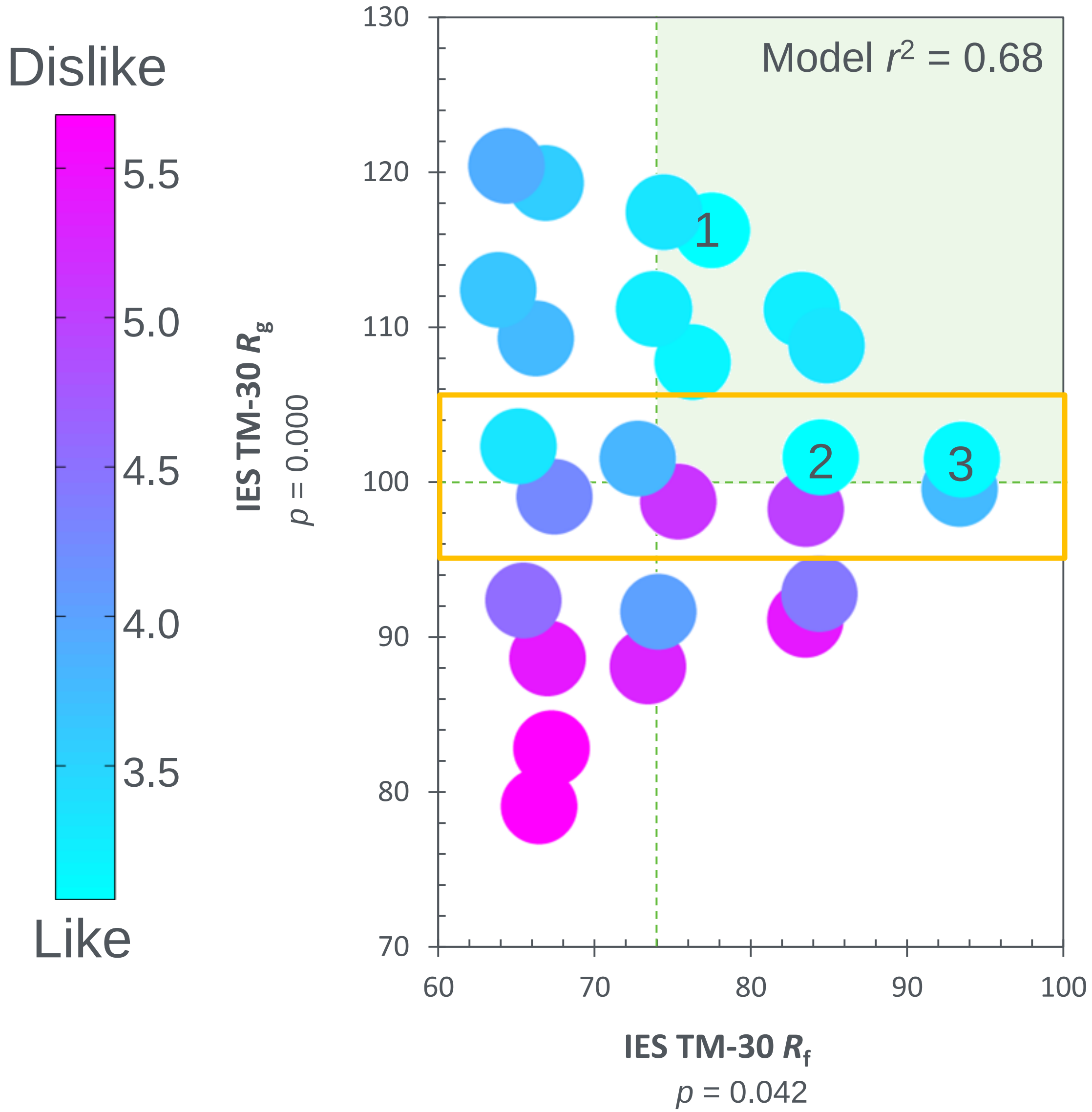

Dr Pepper
66
R_f
79
R_g
D_uv
-0.0001
CCT
3514 K

84
$R_f$
102
$R_g$
$D_{uv}$
0.0007
CCT
3506 K


Dr Pepper
83
$R_f$
98
$R_g$
$D_{uv}$
0.0005
CCT
3513 K

77
$R_f$
116
$R_g$
$D_{uv}$
-0.0004
CCT
3489 K
Dr Pepper

# Are two metrics enough to know preference?



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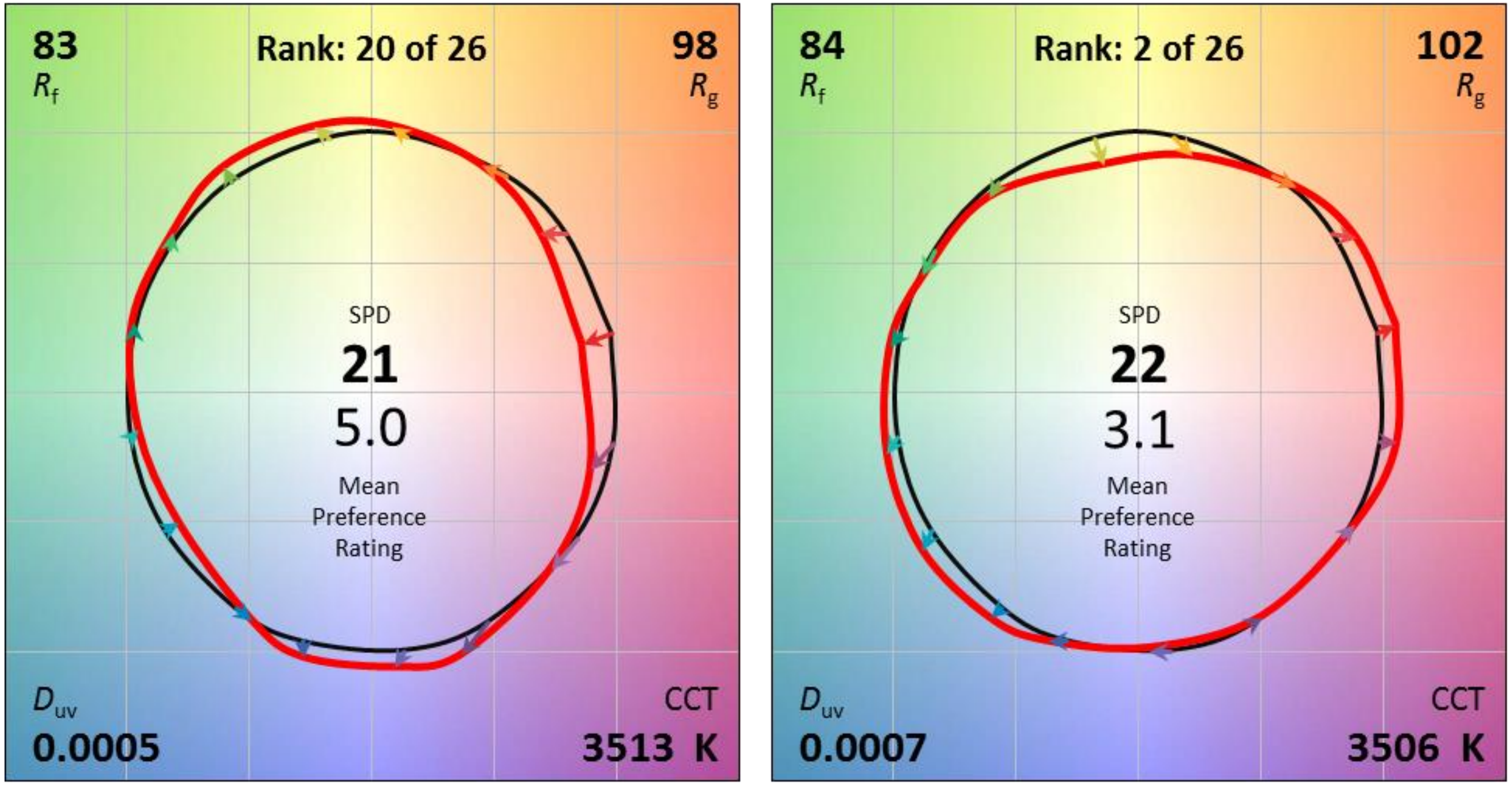
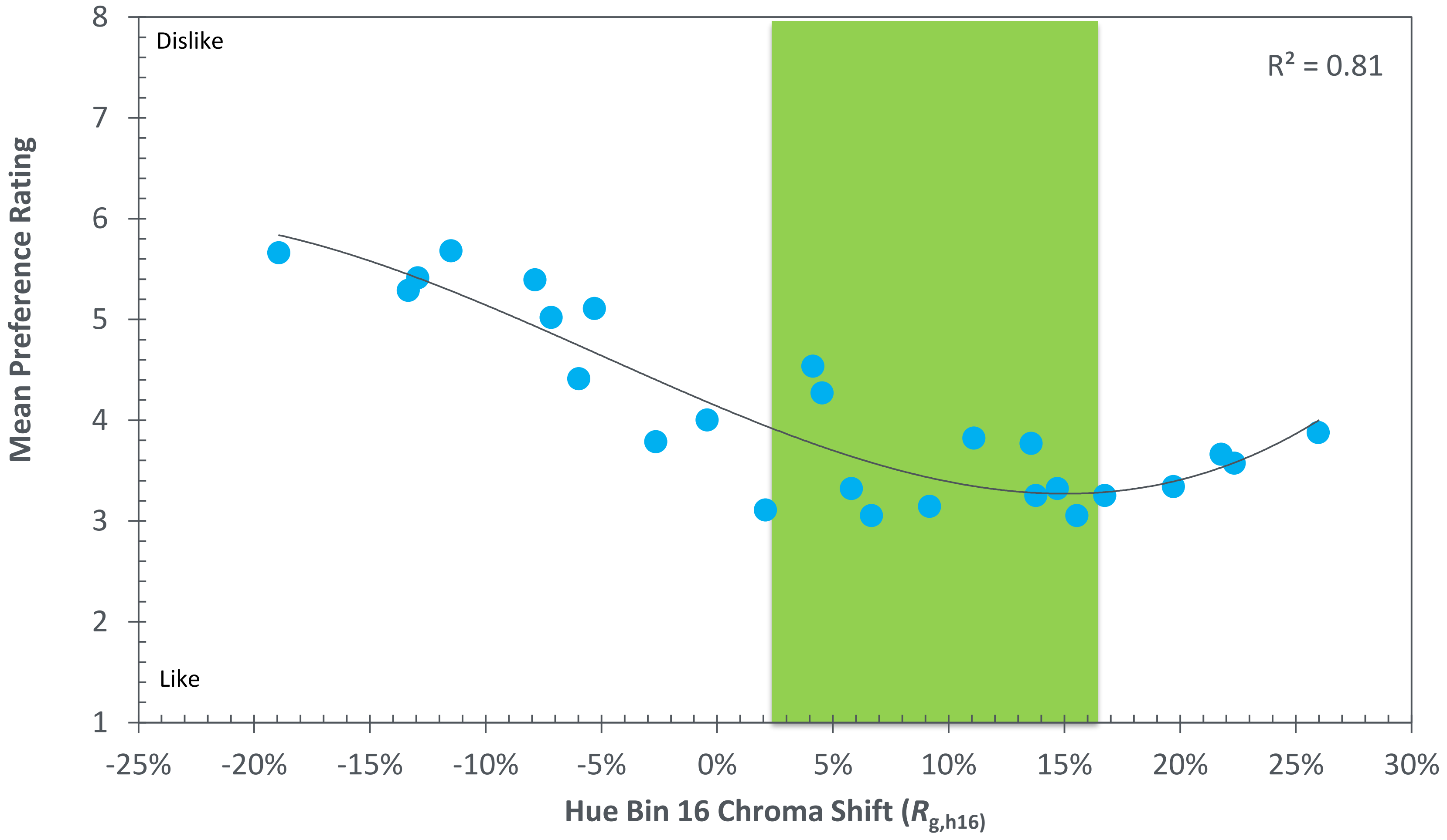
# Gamut Shape is Important for Preference




