Color Discrimination

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Outline

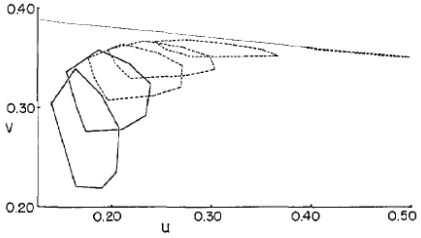
Background

Esposito and Houser 2017

Esposito 2019 [unpublished]

Moving forward

Background: color discrimination



WA Thorton [1972] – Color Discrimination Index

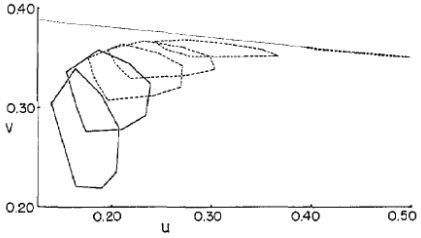
"…the extent to which the illumination allows the observer to discriminate among a large variety of object colors simultaneously viewed."

Gamut area as a predictor of discrimination ability, CDI

Good

Bad

Background: color discrimination



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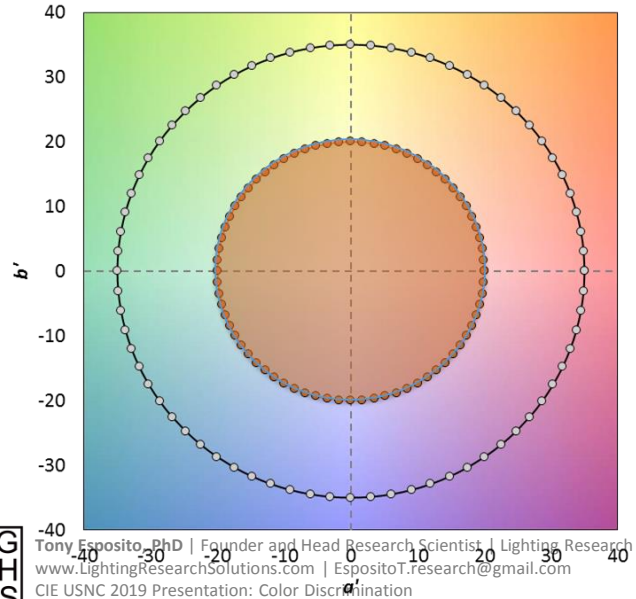
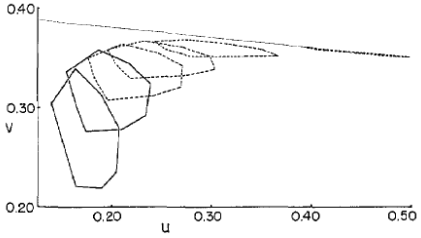


Example

$R_g = 100$

Background: color discrimination



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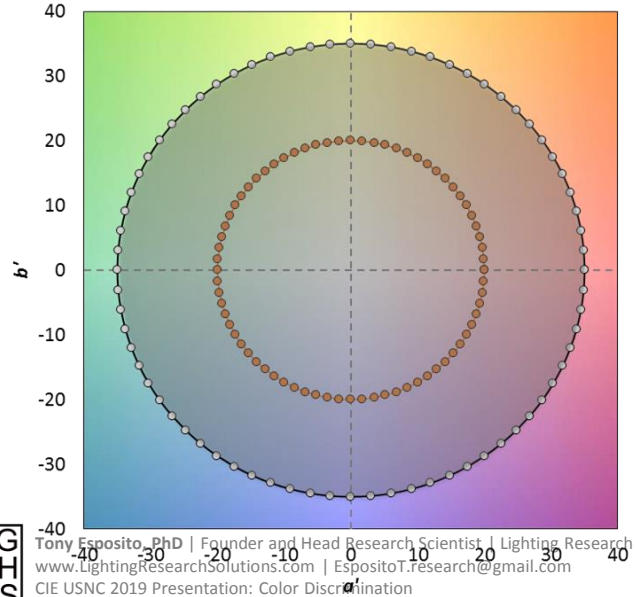
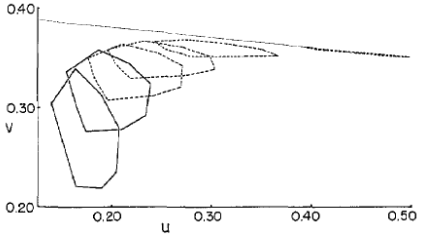


Example

$R_g = 100$

$R_g = 130$

Background: color discrimination



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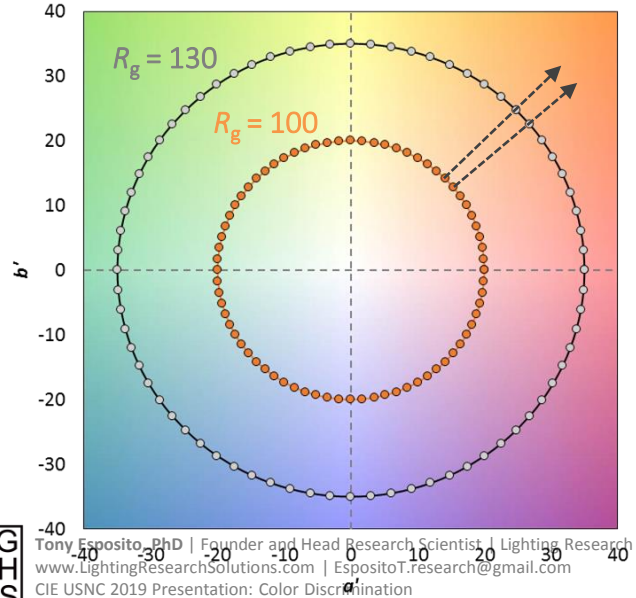
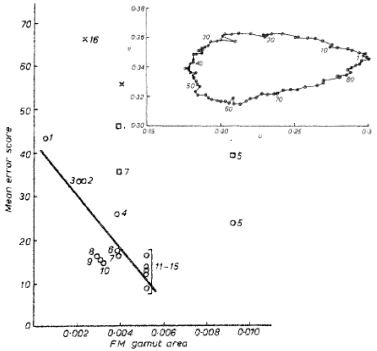


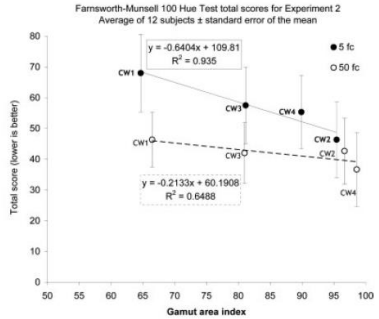
Does Larger gamut = better CD?

Background: color discrimination



Boyce, Boyce and Simons [1976, 1977]

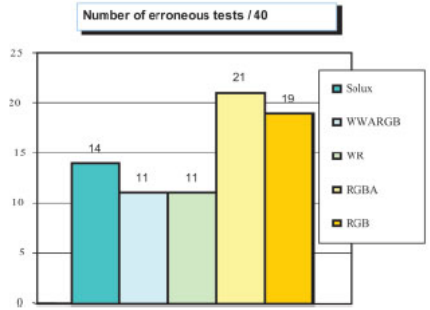
- R_a (“CRI”) and CDI are approximate predictors
- Above 300 lux, lamp type is more important than illuminance
- Age is a significant factor



Rea and Freyssinier-Nova [2007]

- Evaluated *cool white* and *warm white* sources
- Color discrimination better (i.e. error scores consistently lower) at higher illuminances
- GAI is a better, and more consistent predictor than CIE R_a

Background: color discrimination

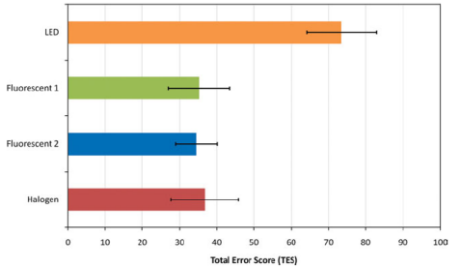


Mahler and Others [2008]

CRI correlates well with discrimination for LED sources

Increasing chroma (saturation) doens't imply improved Color Discrimination

Color discrimination ability of "…RGB LED illumination is reduced precisely for the falsely saturated colors."



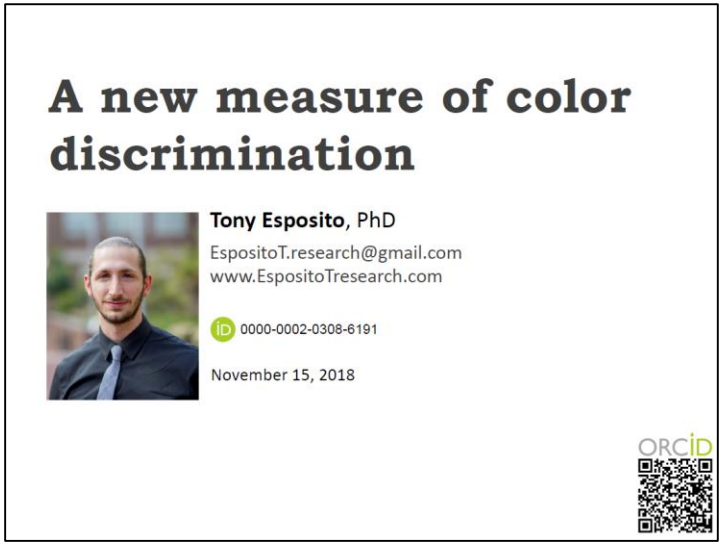
Royer and Others [2011]

CRI, CDI, and FM Gamut all fail to predict (or correctly rank order) the four experimental SPDs

Gamut measures "…are not accurate predictors of color discrimination capability when highly structured SPDs are included."

Esposito and Houser 2017

Background: Esposito and Houser define Rd



https://www.ies.org/lighting-education/a-new-measure-of-color-discrimination/

Background: Esposito and Houser define Rd

Lighting Research and Technology

Esposito T, Houser KW. 2017. A new measure of color discrimination for LEDs and other sources. Lighting Research and Technology. 51(1): 5-23.

Personal Website – Green Open Access Free Download

https://espositotresearch.com/bibliography/

https://espositotresearch.files.wordpress.com/2018/07/espositot_houserkw_2017_a-new-measure-of-colour-discrimination-for-leds-and-other-light-sources_greenopenaccess.pdf

Background: Esposito and Houser define Rd

Available fidelity and gamut indices cannot predict a light source's ability to permit the accurate discrimination of colors.

Previous research highlights this problem specifically for highly structured spectra (e.g. sharp peaks and valleys).

PROBLEM

We don’t have an accurate and reliable CD metric for applied lighting

GOAL

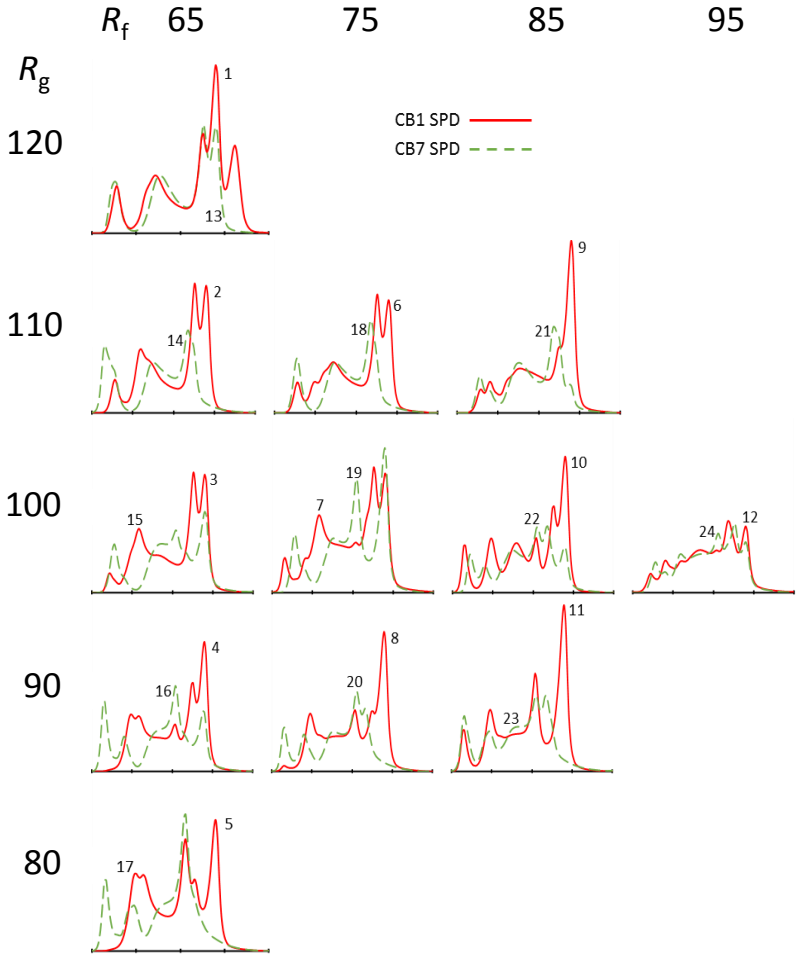
To develop a generalizable method for quantifying a light source's CD ability:

Background: stimuli

CCT = 3500 K

D_{uv} = 0.000

E = 600 lx



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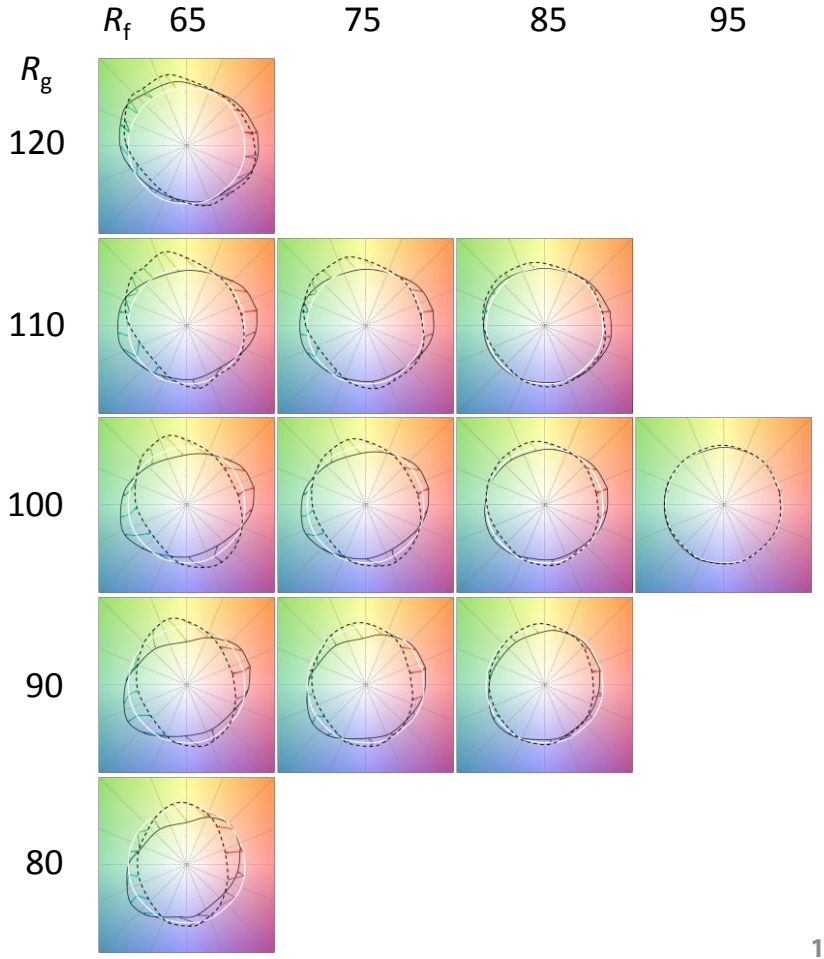

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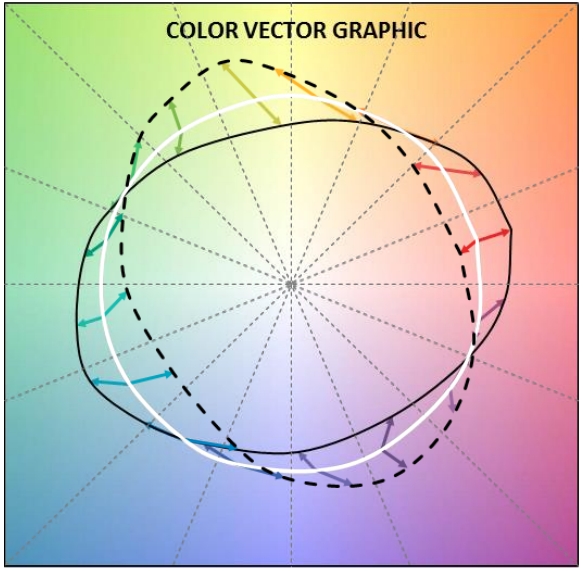

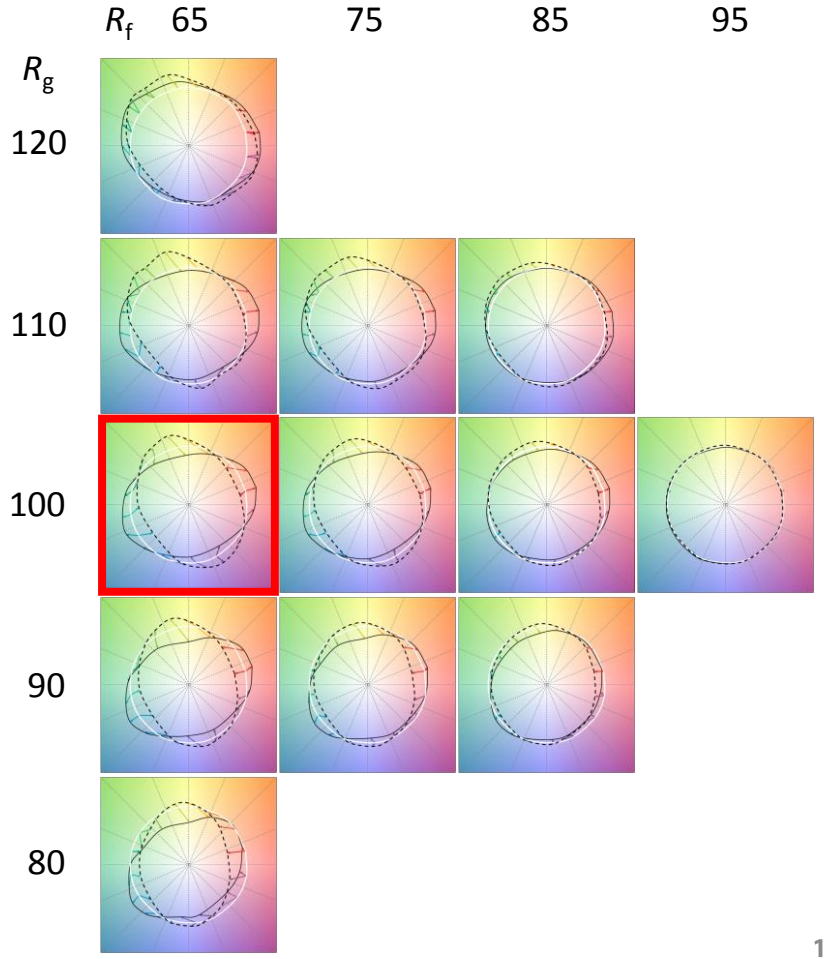

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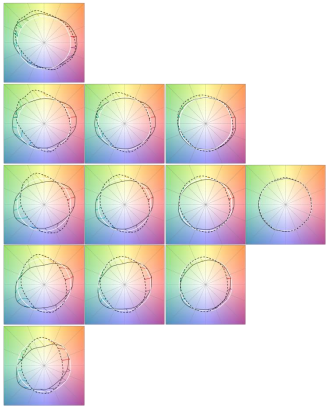
Background: stimuli

24 spectra

4 nominal R_f values

5 nominal R_g values

2 CVG orientations

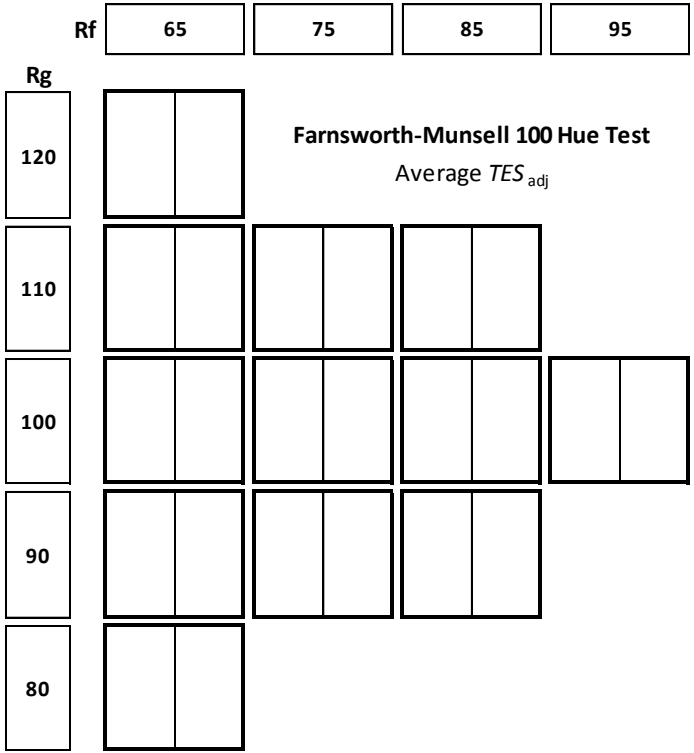


20 participants per spectra

480 FM-100 tests

Average TES_{adj}

Background: results

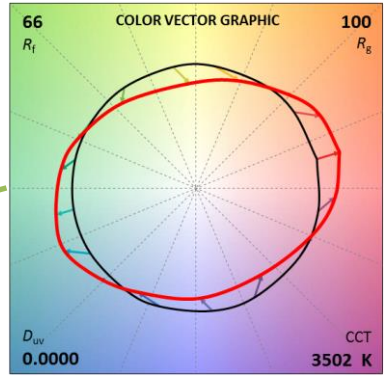


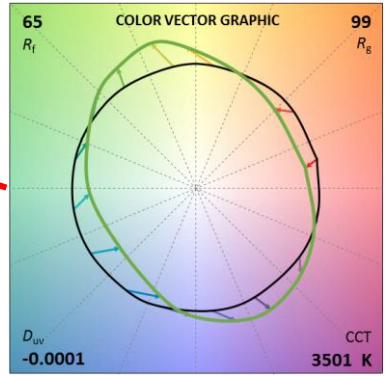
Background: results

Rg \ Rf	65	75	85	95
120				
110				
100				
90				
80				

Farnsworth-Munsell 100 Hue Test

Average TES_{adj}





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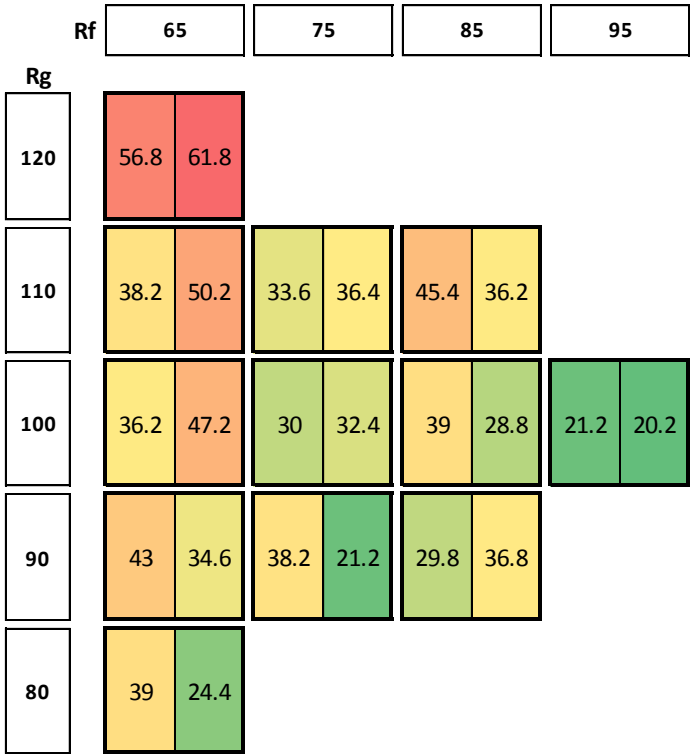

Model	r^2	*p-value* Gamut	*p-value* Fidelity
$R_g + R_f$	61.07	**0.001**	**0.001**
$Q_a + Q_f$	56.20	**0.000**	**0.000**
$Q_g + Q_f$	48.16	**0.002**	**0.036**
GAI + R_a	42.31	**0.004**	0.111
FMG + R_a	40.98	**0.005**	0.131
FMG (CIE CAM02) + R_a	41.72	**0.004**	0.066
CDI + R_a	42.29	**0.004**	0.111

Gamut area is not predictive of TES_{adj}

Even when paired with an average fidelity metric

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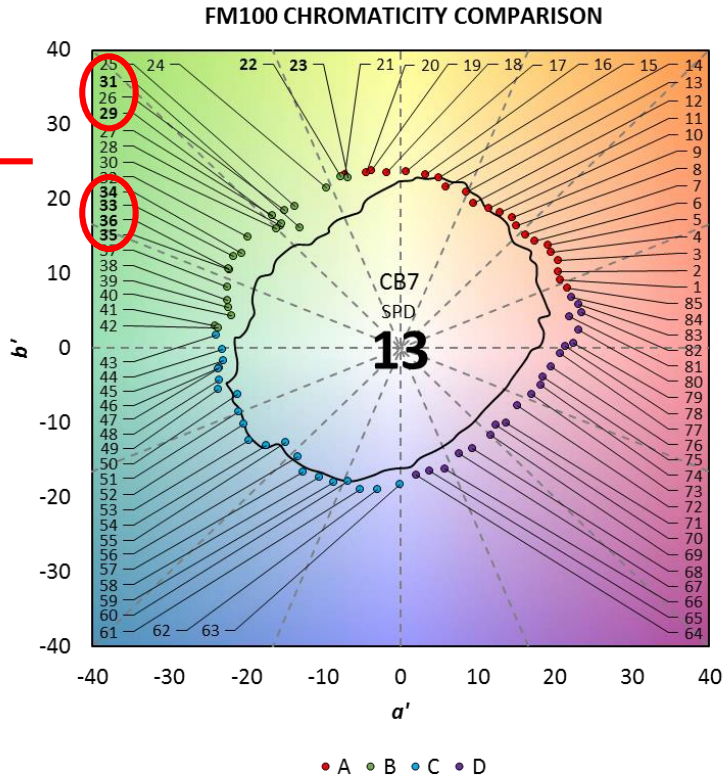
Rg \ Rf	65	75	85	95
120	56.8	61.8		
110	38.2	50.2	33.6	36.4	45.4	36.2		
100	36.2	47.2	30	32.4	39	28.8	21.2	20.2
90	43	34.6	38.2	21.2	29.8	36.8		
80	39	24.4						