**Same Fidelity, Same Gamut, Significantly Different Rating.**

# Red Chroma Shift and Preference?



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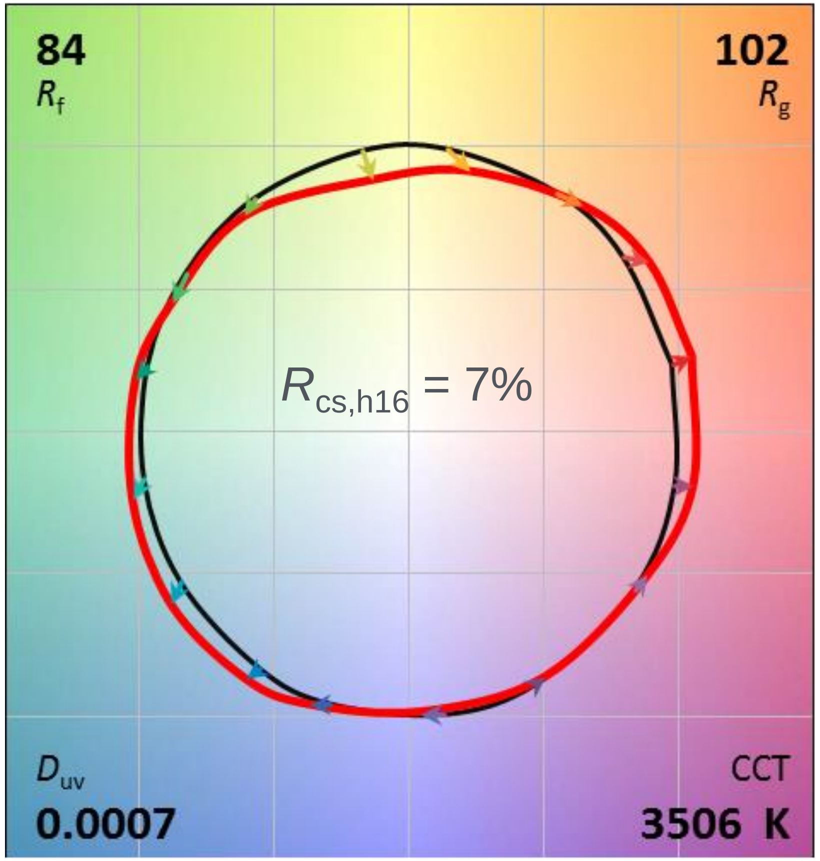
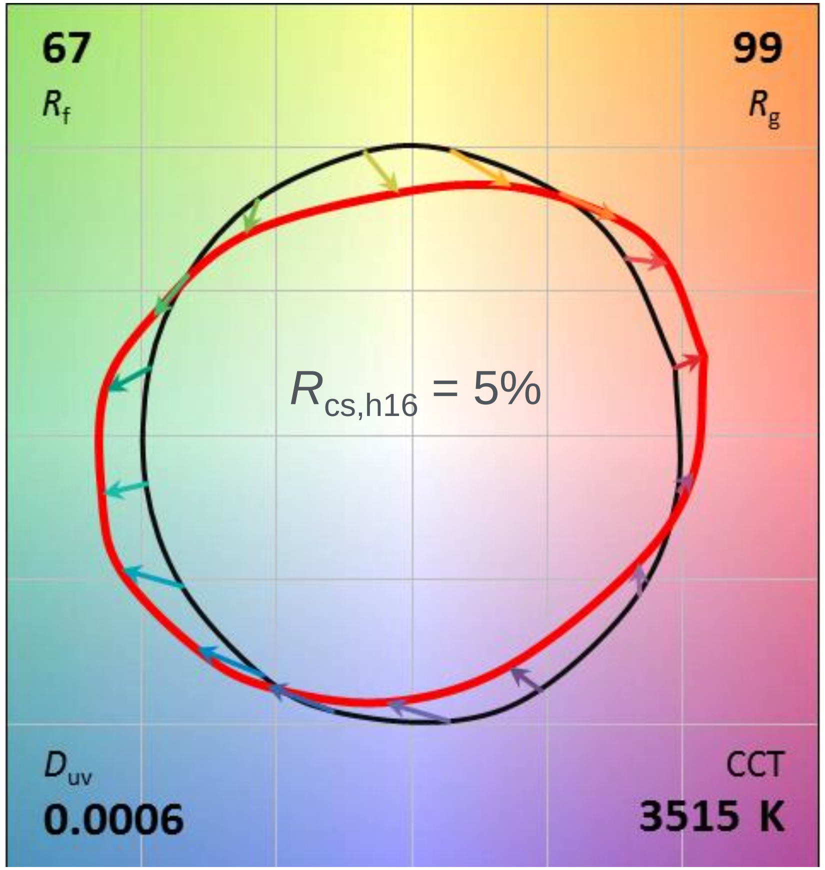
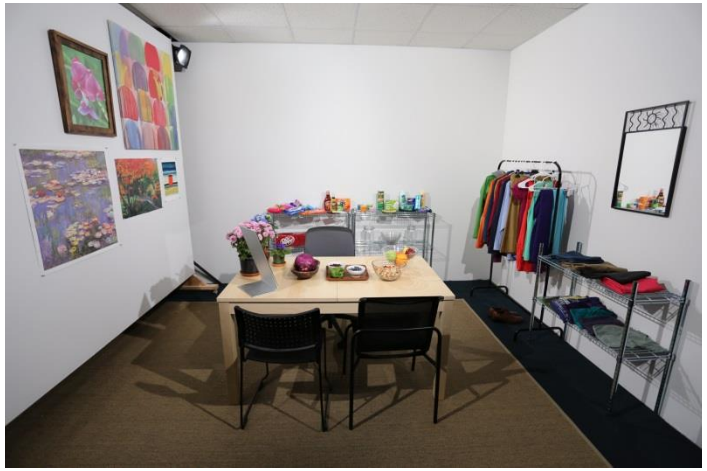
# Red Chroma Shift and Preference?



Context = 

Normalness = Fidelity + Red Fidelity/Saturation

$R_f > 80$ $R_{f,h1} > 80$ $0\% < R_{cs,h1} < 8\%$

Saturation = Red Saturation

Maximize $R_{cs,h16}$, $R_{cs,h1}$

Preference = Fidelity + Red Saturation

$R_f > 74$ $0\% < R_{cs,h16} < 15\%$ ($R_g > 100$)

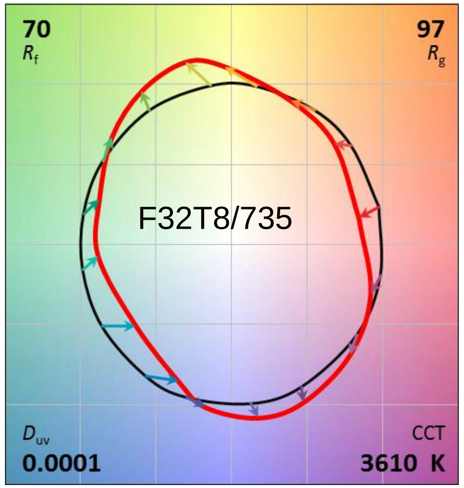
$0\% < R_{cs,h1} < 15\%$

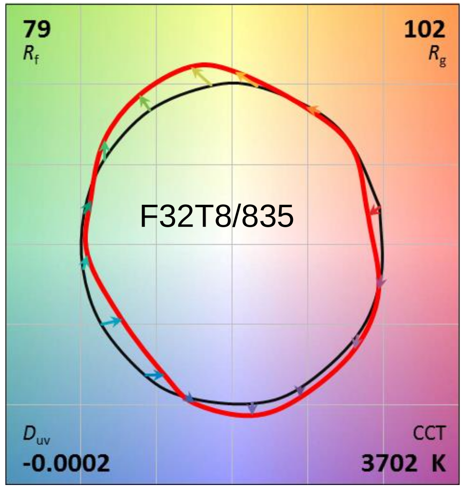


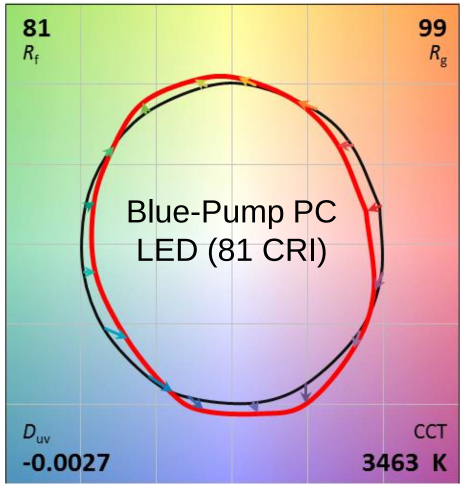
53

# Existing versus Future?

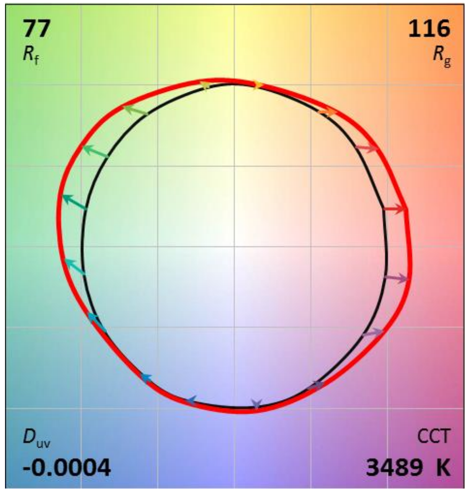
When designed for CRI/Efficiency, sources tend to look like this:

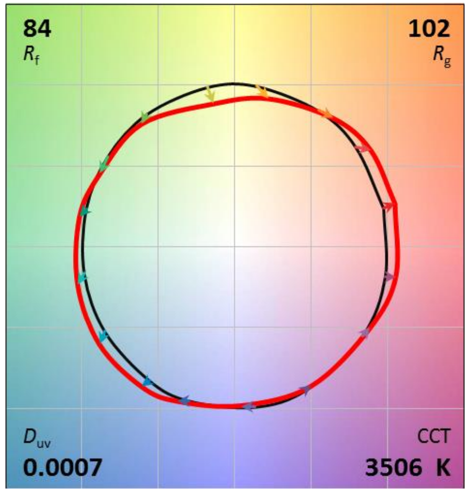


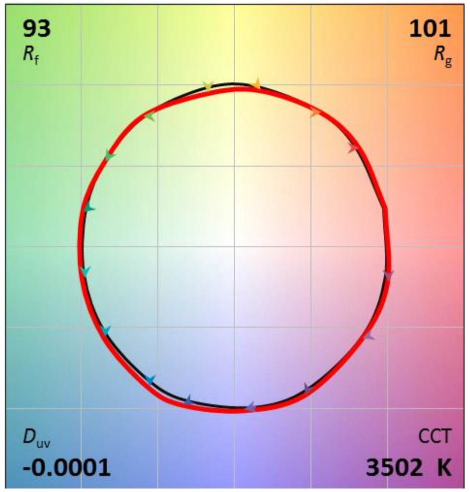



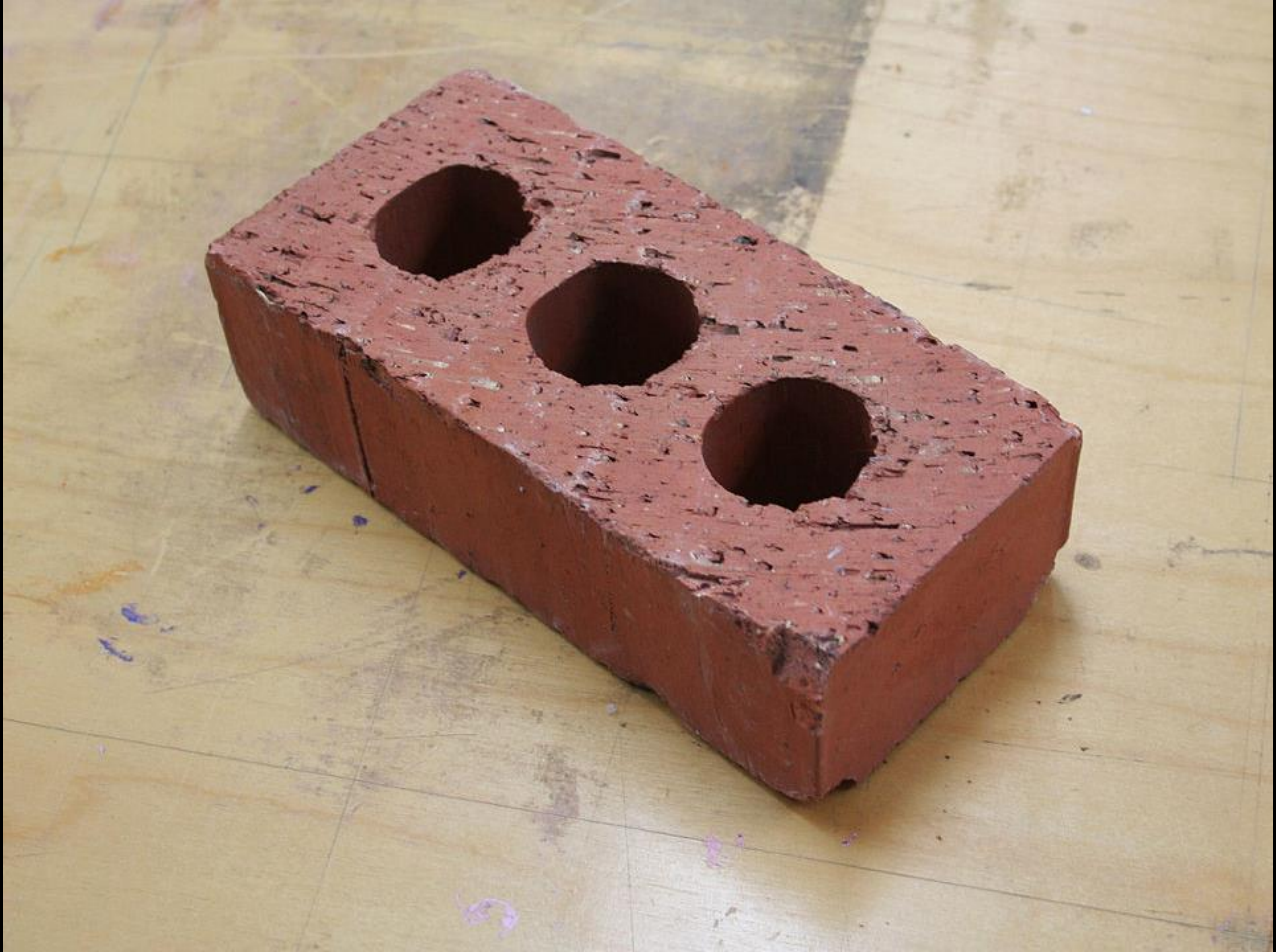

When designed for color preference, sources tend to look like this:

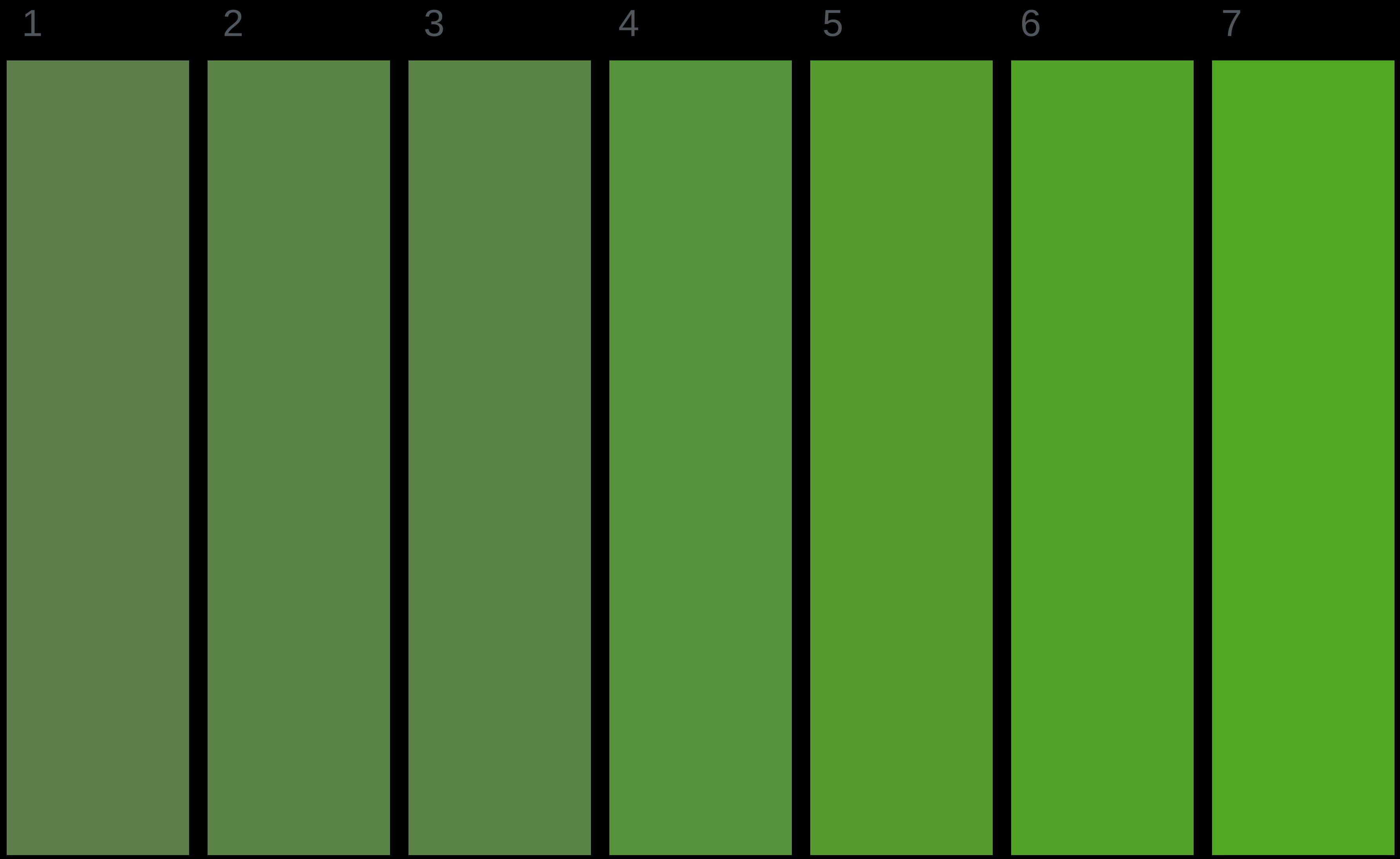


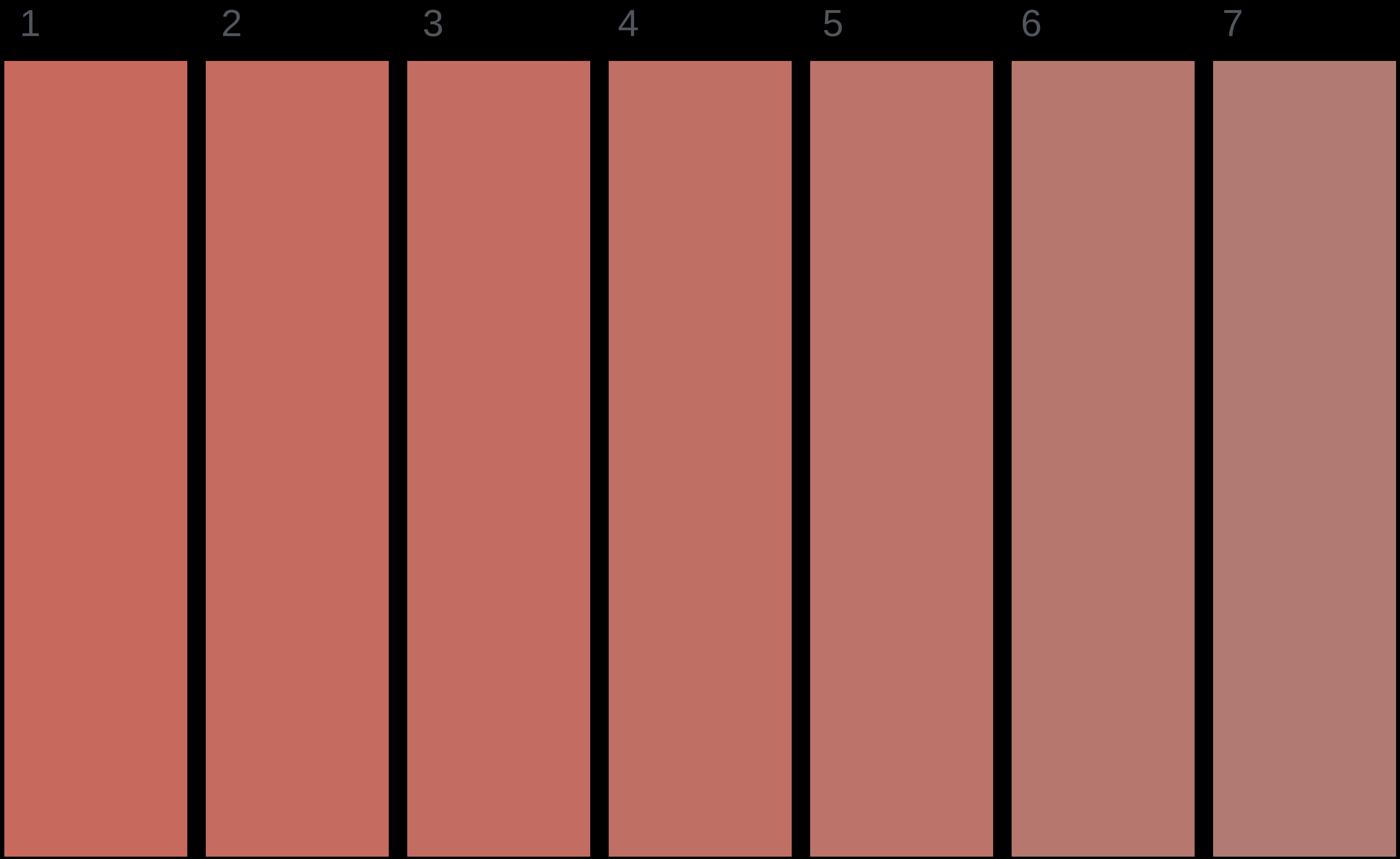



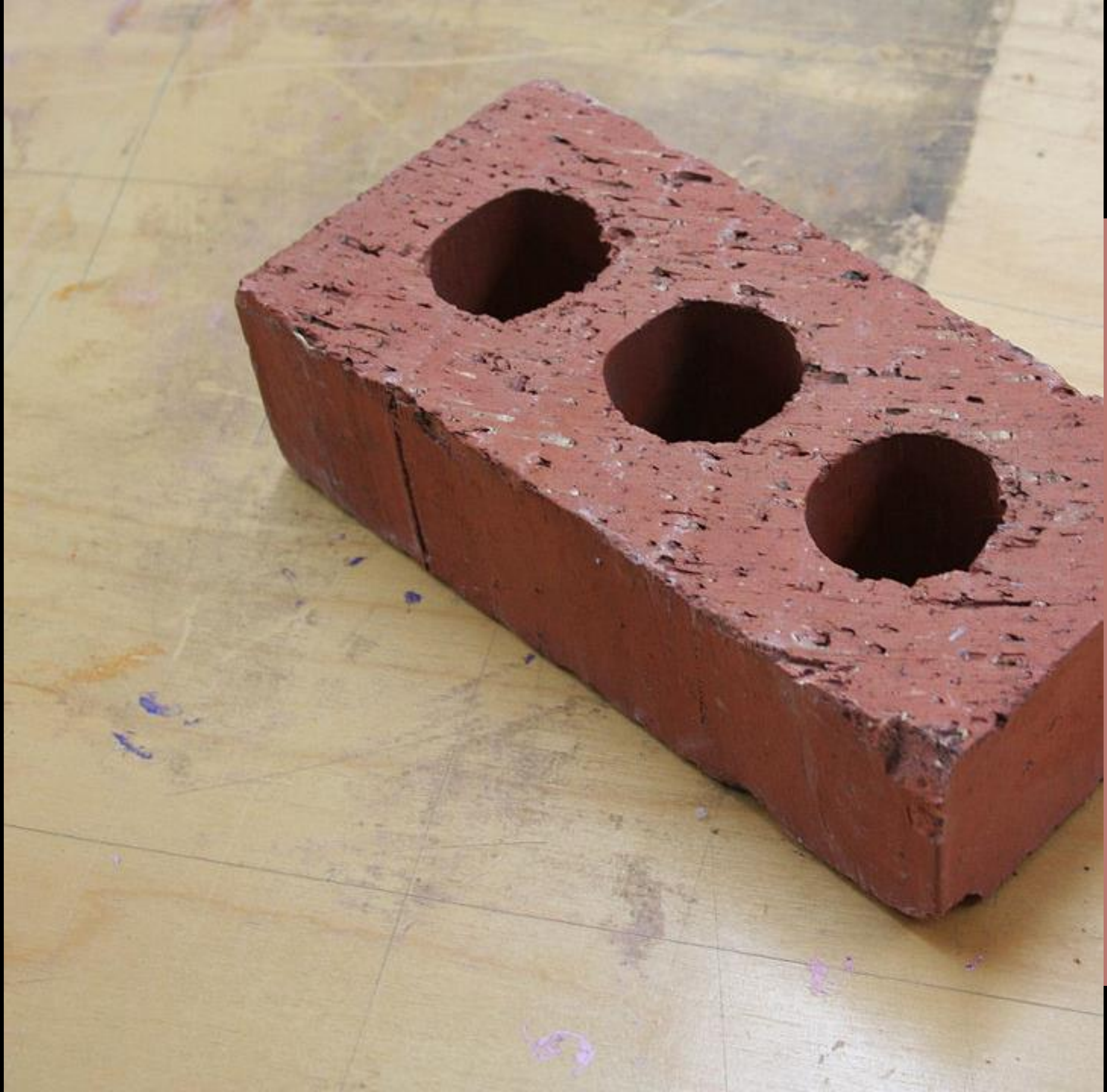
**Preference versus Fidelity:**
An examination of the preference for increased (red) saturation.




1
2
3
4
5
6
7


5
6
7


1
2
3
4
5
6
7



# Preference for High (Red) Saturation

1. Many (every?) study has shown preference for increased saturation, particularly for reds.
2. We remember colors to be more saturated than they actually are, and more like primary colors.
3. Increased saturation can improve color discrimination. It may also improve the signal difference for opponent channels.
4. Saturation counters the natural decay pattern of foods.
5. The neodymium incandescent lamp has been a very successful commercial product over a long period of time.
6. Take a look at other industries, such as photography.
7. Look at product packaging, cosmetics, etc.
8. Interior illuminances are much lower than exterior daylight illuminances. The Hunt effect.

# Fidelity or (Targeted) Saturation?

**Studies showing preference for increased saturation:**

Sanders, 1959
Judd, 1967
Jerome, 1972
Thornton, 1974
…
Smet and others, 2010
Rea and Freyssinier, 2010
Liu and others, 2012
Islam and others, 2013
Szabo and others, 2014
Wei and others, 2014
Wei and others, 2015
Ohno and others, 2015
Jost-Boissard and others, 2015 Teunissen and others, 2016
Lin and others, 2015
Wei and Houser, 2016a
Royer and others, In Press

**Studies showing preference for high fidelity:**

# Memory Color

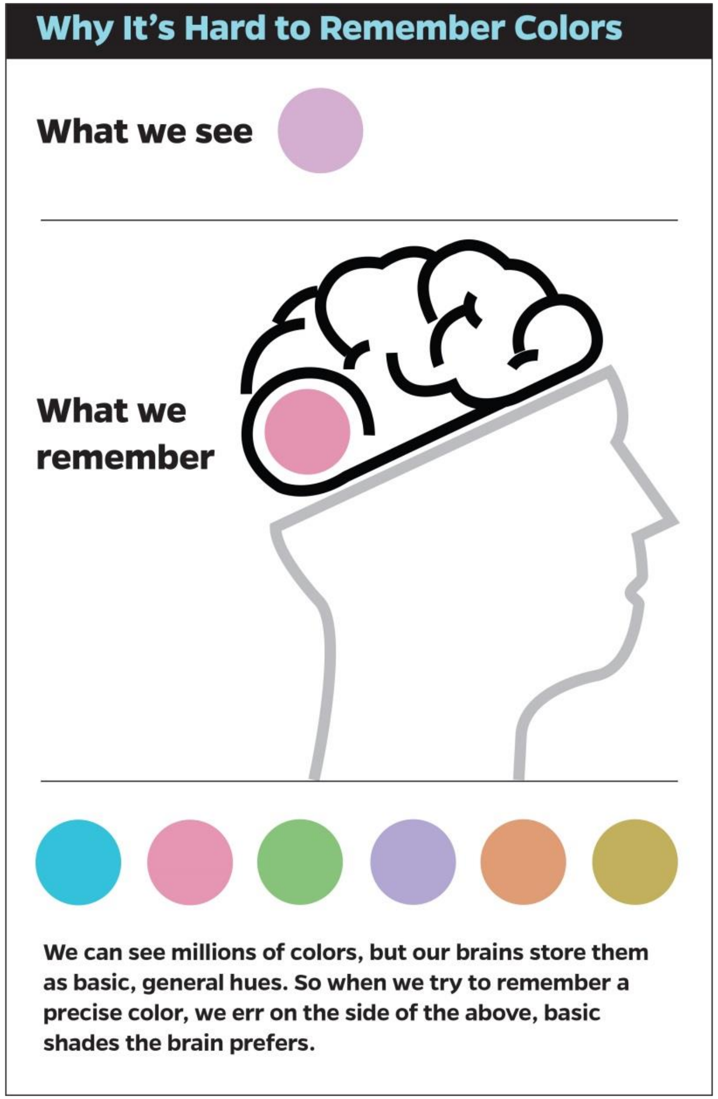
## Memory Colors of Familiar Objects*

C. J. Bartleson
*Research Laboratories, Eastman Kodak Company, Rochester, New York*
(Received March 9, 1959)

### CONCLUSIONS

It seems apparent that the mean memory colors for the familiar objects examined are not of the same chromaticities as the original object-color means. There is evidence of increased saturation in the memory colors. In most cases there are hue shifts with memory in the direction of what is probably the most impressive chromatic attribute of the object in question.

# Memory Color




**Why some colors appear more memorable than others: A model combining categories and particulars in color working memory.**

Bae, Gi-Yeul; Olkkonen, Maria; Allred, Sarah R.; Flombaum, Jonathan I. Journal of Experimental Psychology: General, Vol 144(4), Aug 2015, 744-763.

# Memory Color

## Differential binding of colors to objects in memory: red and yellow stick better than blue and green

**Christof Kuhbandner[1]*, Bernhard Spitzer[2], Stephanie Lichtenfeld[3] and Reinhard Pekrun[3]**

[1] Department of Psychology, University of Regensburg, Regensburg, Germany
[2] Department of Education and Psychology, Freie Universität Berlin, Berlin, Germany
[3] Department of Psychology, University of Munich, Munich, Germany

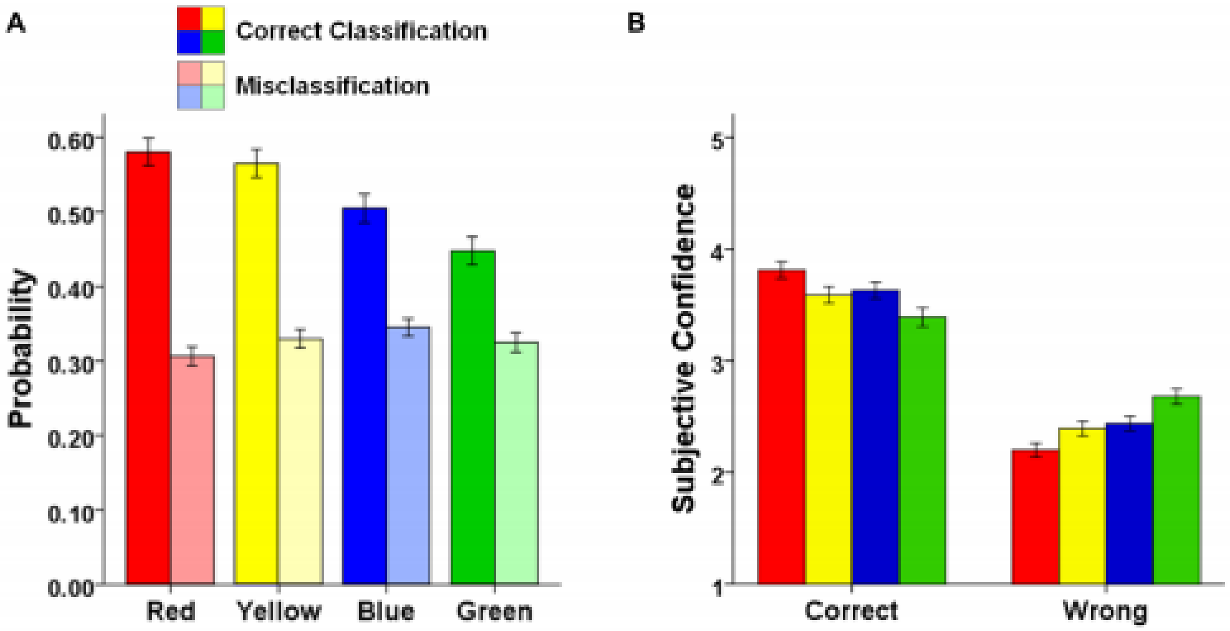



**FIGURE 4 | Combined data set.** Color effects on **(A)** the probability of correctly classifying an object's color (saturated colors) and erroneously reporting a color in case of misclassification (pale colors), and **(B)** subjective confidence in correct and wrong color memories for the combined data set. Error bars represent SE of the means.



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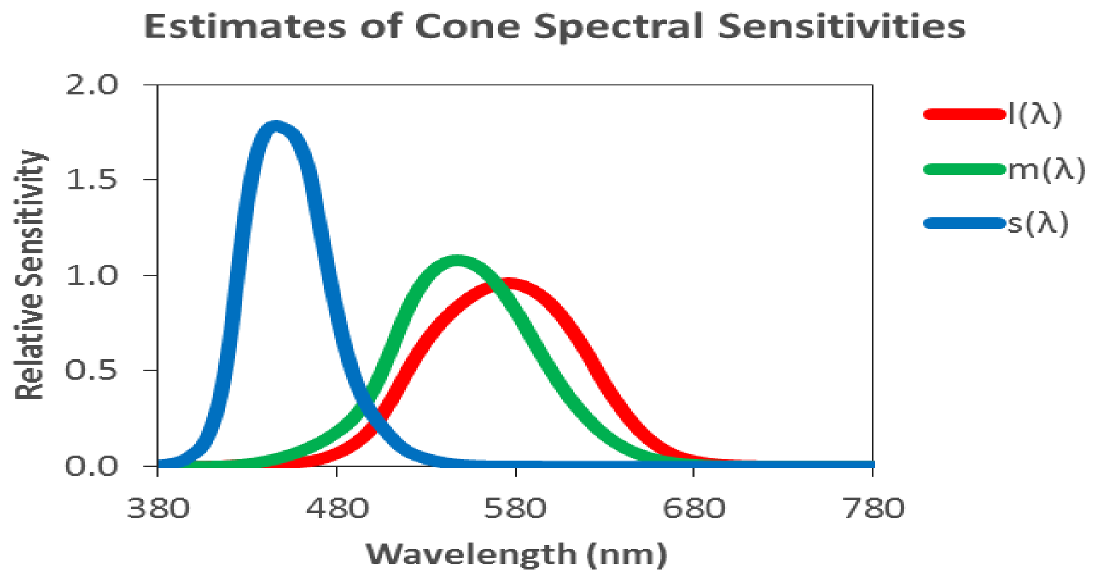
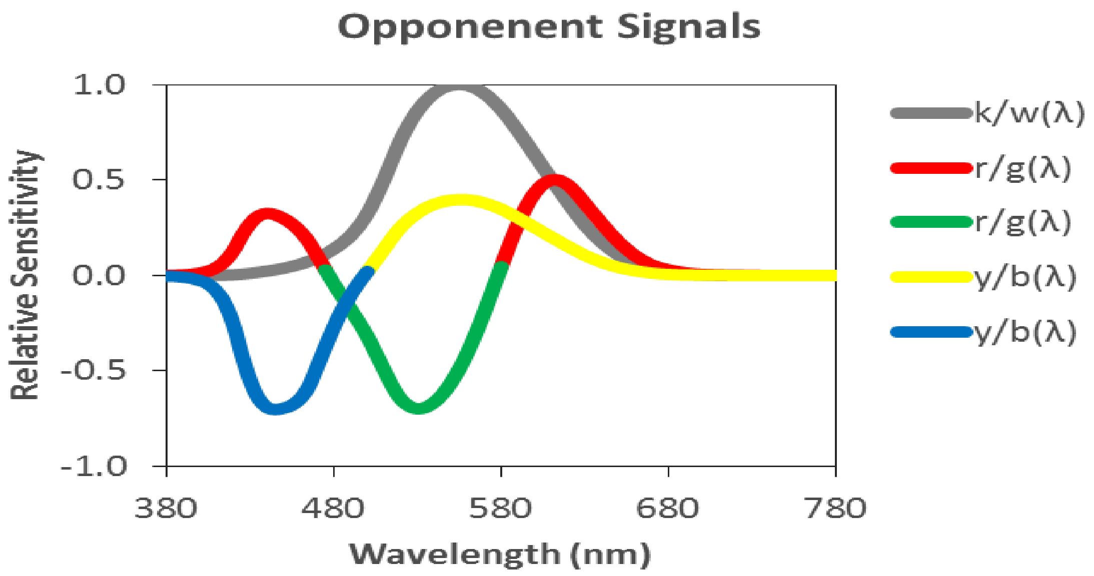
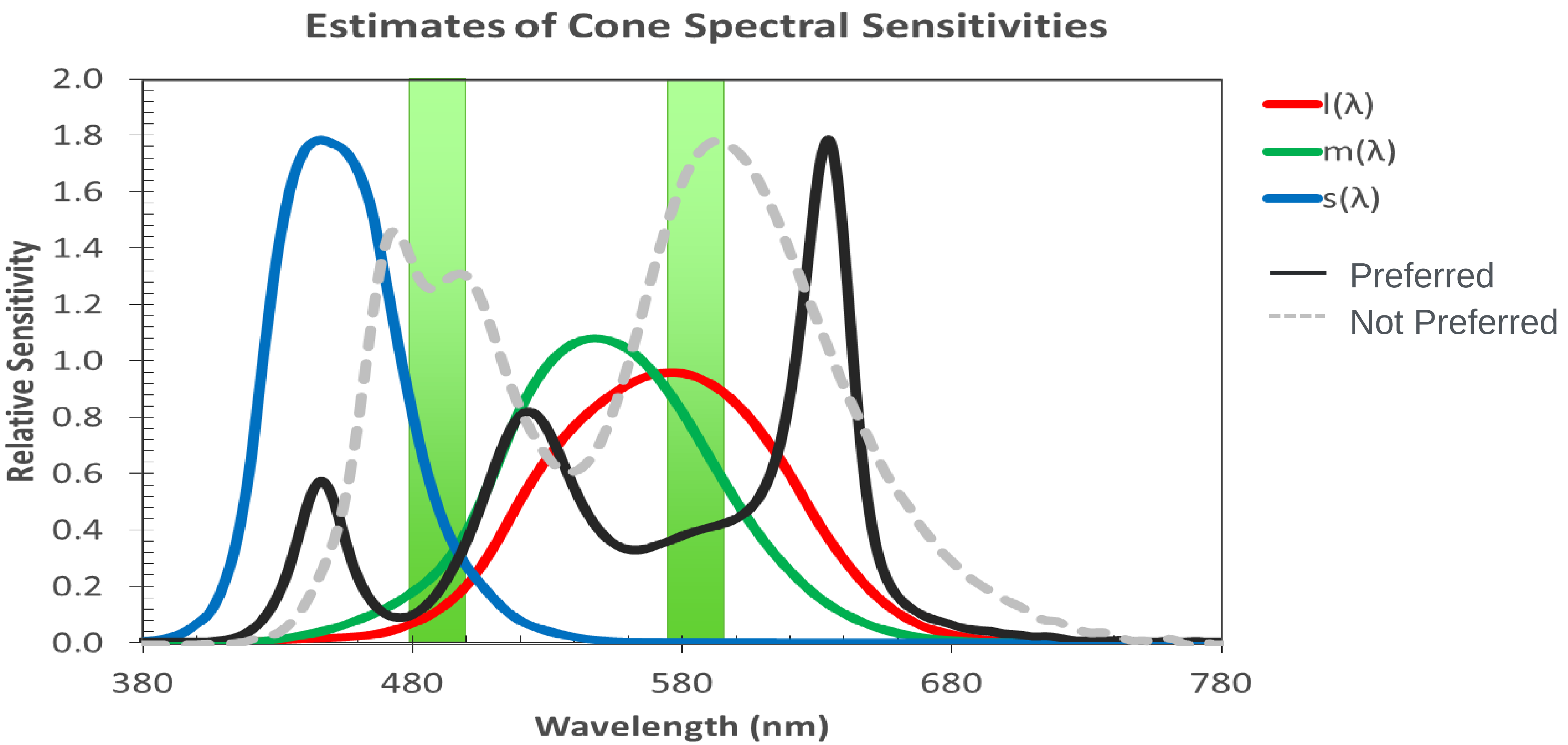
# Photoreceptors and Opponent Channels