SPD transposes MANY caps



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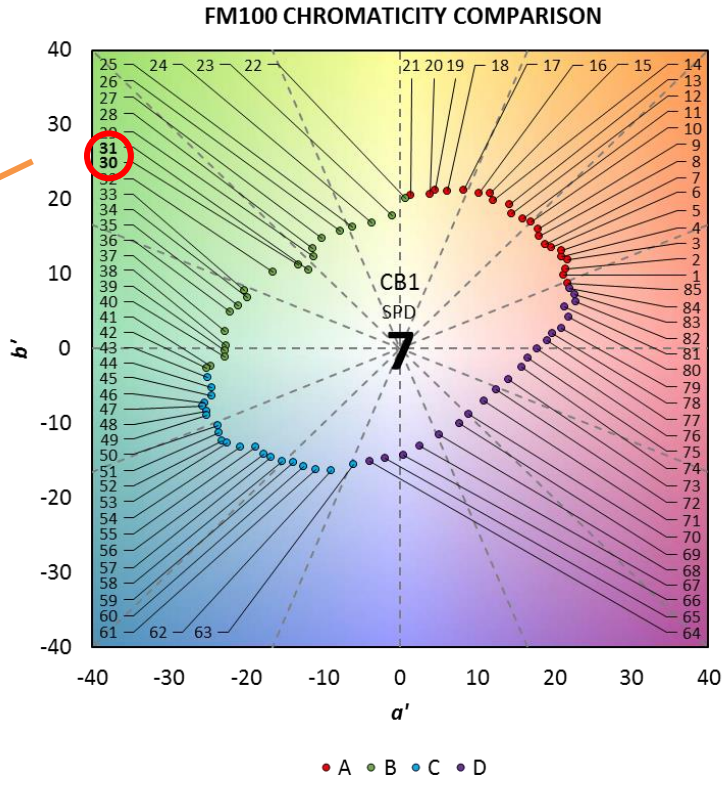
80	39	24.4		

SPD transposes ONE cap



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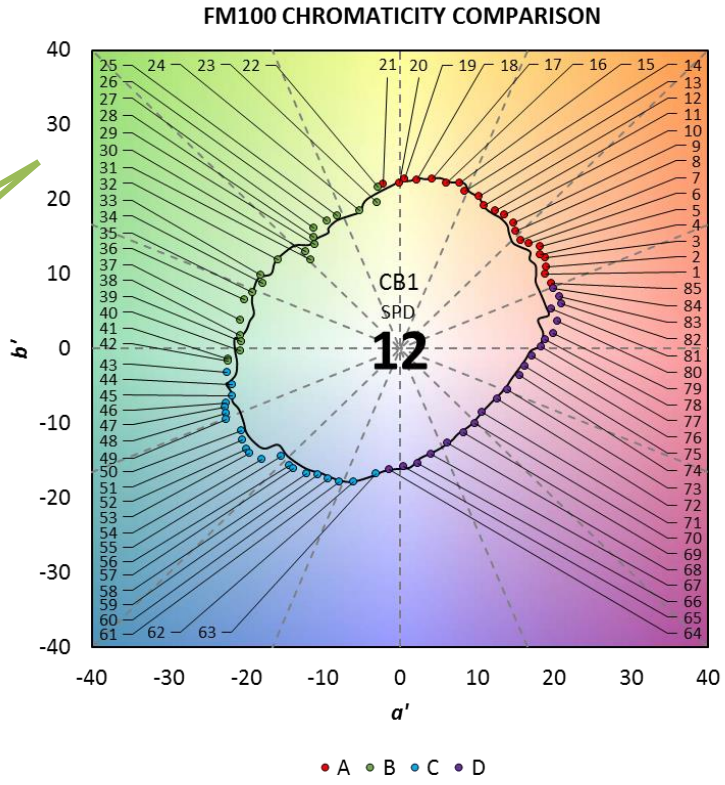
SPD transposes NO caps



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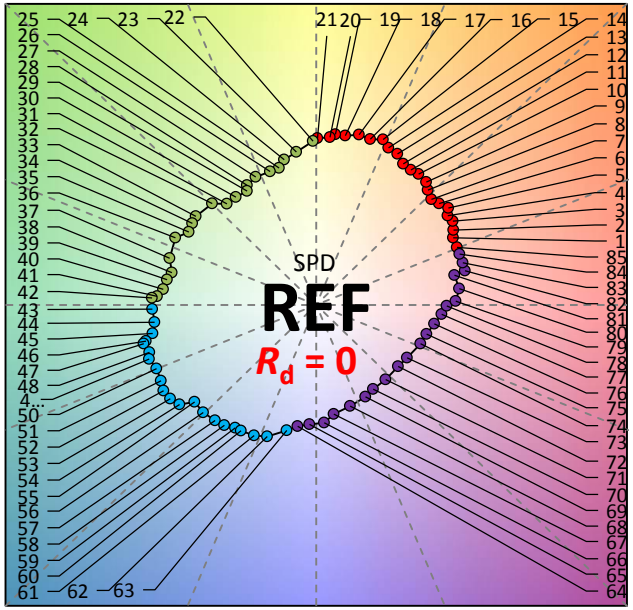
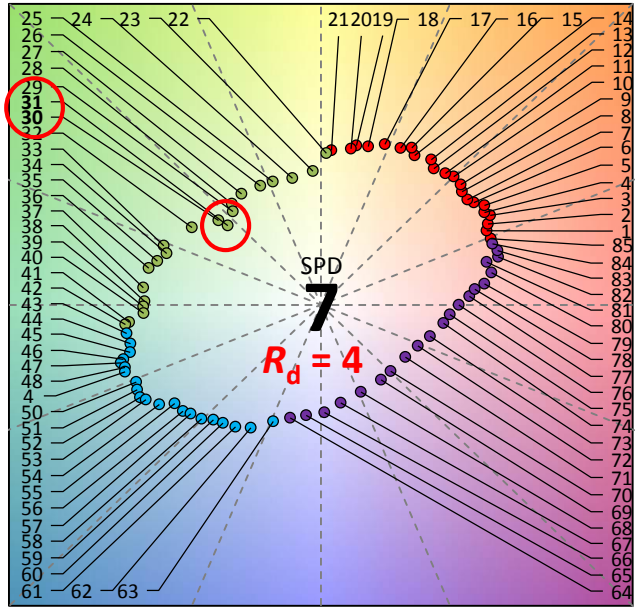
Background: results

Standard Illuminant



Experimental Source



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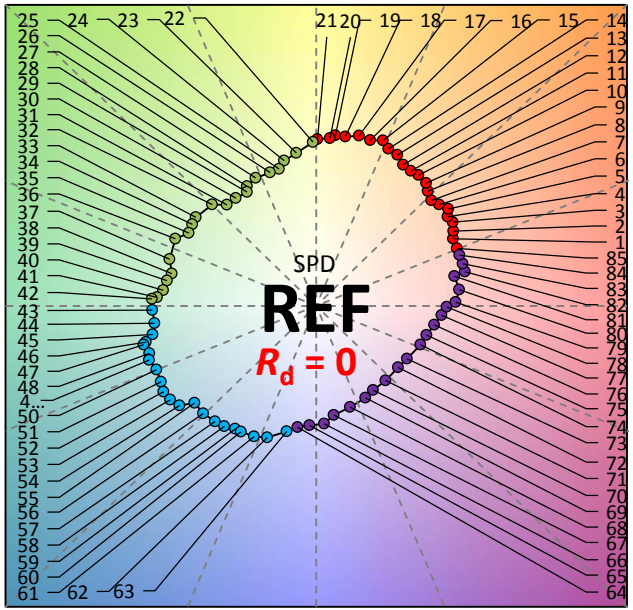
Standard Illuminant



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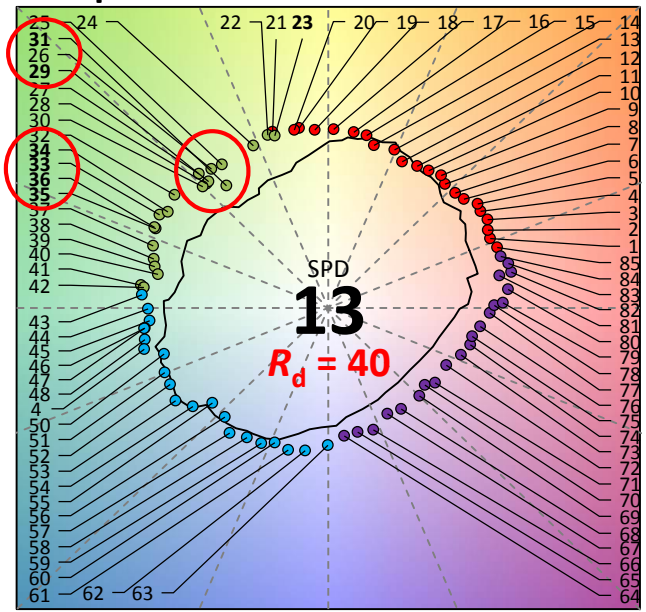

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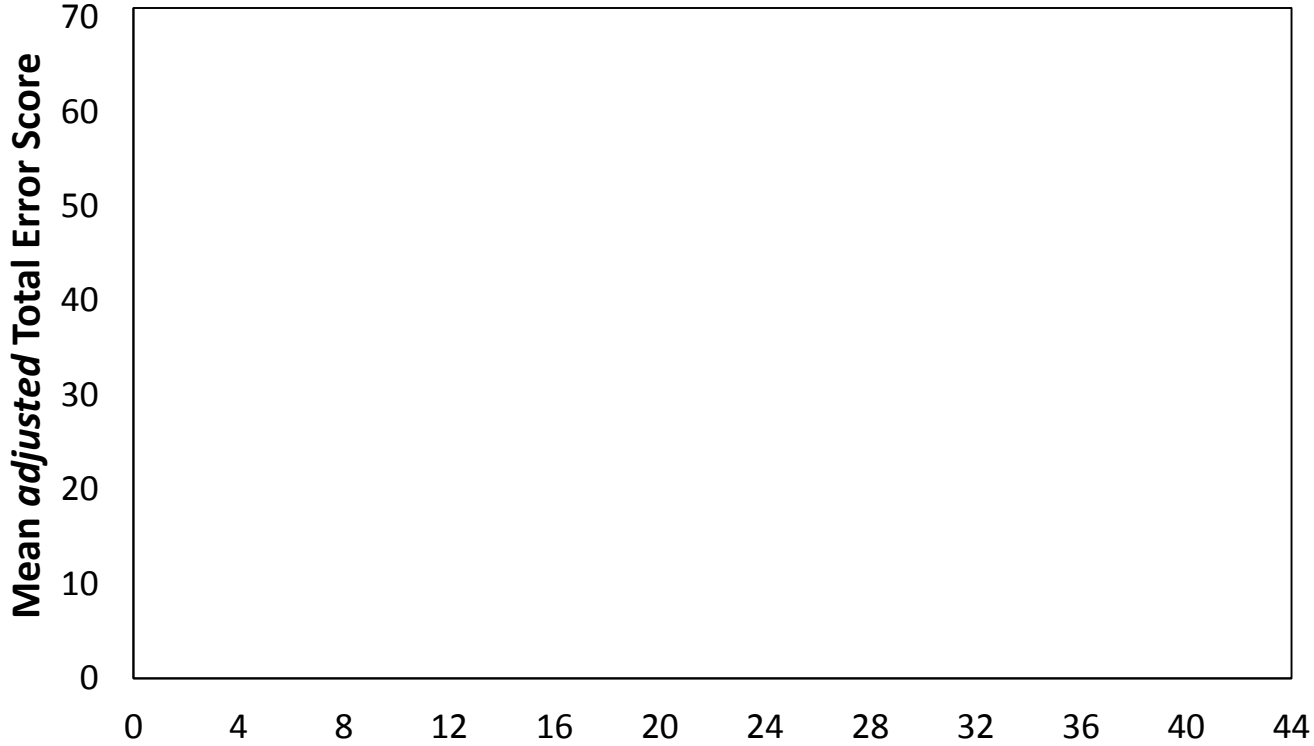