# Photoreceptors and Opponent Channels



# Photoreceptors and Opponent Channels

**Color Preference under LEDs with Diminished Yellow Emission**

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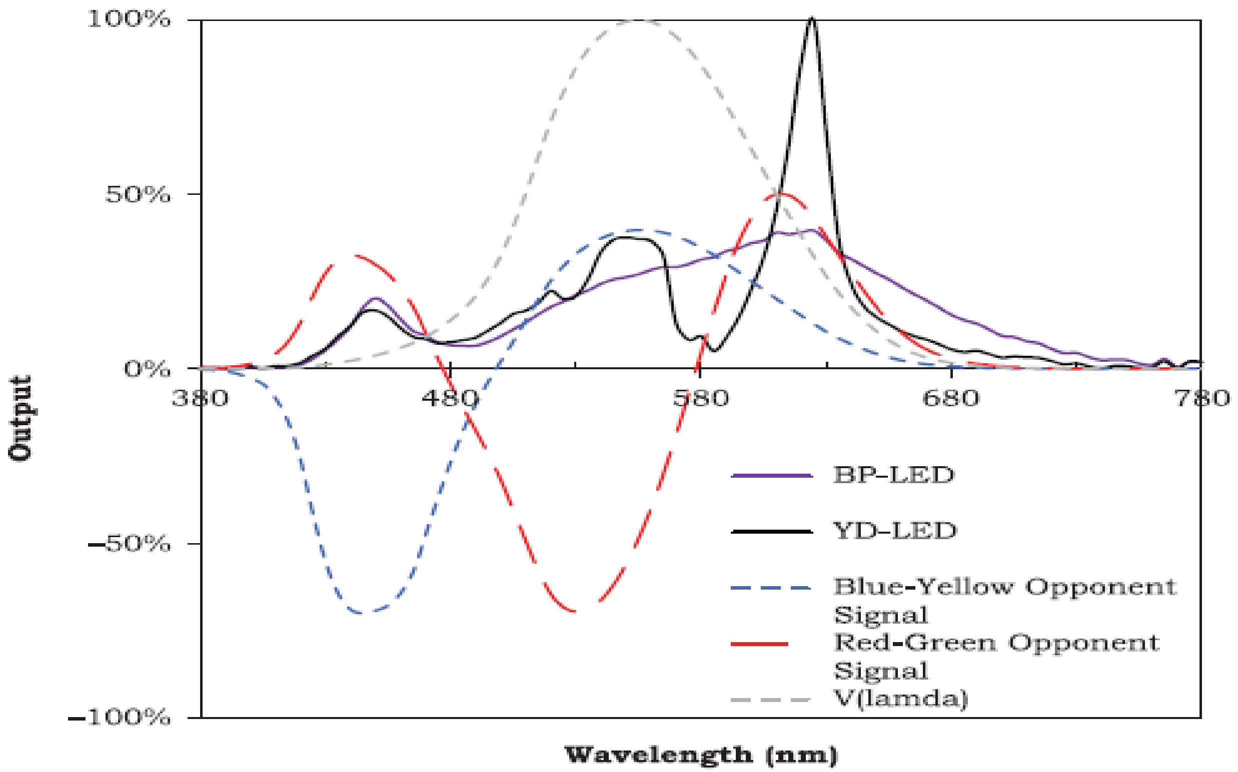
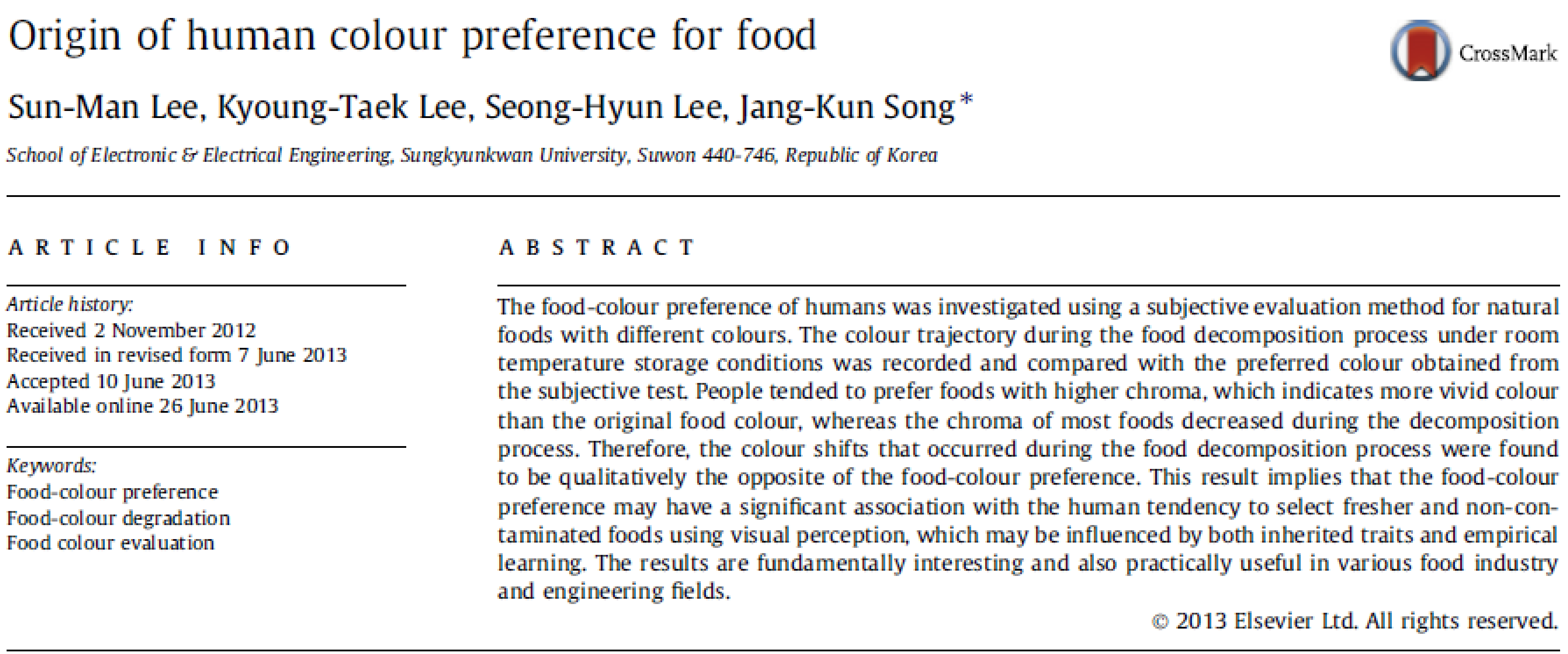



Fig. 9 Red–green, blue–yellow, and luminance opponent channel responses [Hurvich 1981]. SPDs of BP-LED and YD-LED scaled to the same V(λ)-based quantities (for example, lumen output) are overlaid in arbitrary *y*-axis units for visual comparison on the basis of wavelength. The ratio of the total red–green signal of YD-LED to BP-LED is 1.18 and the ratio of total blue–yellow signal is 0.97. When taking the 3.5% fewer lumens of BP-LED for equal brightness perception, the ratios become 1.22 and 1.01 for the red–green and blue–yellow signals, respectively.

**Saturating source provides 22% stronger red-green signal, blue-yellow channel unchanged.**

# Decay Processes


Origin of human colour preference for food

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ABSTRACT

The food-colour preference of humans was investigated using a subjective evaluation method for natural foods with different colours. The colour trajectory during the food decomposition process under room temperature storage conditions was recorded and compared with the preferred colour obtained from the subjective test. People tended to prefer foods with higher chroma, which indicates more vivid colour than the original food colour, whereas the chroma of most foods decreased during the decomposition process. Therefore, the colour shifts that occurred during the food decomposition process were found to be qualitatively the opposite of the food-colour preference. This result implies that the food-colour preference may have a significant association with the human tendency to select fresher and non-contaminated foods using visual perception, which may be influenced by both inherited traits and empirical learning. The results are fundamentally interesting and also practically useful in various food industry and engineering fields.





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# Decay Processes

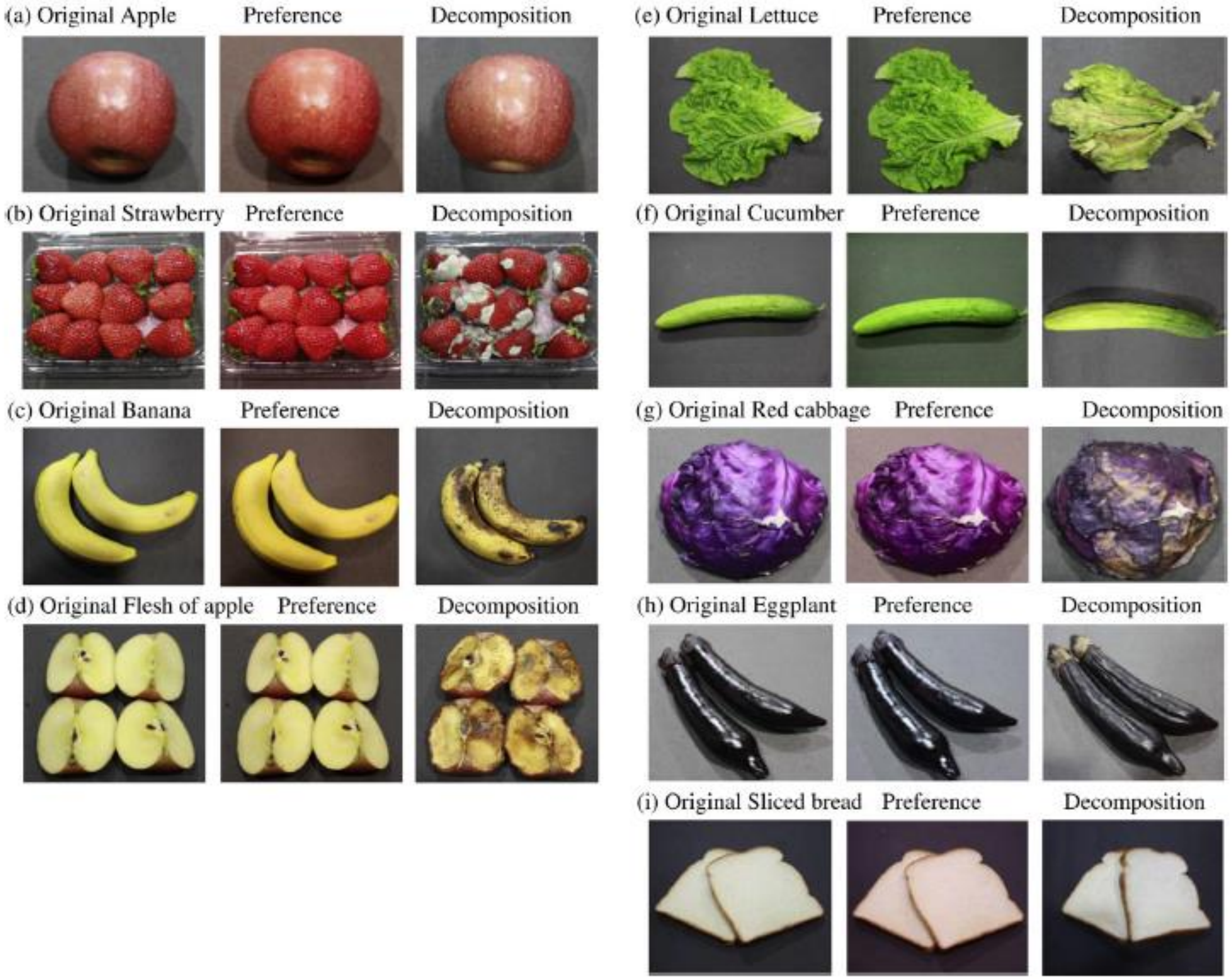
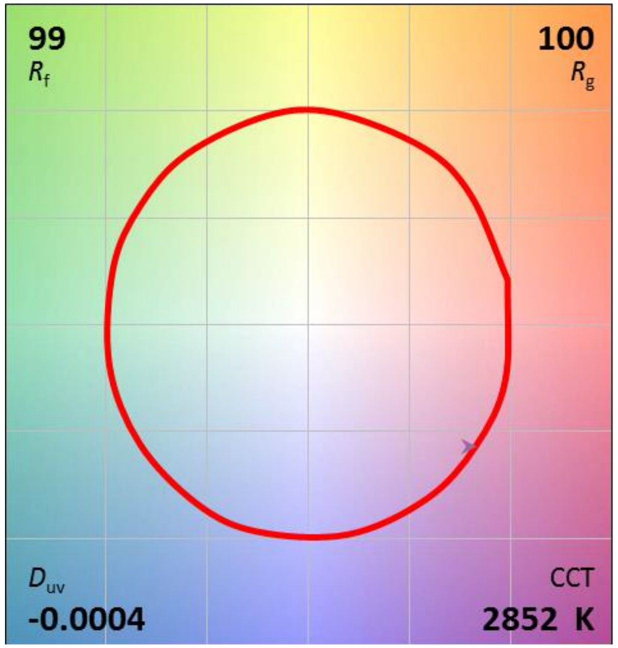
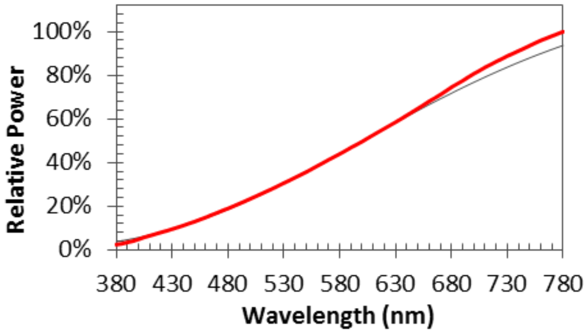



**Fig. 3.** The photographic images of the original image, the image with average preferred colour, and the image after decomposition test, respectively, for each food.

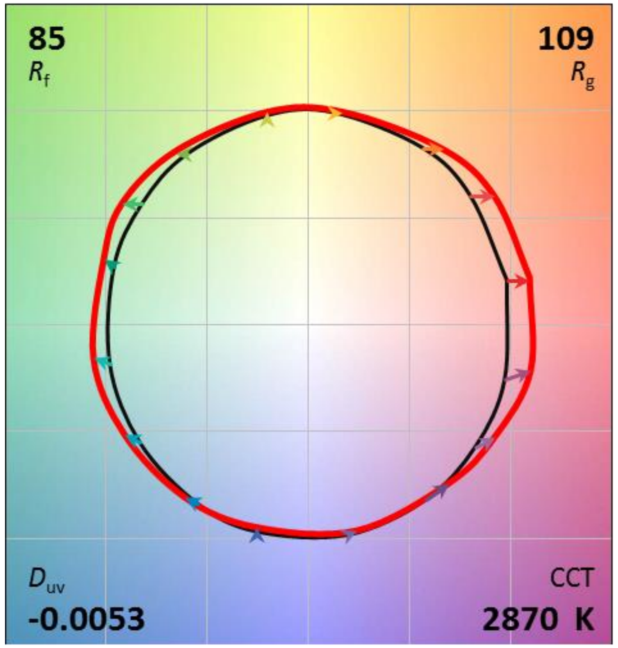
# Neodymium (Reveal) Lamp: Long-term Evidence

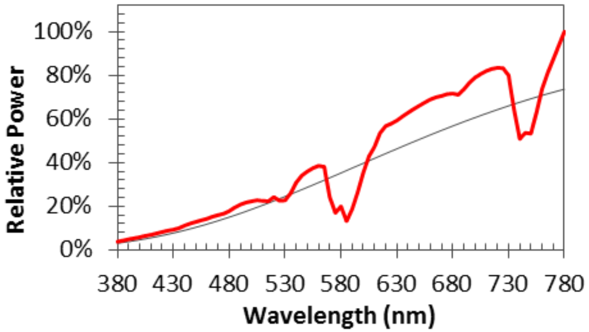
## Standard Incandescent




## Neodymium Incandescent




# Film/Photography Industry

Velvia Film:

*Velvia moved colours around, shifting yellows to reds, separating yellow greens from blue greens to produce a vivid colour range in foliage.* ***It did boost saturation but other films had done so previously. It's that it purified low level saturation that produced the revelation.*** *It could take a 'mucky' uniform green and purify the colours and separate out the yellow greens from the blue greens, creating strong contrast and interest.*

Tim Parkin
https://www.onlandscape.co.uk/2011/05/psychology-of-saturation/


# Film/Photography Industry

Velvia Film:

*After twenty-five years of using Kodachrome film whenever sharpness was of the utmost importance, **I abruptly gave up on it in February 1990 after seeing tests of an amazing new slide film from Japan…. Fuji's introduction of ISO 50 Velvia** at the Photo Marketing Association show in Las Vegas… After I returned home, I ran controlled comparisons of Velvia against Kodachrome 25, Kodachrome 64 and Fuji Pro 50. On my own light table the next morning, I clearly saw the end of an era. Velvia was the best of all existing worlds. Its resolution exceeded that of Kodachrome 25 and the other test films in high-contrast tests simulating daylight and equaled Kodachrome 25 in soft light. **Its color saturation and separation of tones exceeded those of Fuji Pro 50 and the other films.** I was aware that many photographers would prefer Kodachrome's relatively muted colors, but I believed much of this was due to a conditioned constancy illusion that Kodachrome slides accurately represented the natural world. I knew better and fully expected Velvia to establish a new constancy illusion with picture editors and the public… I wanted to see the world freshly through this new tool and to push it to the limit to see what it would do. Over the years, the limitations of other films had caused me to consider certain kinds of subject matter and lighting as impossible. Murky renditions of greens in shadow under a blue sky on Kodachrome became vivid on Velvia. Fuji Pro 50 renditions of delicate foliage have very strong color, but also a lack of resolution that calls attention to itself, especially when compared with Kodachrome 25. Velvia holds both color and sharpness.*

Galen Rowell

Via http://landscapephotographyblogger.com/did-velvia-film-change-landscape-photography/

# Film/Photography Industry


https://jcnorreel.wordpress.com/2012/04/06/digital-vs-analog-photography-the-never-ending-story/

# Film/Photography Industry

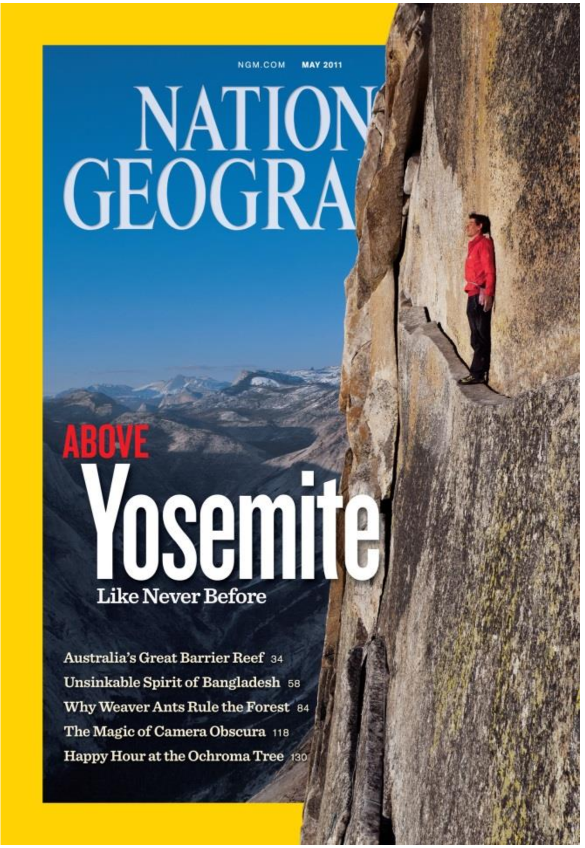
Red shirt photography:

*Even though Kodachrome was already unnaturally bright, photographers ... **splashed the strongest possible colors in their pictures so that they would be more effective in print**. One result was that the staff photographers - who were constantly being sent to colorful places to slake what was seen as the **public's unquenching thirst for colorful scenes** - would often find themselves needing more color to take advantage of the color film and would resort to placing the people in costume.*

C.D.B. Bryan, *National Geographic Society: 100 Years of Adventure and Discovery*, National Geographic Society (ISBN 0810936968)
Via https://en.wikipedia.org/wiki/Red_shirt_(photography)

# Film/Photography Industry

Red shirt photography:




(From Movie)



https://mrhalfdome.wordpress.com/2011/04/26/alex-honnold-in-national-geographic/

# Packaging and Cosmetics


# Why Red?

Color Psychology: Effects of Perceiving Color on Psychological Functioning in Humans

Andrew J. Elliot[1] and Markus A. Maier[2]

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[2]Department of Psychology, University of Munich, Munich 80802, Germany; email: markus.maier@psy.lmu.de

The empirical work that we have reviewed clearly indicates that **color can carry meaning and have an important influence on affect, cognition, and behavior in achievement and affiliation/attraction contexts. Red, especially, has been shown to be a critical color in this regard.** This should come as no surprise, as red has long been identified as a unique, special color. Ellis (1900), for example, commenced his prescient essay "The Psychology of Red" with the following: "**Among all colors, the most poignantly emotional tone undoubtedly belongs to red**" (p. 365). Many things in biology, culture, and language point to the poignancy and prominence of red. Red is the color of blood and, therefore, the color of life and (when spilled) death. **Dynamic variation in visible blood flow on the face and body of a conspecific communicates critical, adaptation-relevant information, from the pallor of fear, to the flush of sexual interest or arousal, to the florid crimson of anger and imminent aggression** (Changizi 2009). More static individual differences in visible blood flow are **indicative of cardiac health or illness** (Stephen et al. 2011). Red is the color of ripe fruit, and vivid red (especially against a green background) **allows such ripe fruit to be detected from afar** (Regan et al. 2001). **Red is the color of many aposematic (warning) signals conveyed on the bodies of poisonous insects and reptiles** (Stevens & Ruxton 2012). Red is regarded by anthropologists to have been the **first chromatic color used in symbolic fashion in interpersonal communication**, and the use of red ochre in prehistoric cave painting is thought to be the first use of chromatic color in art (Henshilwood et al. 2009). Red is a term that appears in all or nearly all lexicons, and **red is the first chromatic term to emerge in most of these languages** (Kay & Maffi 1999). Given all of this, the contemporary use of red in signs (e.g., alarms, sirens), symbols (e.g., hearts, crosses), and sayings (e.g., "in the red," "roll out the red carpet") seems fitting, and the preponderance of red effects observed in the current literature is sensible.

# Why Red?

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## Achievement vs. Attractiveness Scenarios

“Critically, color meanings and effects are posited to be context specific.”

# Why Red?

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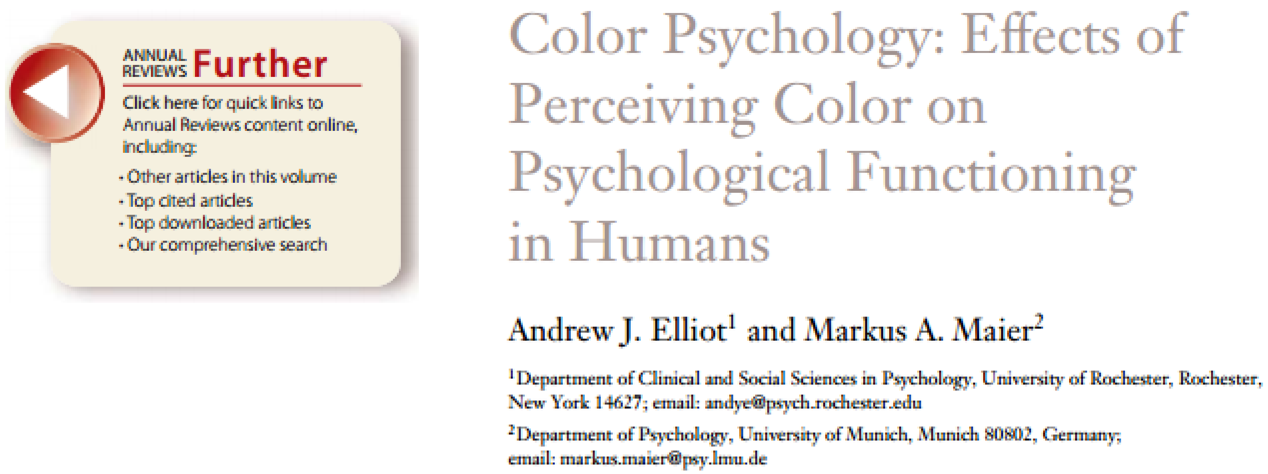
…competitors randomly assigned to red relative to blue sportswear were more likely to win the competition…[Hill & Barton 2005]

…red teams win more virtual matches than blue teams…[Illie et al 2008]