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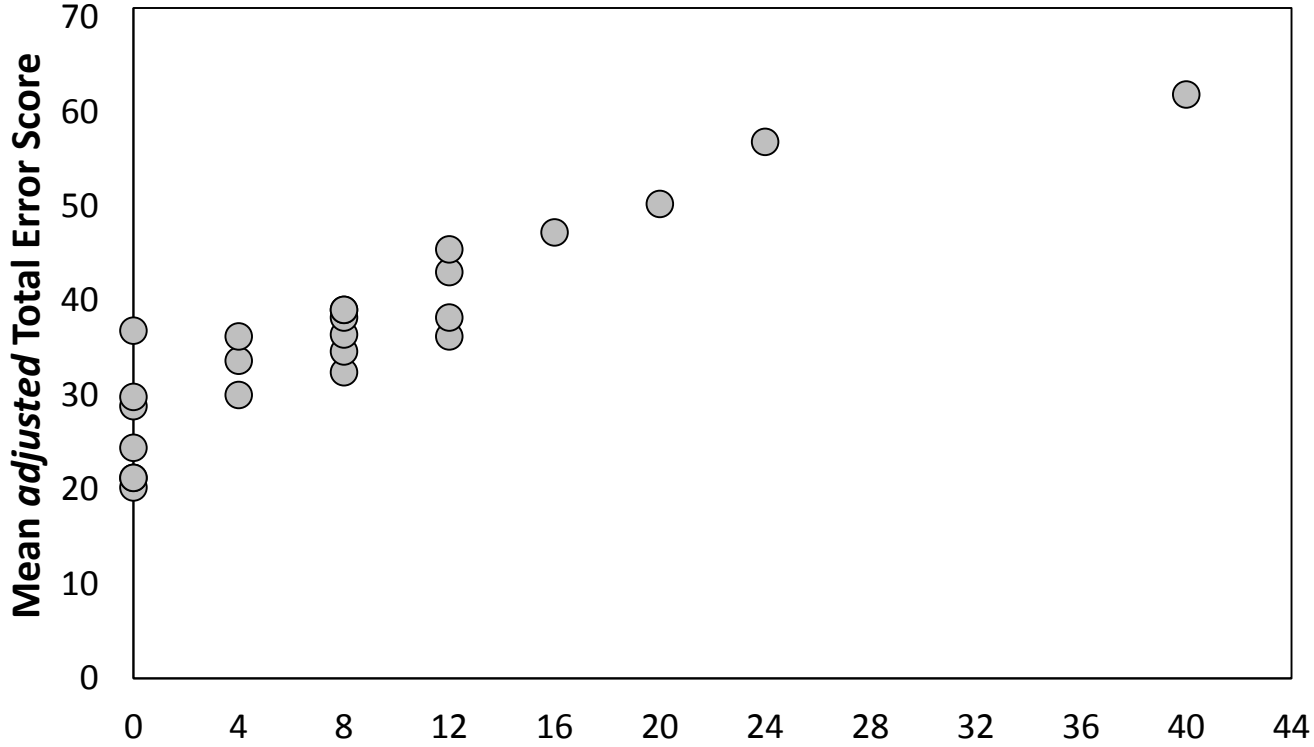

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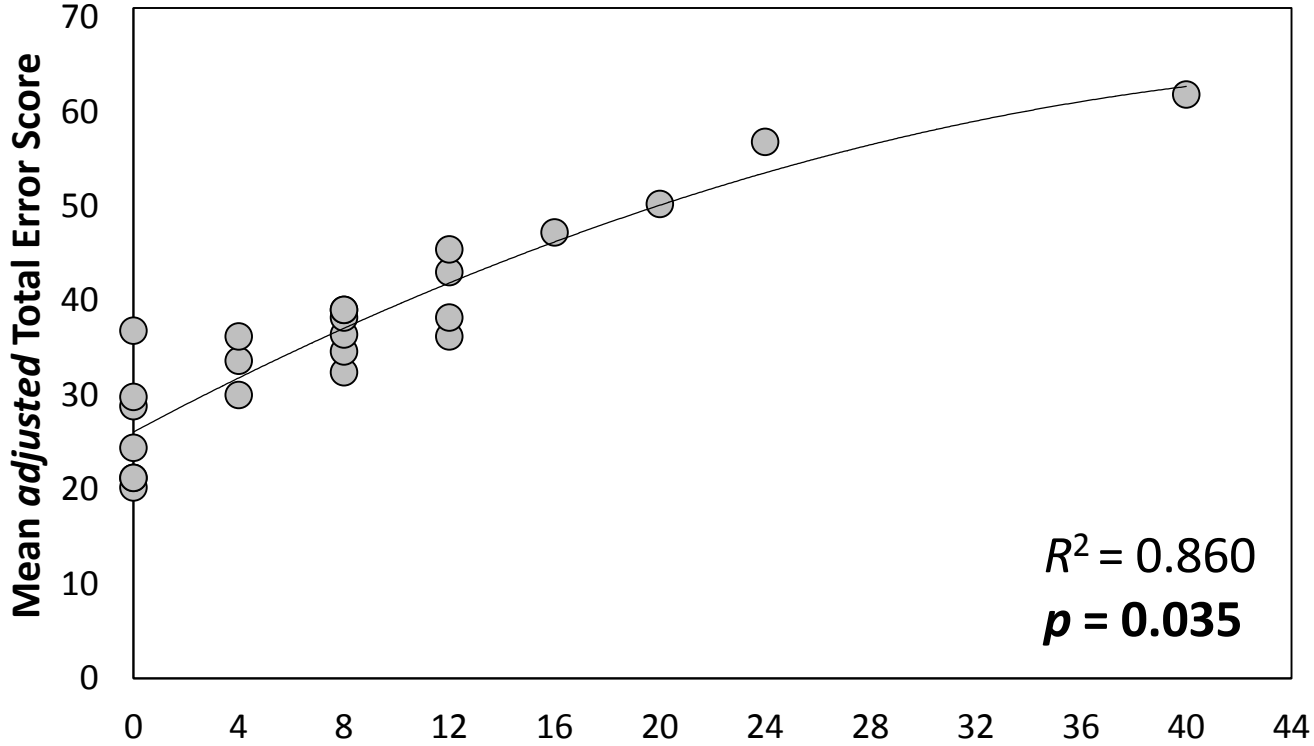

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CIE USNC 2019 Presentation: Color Discrimination

Background: results

Source Type	Source Name	R_d	Discrimination
Incandescent	75WA19 Neodymium	12	Average
Incandescent	Halogen/Halogen MR16	4, 8	Average
Incandescent	Filtered Halogen	0	Superior
HID	HPS Standard	40, 48	Poor
HID	HPS Deluxe	36	Poor
HID	Super HPS	40	Poor
HID	Mercury	36, 44, 52	Poor
HID	CDM940 - Metal Halide	0	Superior
HID	CDM830, MHC100/U/MP/3K	4, 8	Average
LED	Mixed (Experimental)	0-40	Superior, Average, Poor
LED	Hybrid (Commercial)	0-16	Superior, Average, Poor
LED	Phosphor	0-28	Superior, Average, Poor
Fluorescent	Narrowband - F32T8/7XX	8, 12, 24	Average, Poor
Fluorescent	Narrowband - F32T8/8XX	0-16, 24	Superior, Average, Poor
Fluorescent	Narrowband - F32T8/9XX	0, 8	Superior, Average
Fluorescent	Narrowband - F40T12/XXU	8, 12, 24	Average, Poor
Fluorescent	Broadband	0, 4, 8, 20	Superior, Average, Poor
Model	CIE D65	0	Superior
Model	Equal Energy	0	Superior
Model	Ideal Prime Color	60	Poor

R_d, Total Light Source Error Score

(Sum of Partial Light Source Error Score, $R_{d,i}$)

"R_d was developed from 480 individual FM-100 tests and back tested on more than 200 common light sources to verify accordance with experience and anecdote. R_d is a strong predictor of [total error score] and has face validity."

Esposito 2019 [unpublished]

Study: Prime Color Wavelengths

Thornton WA. 1971. Luminosity and color-rendering capability of white light. J Opt Soc Am. 61(9): 1155-1163

"The peculiar wavelength dependences…can be summarized as follows: Three wavelengths, approximately **450**, **540**, and **610** nm, are strikingly effective in promoting good color rendition by white light.
Two wavelengths, approximately **495** and **575** nm, have deleterious effects on color rendition, and the first of these is also relatively ineffective for luminosity."

Not all wavelengths are created equal!

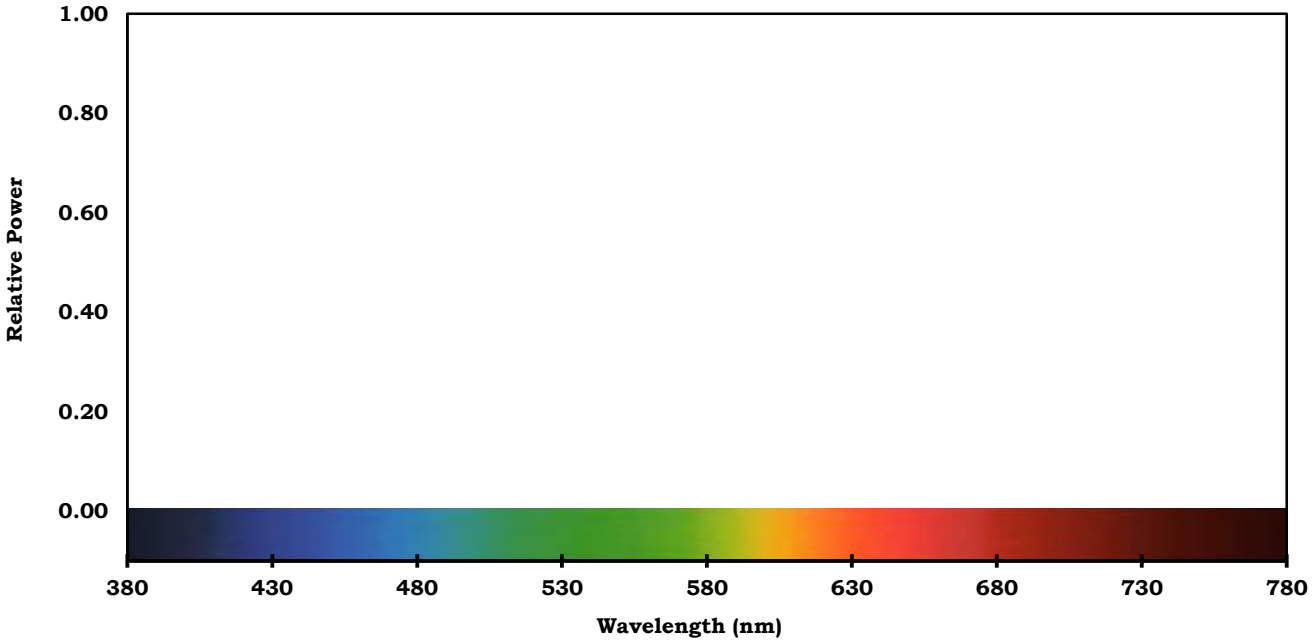
Study: goals

GOAL

To evaluate the color discrimination ability of spectra about Thornton's PC and anti-PC wavelengths (using Rd as a measure of color discrimination performance.)

To further explore the relationship between CD and Gamut Area (R_g)

Study: Spectral Power Distributions



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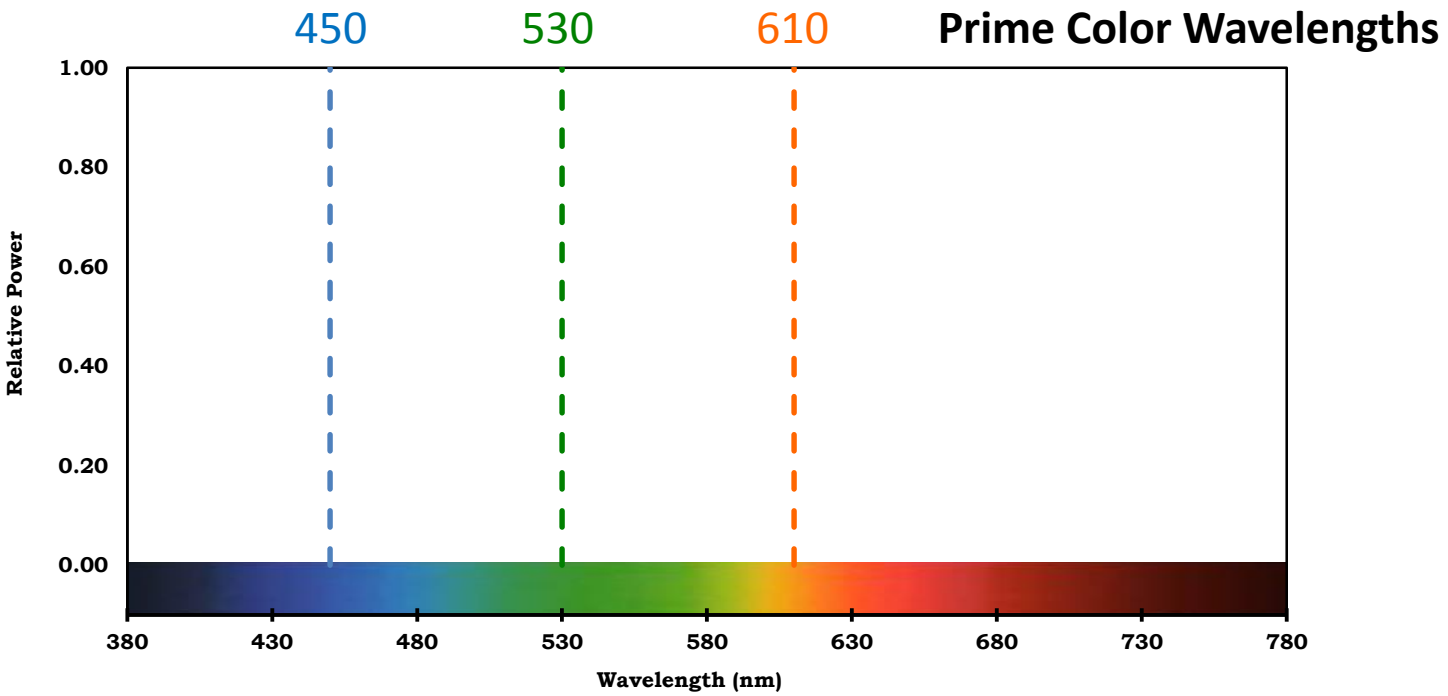

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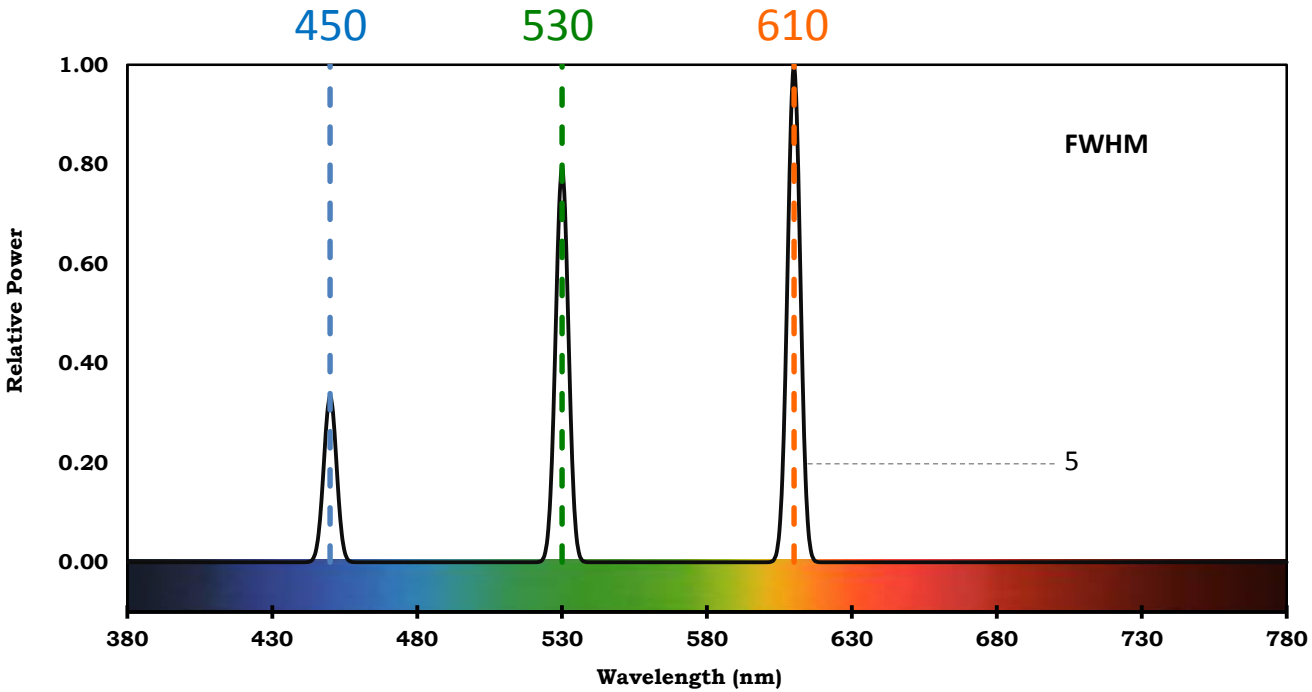
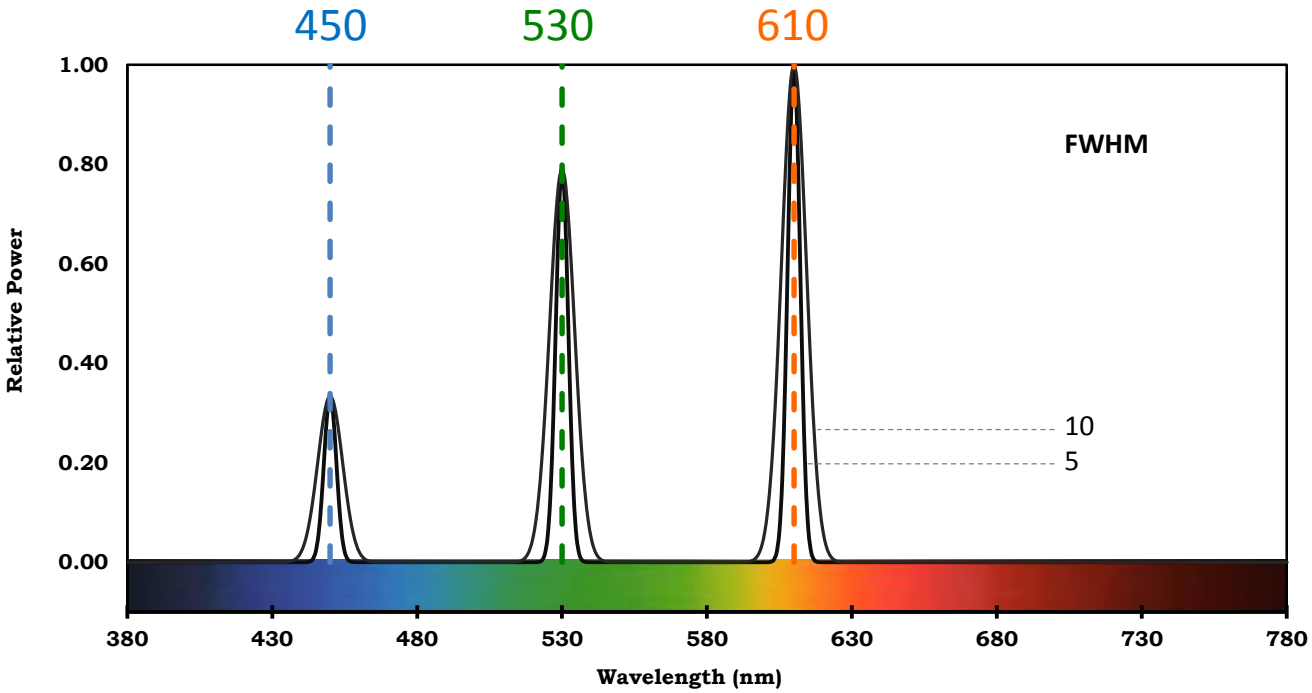


Study: Spectral Power Distributions

PC-set



Study: Spectral Power Distributions

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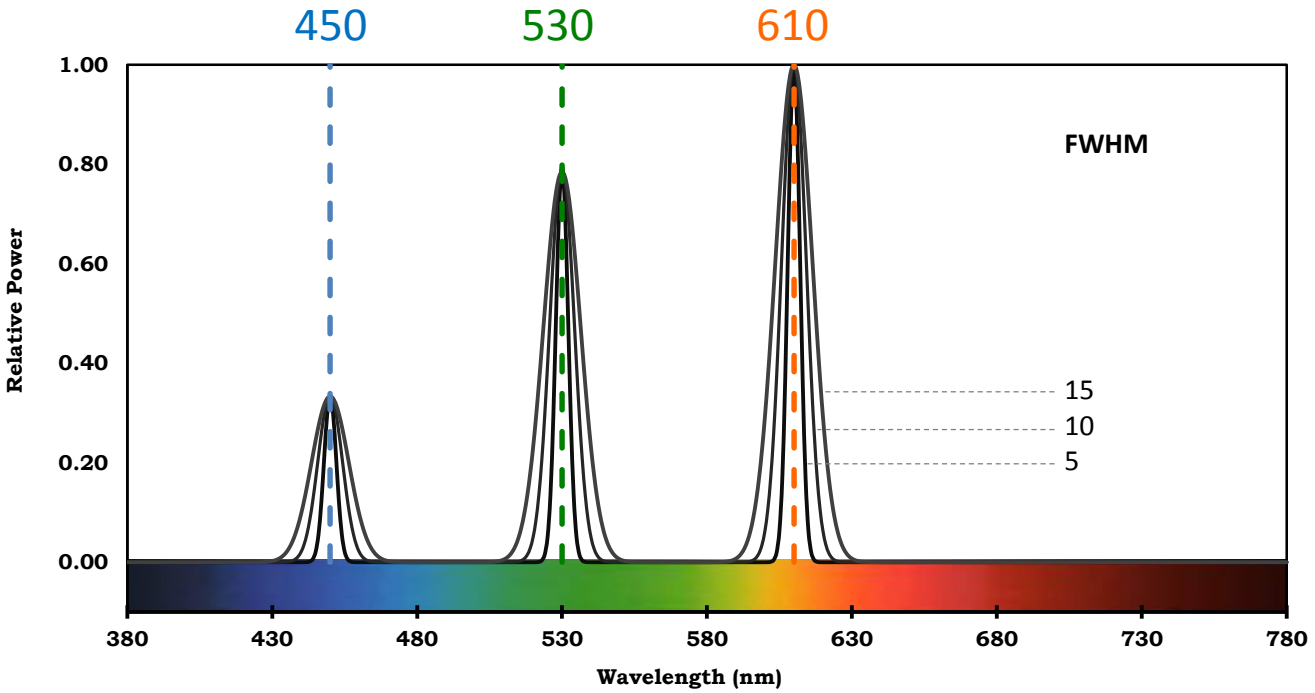

Study: Spectral Power Distributions

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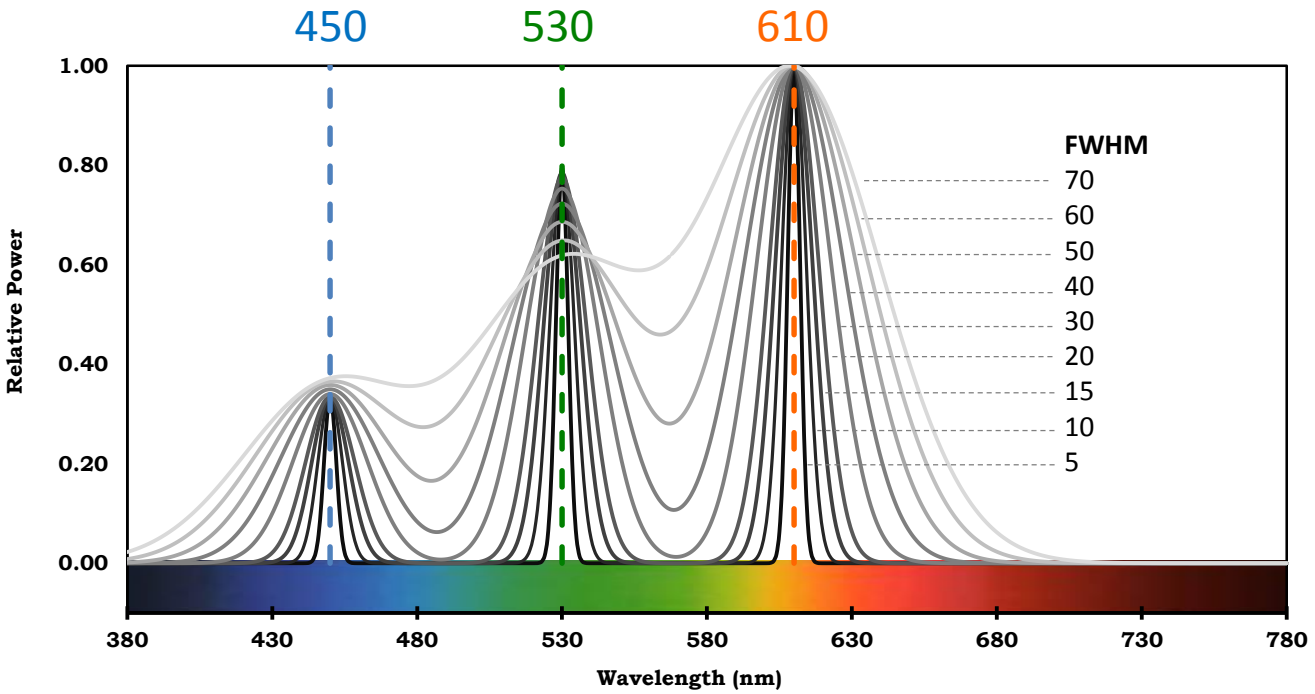
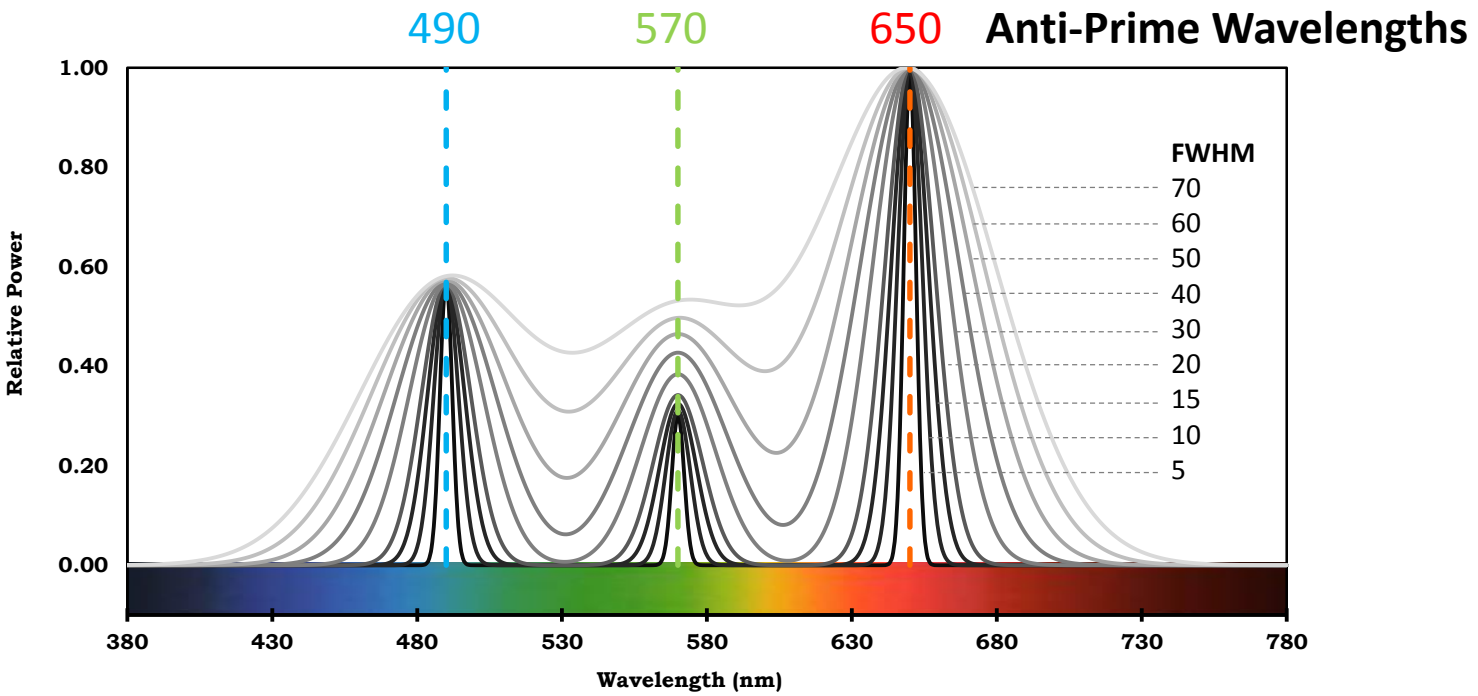