# Why Red?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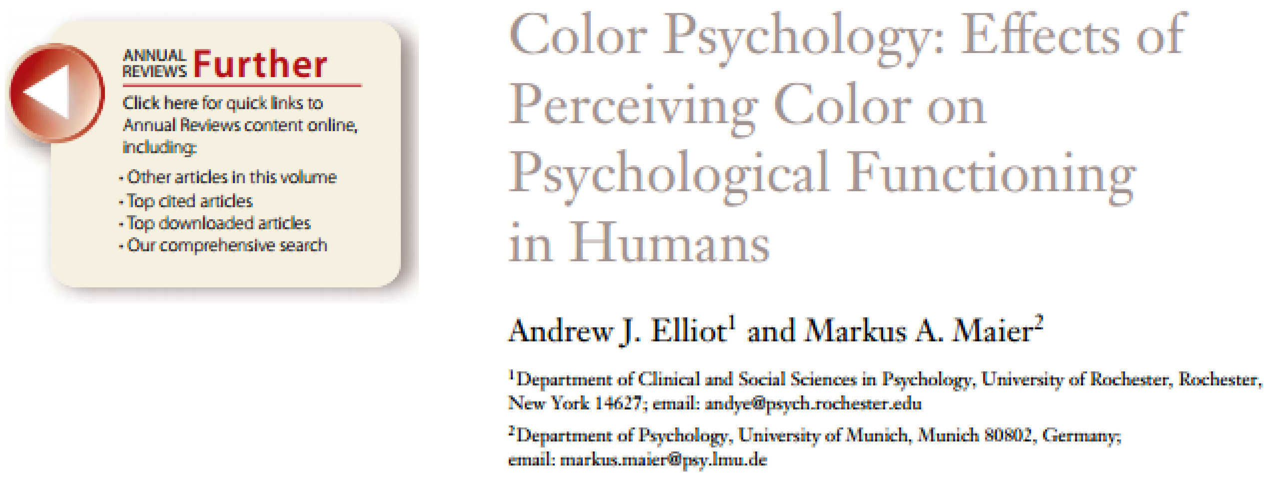
These data suggest that the red effect may be present in some countries but not others, perhaps as a function of culture-specific learned associations to red that run counter to, and weaken the influence of, any inherent meaning. Likewise, the strength of the red effect may vary as a function of team versus one-on-one competition…[Kocher & Sutter 2008]

# Why Red?



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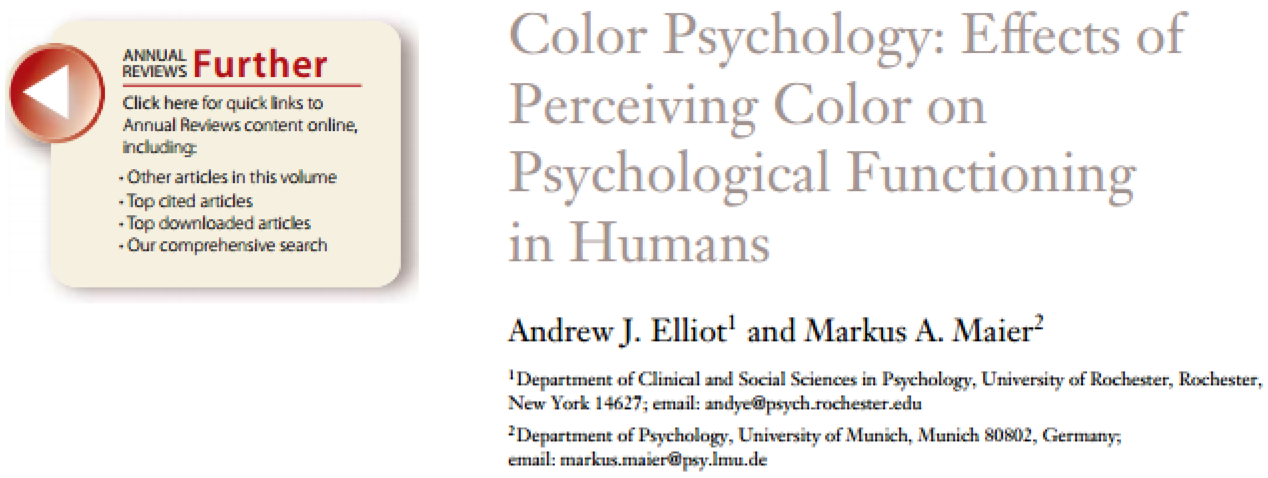
…experimental studies indicated that individuals who viewed red before or during anagram, analogy, and math tasks performed worse than those who viewed green or achromatic control colors. [Elliot et al. 2007]

…several studies have demonstrated that red is implicitly associated with failure and danger in achievement situations.

# Why Red?



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This research has revealed that faces that are redder (presumably due to blood perfusion), yellower (presumably due to carotenoids), and lighter are rated as healthier and more attractive…

…homogeneous facial skin color distribution (i.e., more even skin color) negatively predicts perceptions of age and positively predicts perceptions of health and attractiveness.

# Why Red?

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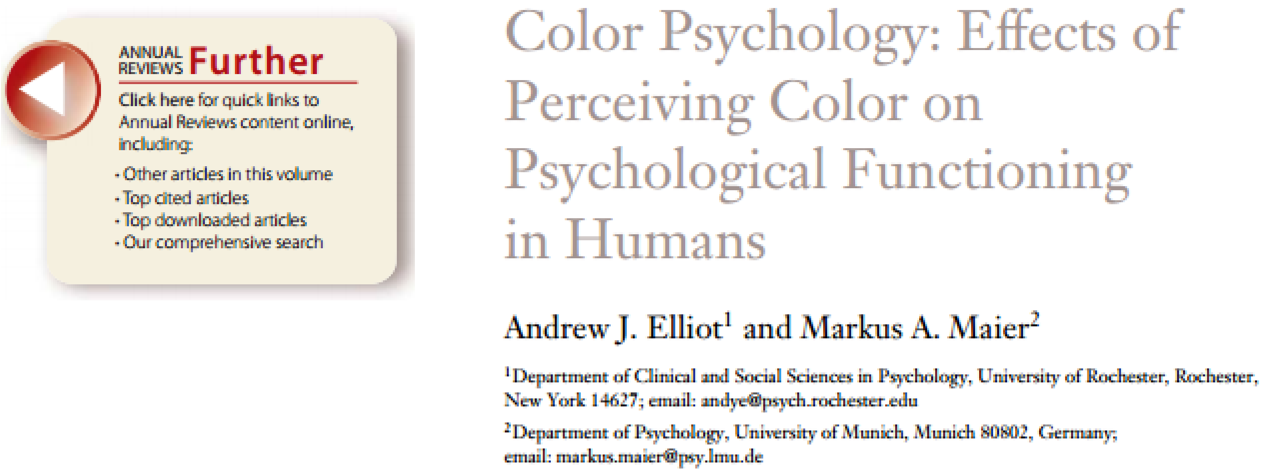
…men rate women as more attractive and sexually desirable when the women are viewed within a red picture border or in red clothing. [Elliot & Niesta 2008]

# Why Red?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men are more likely to contact a woman displaying red on a dating website (Gueguen & Jacob 2013b), tip waitresses in red more generously (Gueguen & Jacob 2012, 2013a), are more likely to approach a woman at a bar wearing red lipstick (Gueguen 2012c), are more likely to pick up a woman hitchhiker wearing red (Gueguen 2012b), ask more intimate questions of and sit closer to a woman in red (Niesta Kayser et al. 2010), and walk more quickly to an interview on dating conducted by a woman in red (Meier et al. 2012)

# Why Red?

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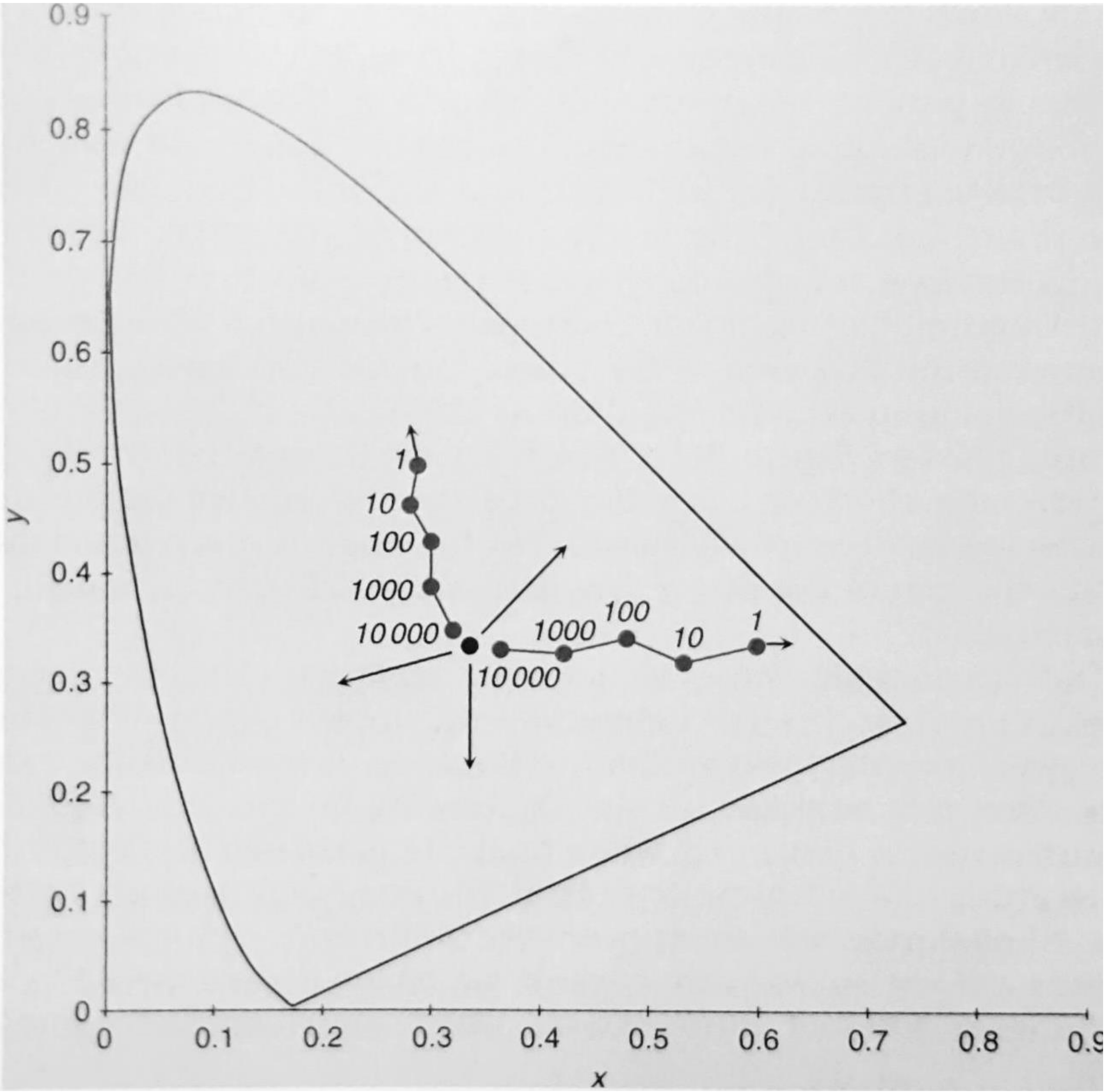
…faces of men photographed while wearing red are rated as more attractive, even when no color is made visible to the rater. [Roberts et al. 2010].