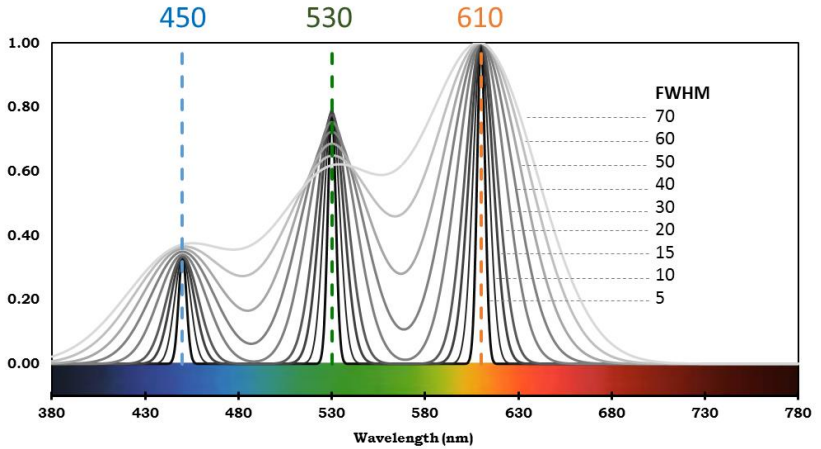
Study: Spectral Power Distributions

AP-set



Study: Spectral Power Distribution

PC-set



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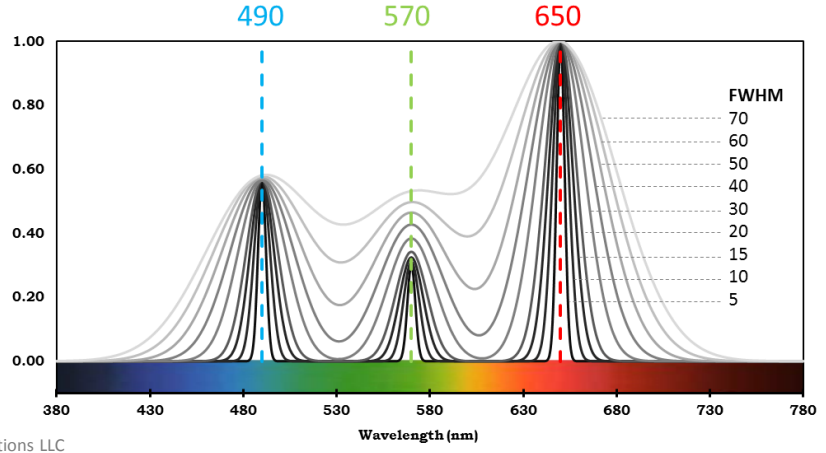
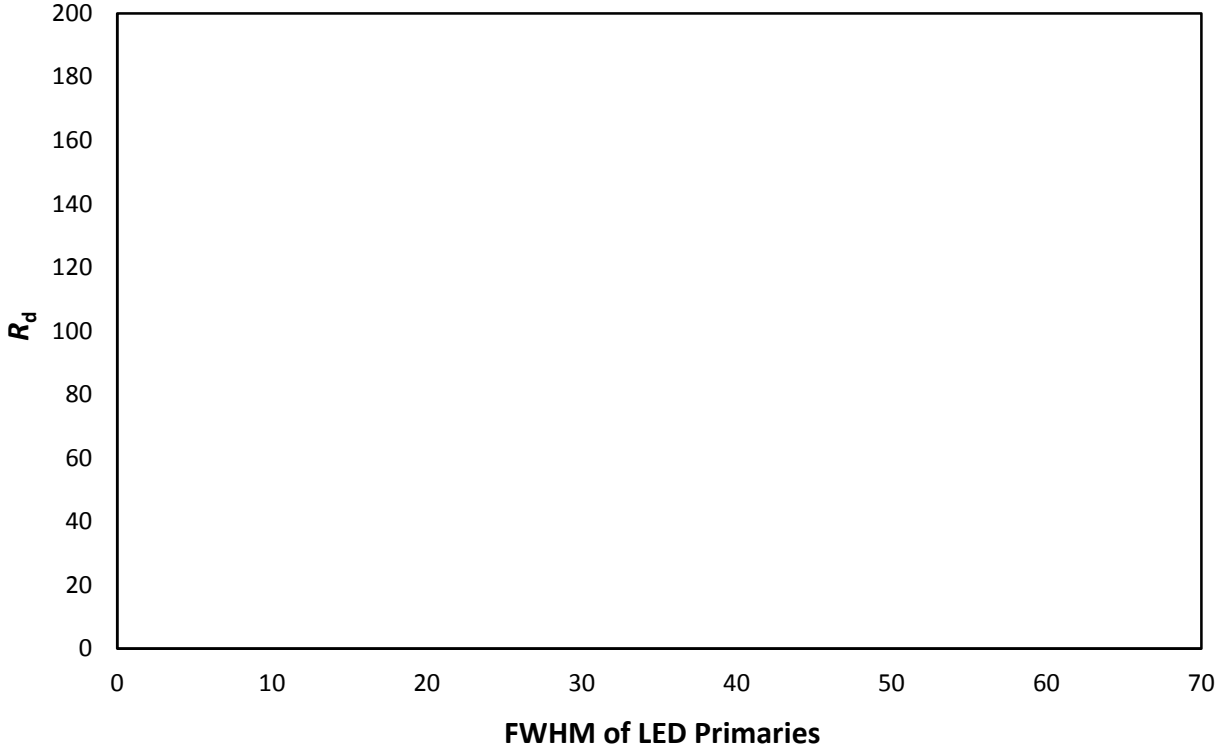
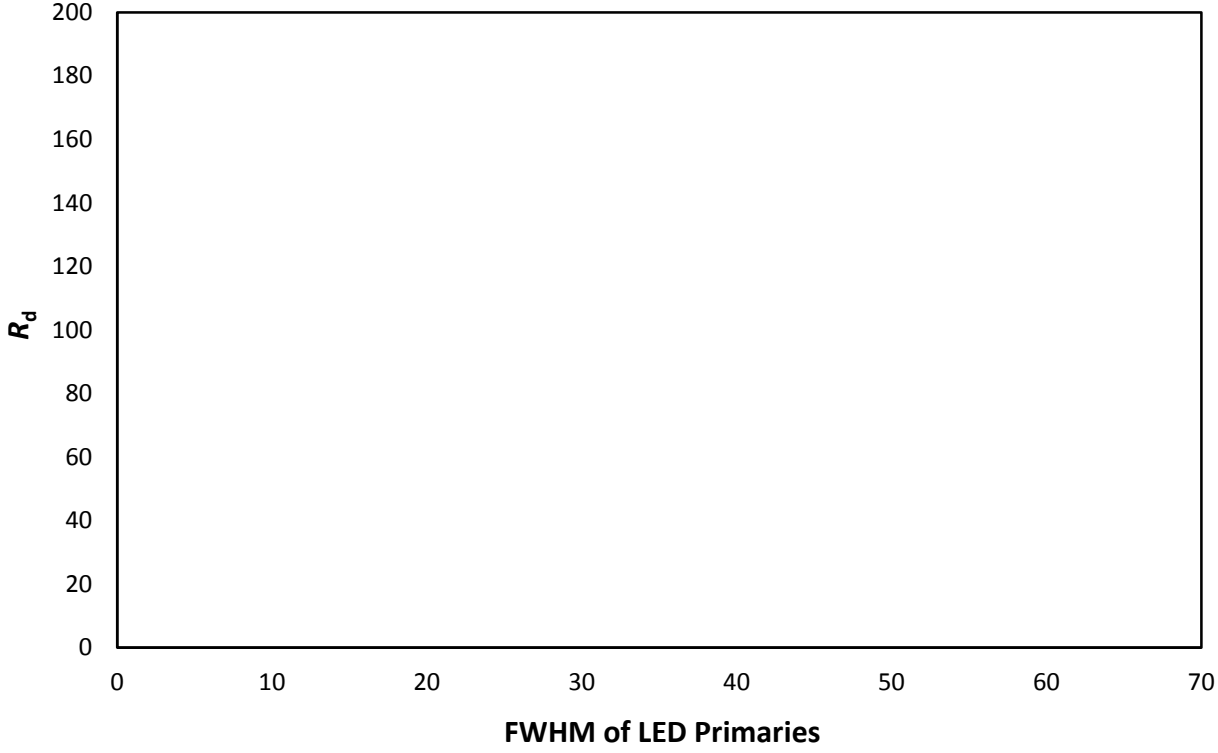


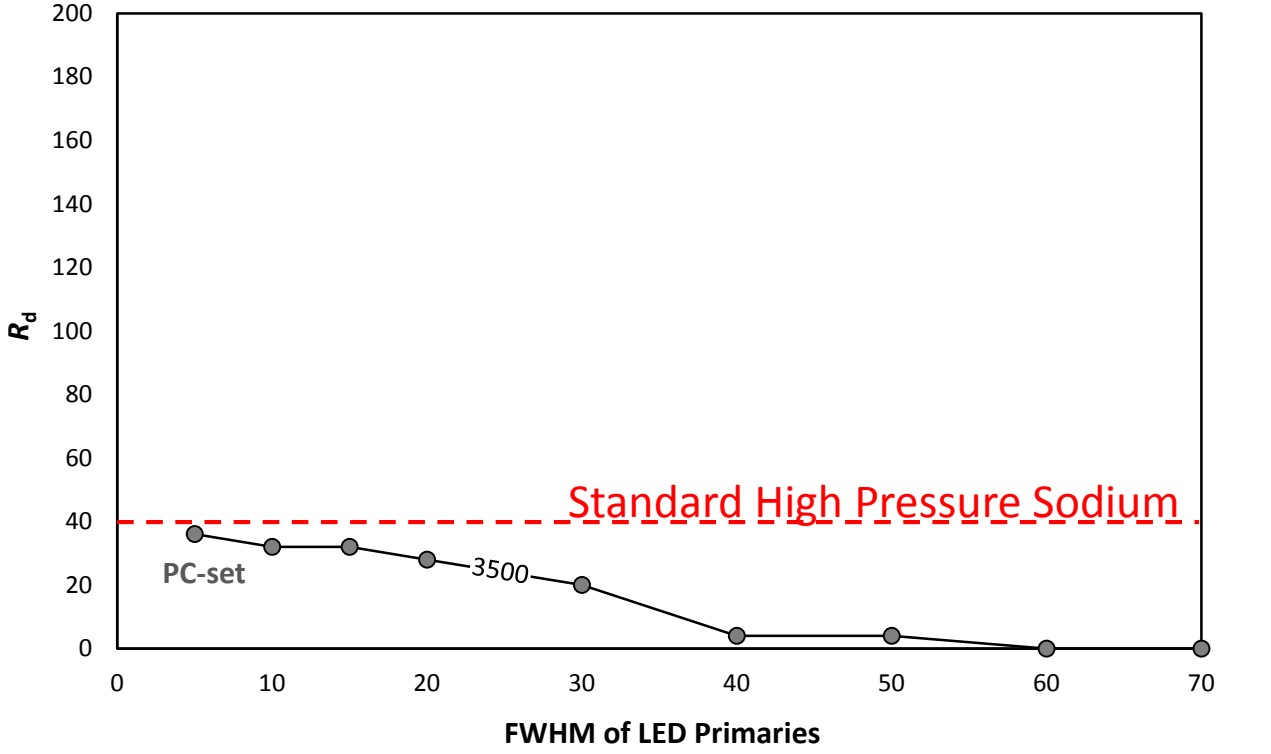
Study: Results

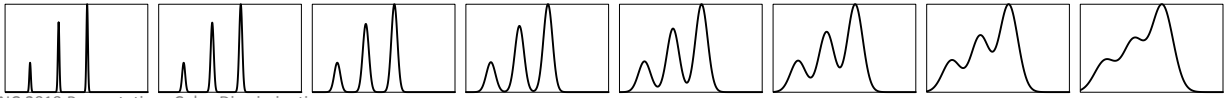


Study: Results



Study: Results





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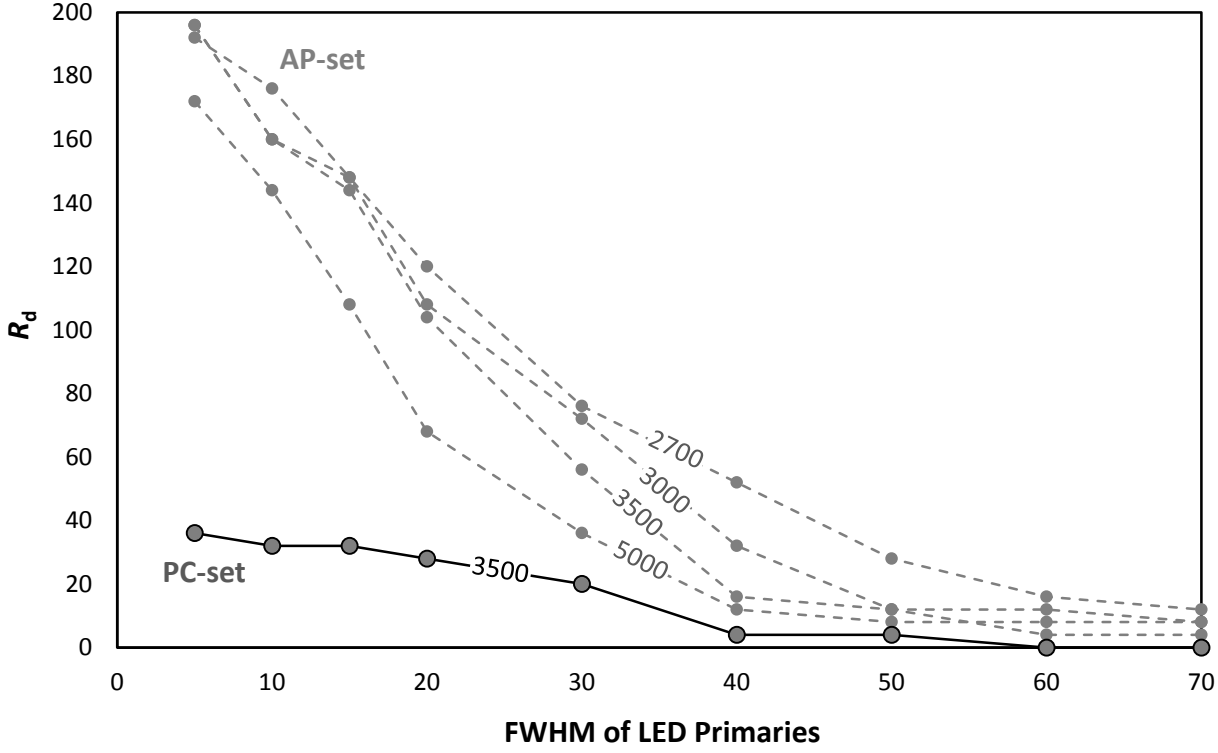

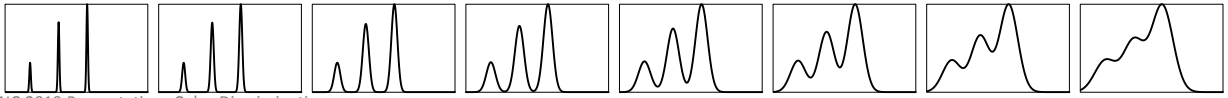

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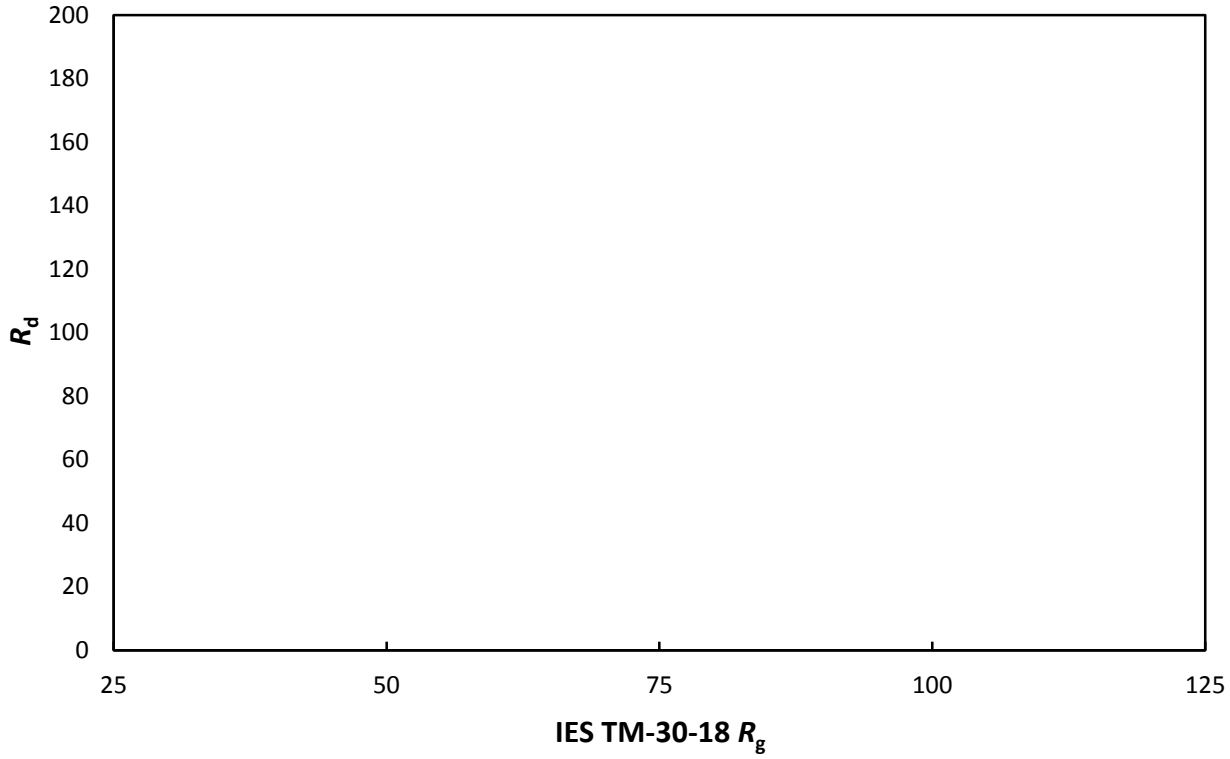

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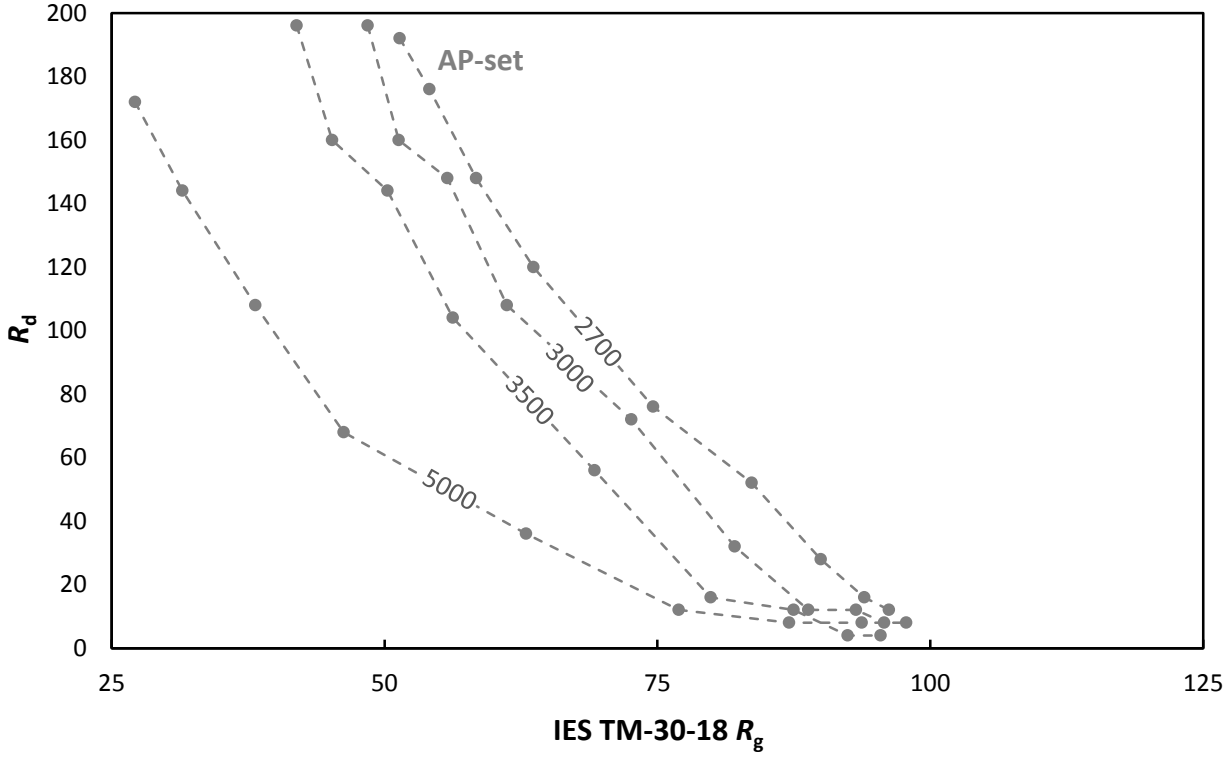

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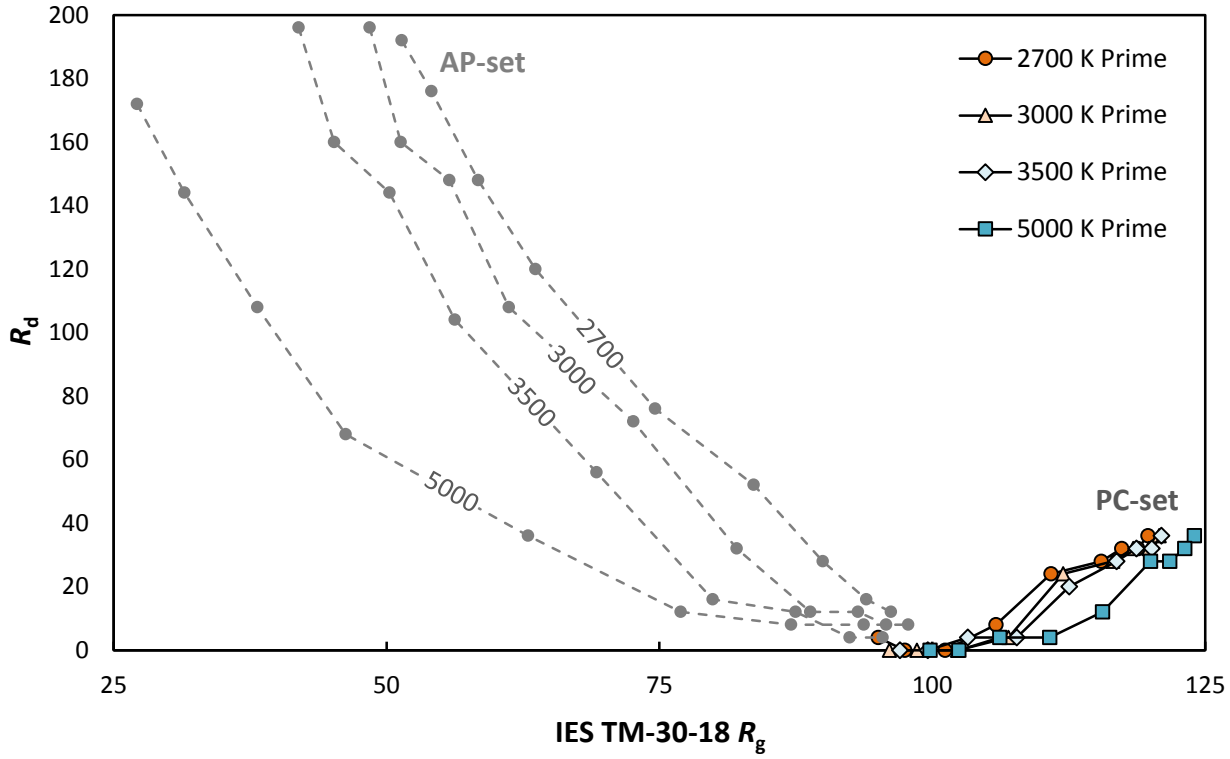