# Hunt Effect

(Illustration)



# Hunt Effect




Mark D. Fairchild
Color Appearance Models

Figure 6.10

# Arguments Against Saturating Sources

1. Hue shifts are objectionable, and hue shifts accompany saturation increases.

2. Designers don't choose more saturated colors for surfaces.

3. Hues will be distorted versus natural daylight.

4. Studies that show preference for increased saturation have all been short term.

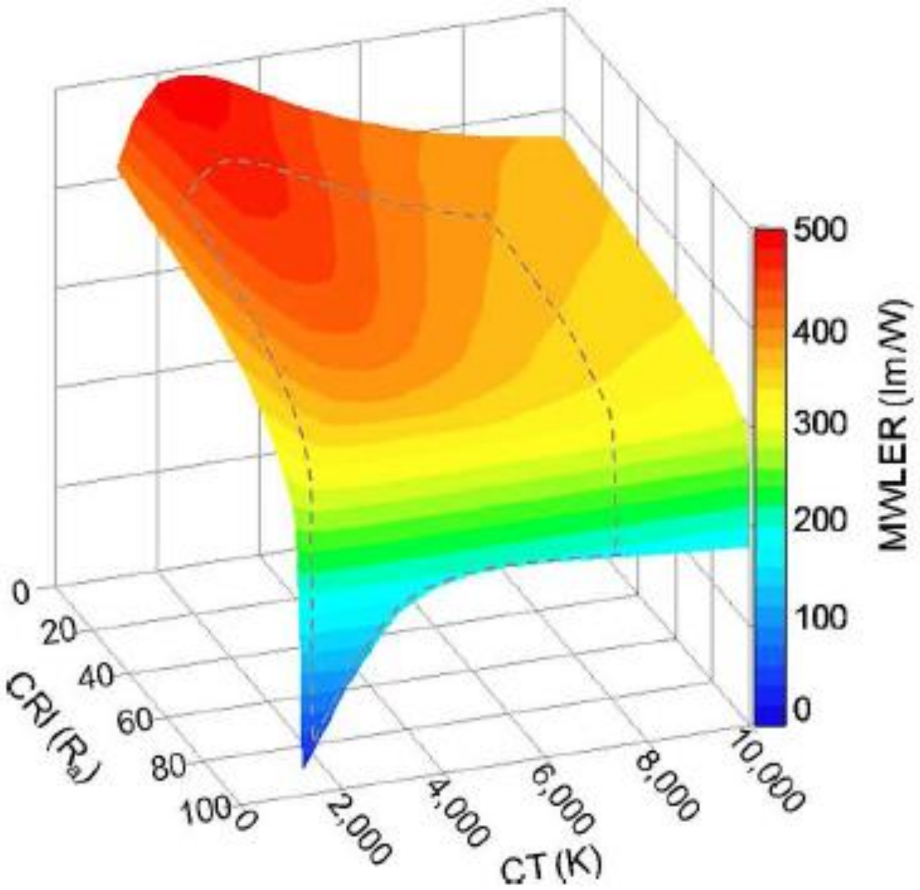
# Energy Considerations

JOURNAL OF DISPLAY TECHNOLOGY, VOL. 9, NO. 6, JUNE 2013 405

## Maximum White Luminous Efficacy of Radiation Versus Color Rendering Index and Color Temperature: Exact Results and a Useful Analytic Expression

Po-Chieh Hung and Jeffrey Y. Tsao, *Member, IEEE*

Fig. 3. The 3D MWLER(CT, $R_a$) surface defining the maximum white luminous efficacy of radiation achievable for various $R_a$'s and CTs. The surface was drawn by interpolating from the exact numerical determinations of Table I. The dashed boundary is the range within which analytical (3) reproduces the numerical determinations within 1% (the CT range 1500–7500 K and the $R_a$ range 30–100).



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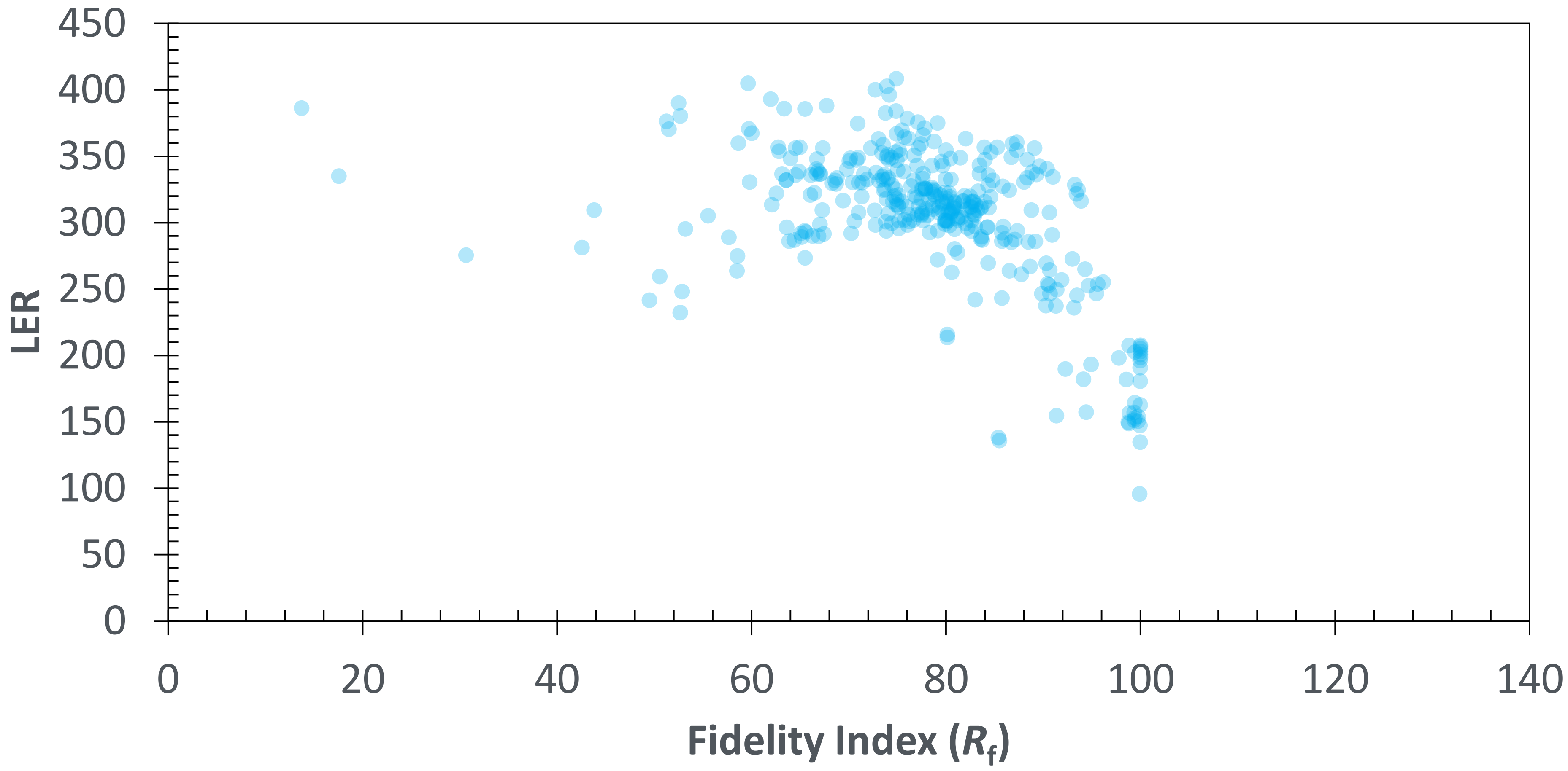

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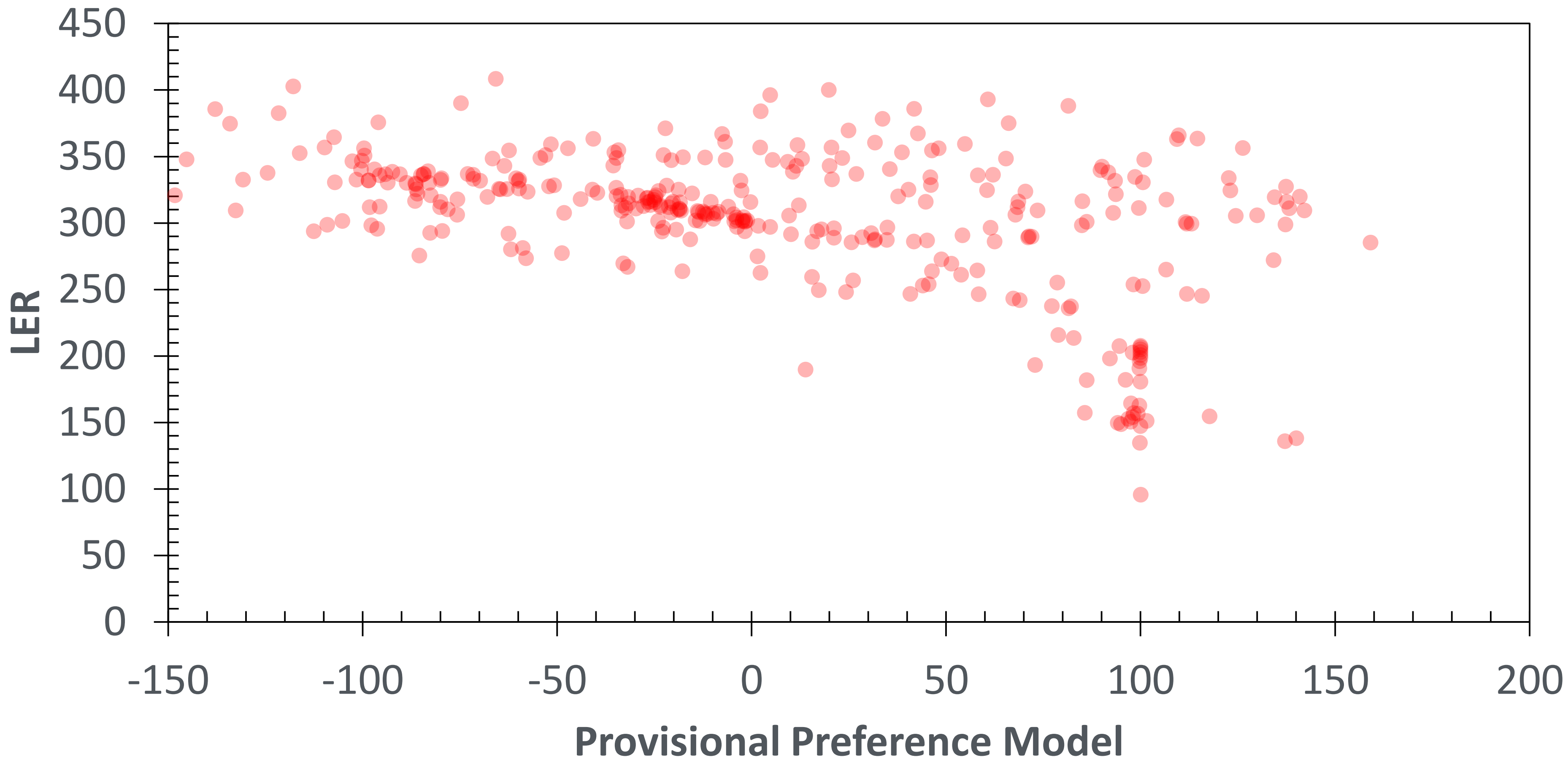

# Going Forward

**Additional Research**

1. Are some hue shifts acceptable in order to increase saturation, or are small hue shifts too objectionable?

2. Do long-term results reflect short-term results?

**Industry Changes**

1. Use new measures (TM-30) to develop and specify preferred sources.

2. Avoid regulations that limit options for spectral engineering of preferred sources.

3. Are there ethical obligations?

# TM-30 Integration Status

1. LED Lighting Facts, ENERGY STAR collecting TM-30/SPD data. No regulations in effect.

2. Many manufacturers beginning to provide TM-30 data. Some new products being released. Product development takes time.
   a. Overly restrictive regulations can stifle product development and force a one-size-fits-all solution.

3. Specifiers beginning to look at TM-30 data.

4. CIE expected to adopt $R_f$ as a replacement for CRI by the end of the year. Official transition will be gradual.
   a. CIE committees not structured to consider an evaluation framework like TM-30.

# Thoughts for the Future

1. Color-rendering tuning?
2. User customizable color rendering? (Store end caps, worker satisfaction)
3. Dim to vibrant?
4. How many choices are needed?
5. Consumer preference index?

# Understanding the Tool

1. A metric value doesn't tell you how the product will perform in any given environment. Context is critical! Individual preferences vary! Illuminance levels vary!

2. An average color rendering metric shouldn't be used to predict how a source will render reds, or skin tones, or any specific set of objects.

3. TM-30 offers substantially more information, which is essential for evaluating color rendering characteristics.

4. TM-30 is an evaluation framework, not a ranking system.





98

# Resources

IES Technical Memorandum (TM) 30-15 (Includes Excel Calculators):
**IES Method for Evaluating Light Source Color Rendition**
http://bit.ly/1IWZxVu

*Optics Express* journal article that provides overview of the IES method:
**Development of the IES method for evaluating the color rendition of light sources**
http://bit.ly/1J32ftZ

Application webinar co-sponsored by US Department of Energy and Illuminating Engineering Society:
**Understanding and Applying TM-30-15: *IES Method for Evaluating Light Source Color Rendition***
http://1.usa.gov/1YEkbBZ

Technical webinar co-sponsored by US Department of Energy and Illuminating Engineering Society:
**A Technical Discussion of TM-30-15: Why and How it Advances Color Rendition Metrics**
http://1.usa.gov/1Mn15LG

*LEUKOS* journal article supporting TM-30's technical foundations:
Smet KAG, David A, Whitehead L. 2015. **Why Color Space and Spectral Uniformity Are Essential for Color Rendering Measures.** *LEUKOS*. 12(1,2):39-50.
http://dx.doi.org/10.1080/15502724.2015.1091356



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99

# Resources

*LEUKOS* editorial discussing next steps:
Royer MP. 2015. **IES TM-30-15 Is Approved—Now What? Moving Forward with New Color Rendition Measures.** *LEUKOS*. 12(1,2):3-5.
http://dx.doi.org/10.1080/15502724.2015.1092752

Lighting Research and Technology, Open Letter:
**Correspondence: In support of the IES method of evaluating light source colour rendition (More than 30 authors)**
http://dx.doi.org/10.1177/1477153515617392

**DOE Fact Sheet on TM-30**
http://energy.gov/eere/ssl/downloads/evaluating-color-rendition-using-ies-tm-30-15

**DOE TM-30 FAQs Page:**
http://energy.gov/eere/ssl/tm-30-frequently-asked-questions