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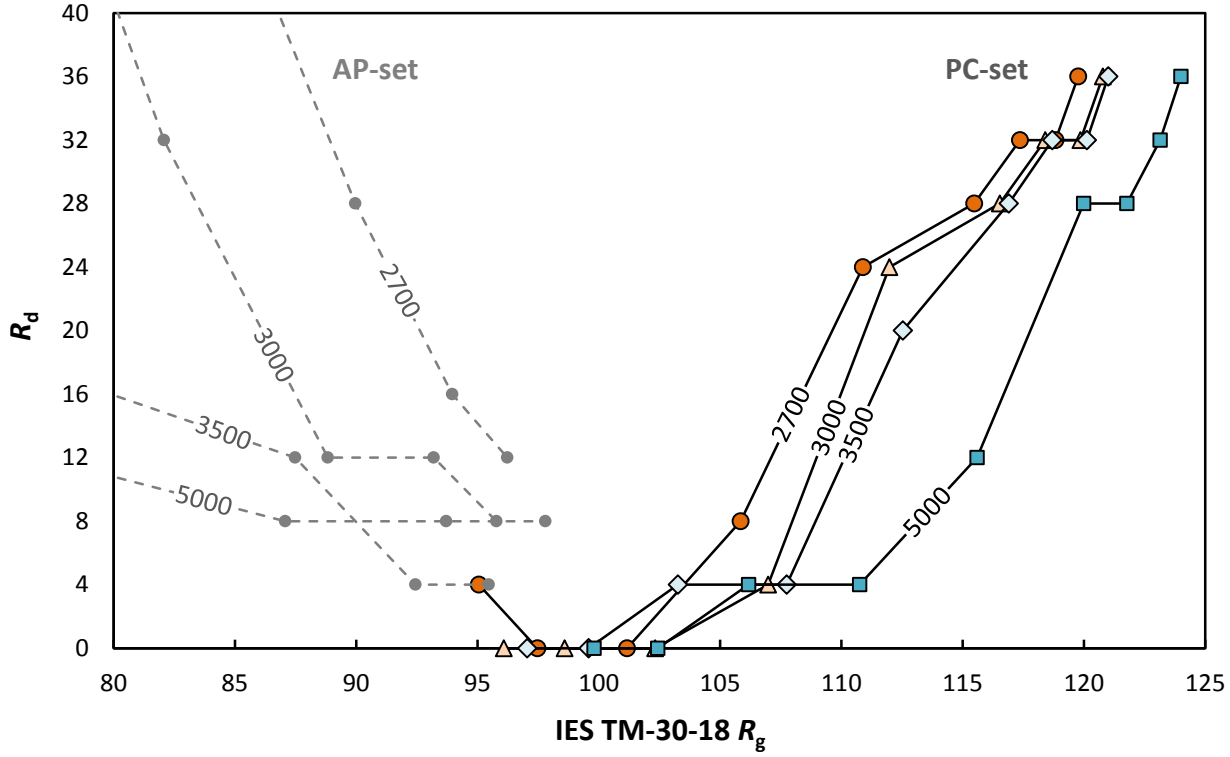

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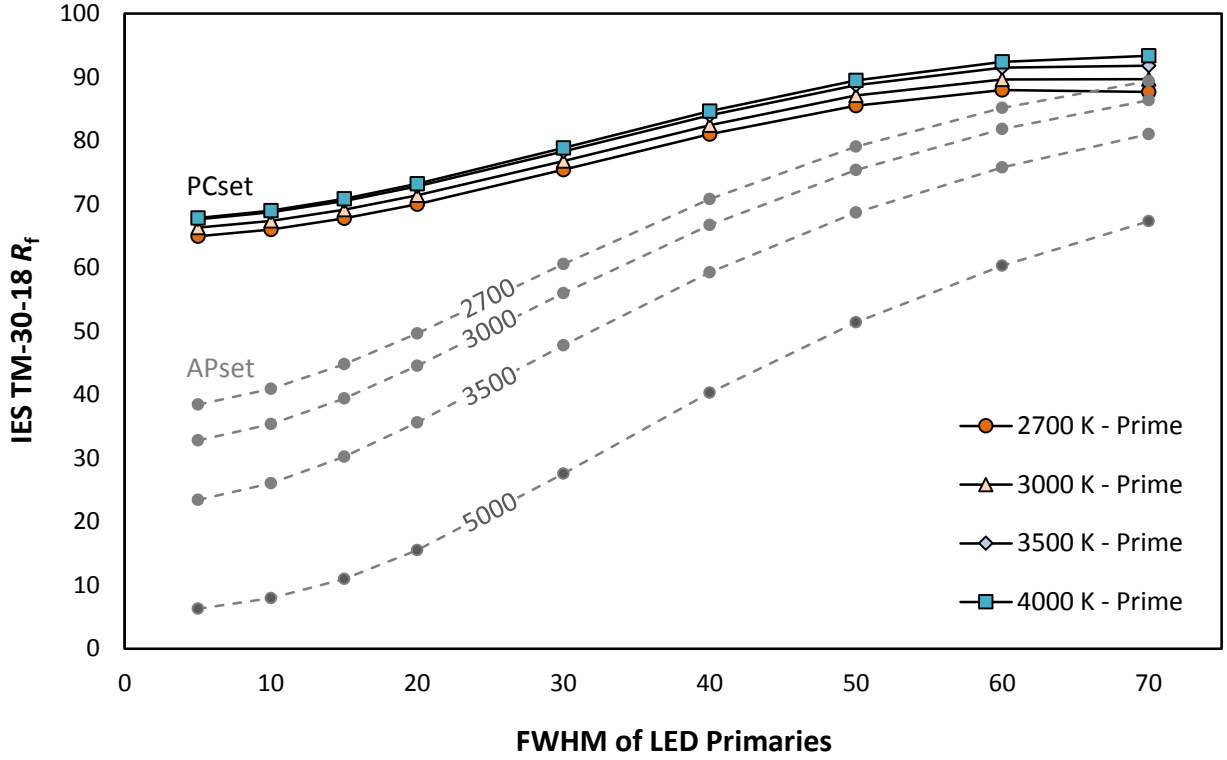
Study: Results



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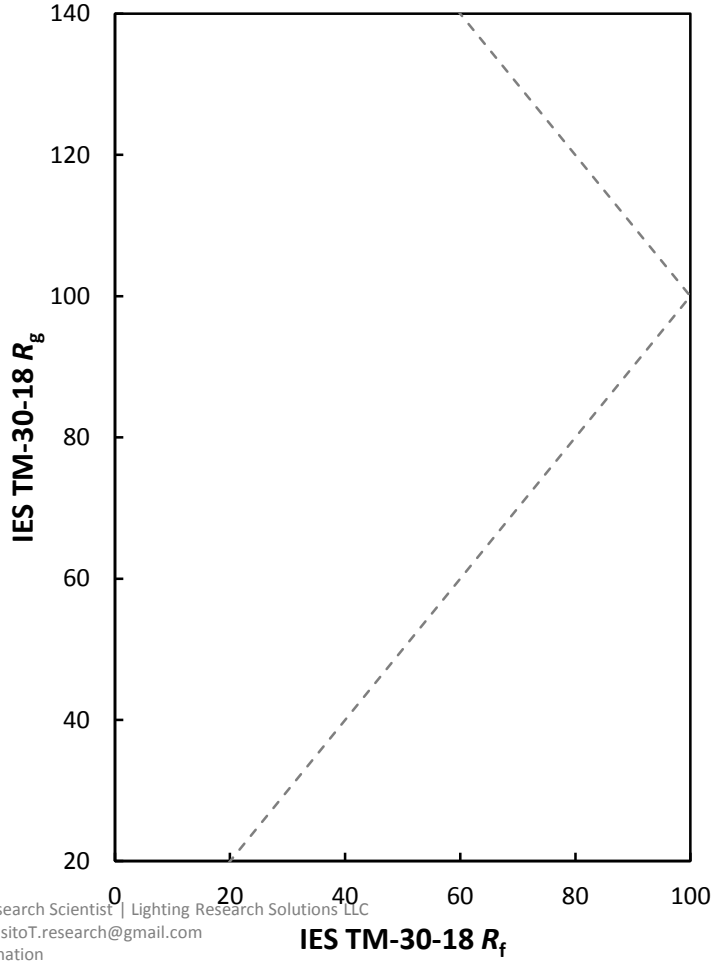
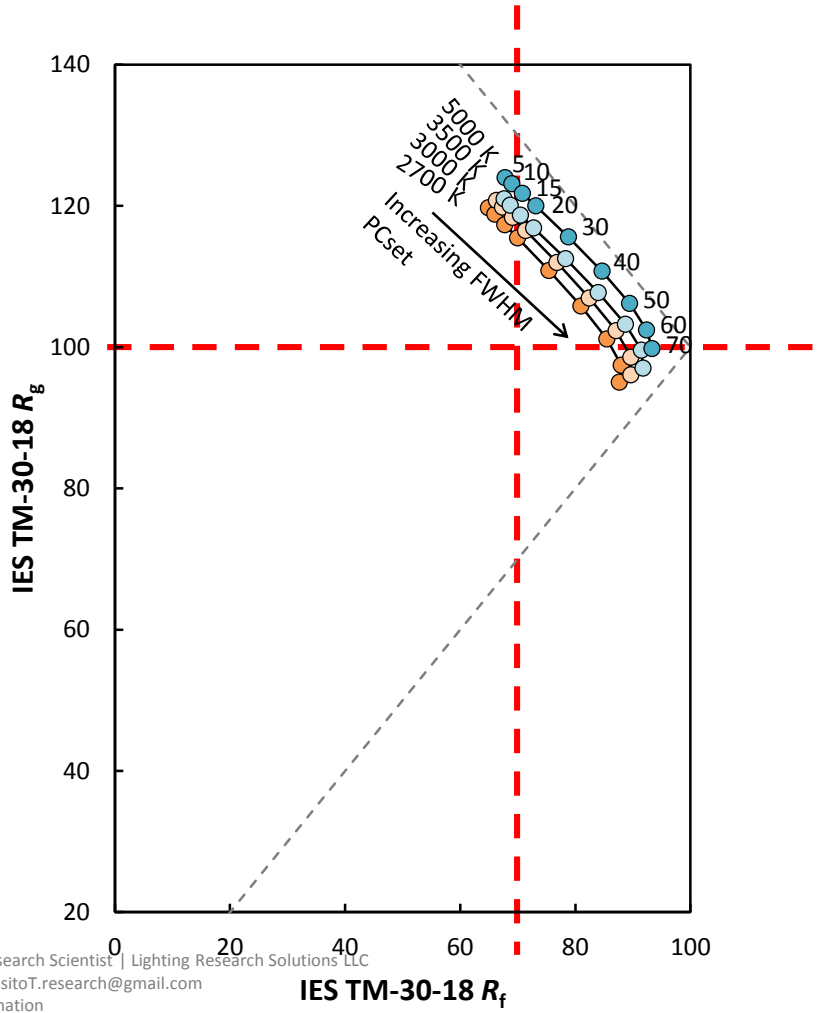


Study: Results



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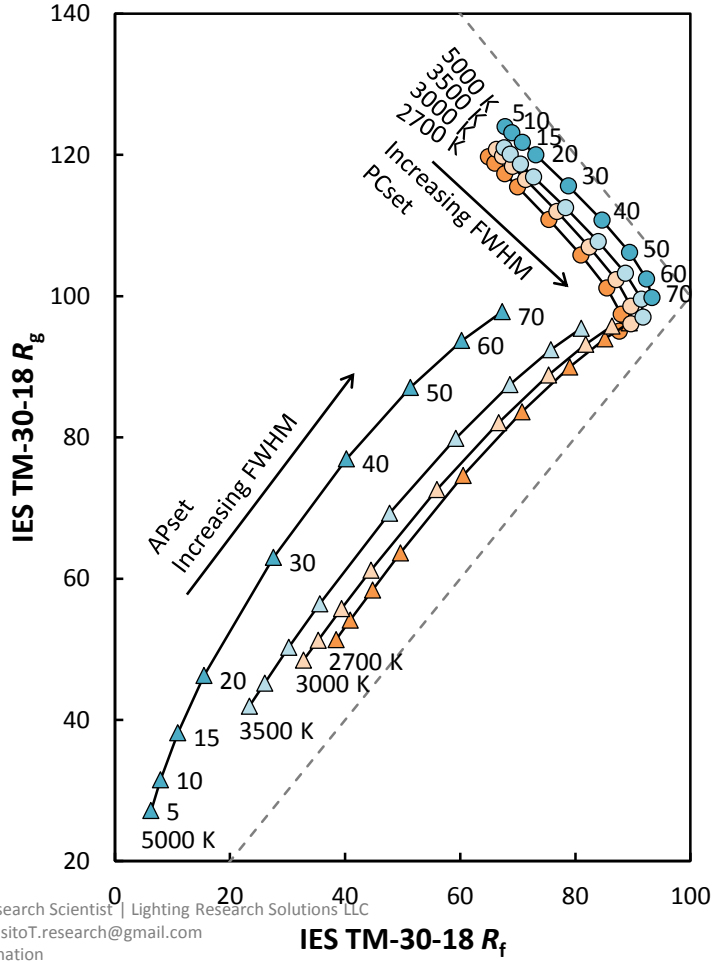
Study: Results



Conclusions

R_d is a new measure of CD that shows face validity

Gamut area does not predict CD across many/varied light sources

Larger gamut area may lead to worse CD

For three-component SPDs:

- Locating radiation about PC wavelengths is advantageous to ↓ R_d (good)
- (though difference between PC and AP decreases as FWHM/R_f increases)
- Maximizing gamut area is deleterious to Color Discrimination

R_d has internal consistency regarding daylight as an ideal color discriminator

There are tradeoffs between CD (R_d) and other aspects of color rendition

Future Work

Experimental Validation of R_d (i.e. direct testing)

Expansion of simulation work to include variable FWHM

Expansion of simulation work to include 4, 5, 6-component SPDs

Exploration of Rd sample set (spectral non-uniformity)

Generalized CD metric (not linked to FM100)

Age-related R_d trends

Does the frequency of hue transpositions vary with hue?

Evaluate impact of standard observer and color space

Relationship to metameric uncertainty and R_t

Defining a framework for a nuanced discussion of Color Discrimination

Relationship between Color Discrimination (R_d) and light level

Relationship between Color Discrimination (R_d) and CCT

End-Box Scoring artefacts, R_d, and custom CD tests

Evaluating R_d in a field study research project

Thank you!

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