The Visual Experience of Fine Art Under Low Illuminance

Jeffrey J. Mundinger, Penn State University

Kevin W. Houser, Oregon State University

Author Contributions

Concept:	KH	Data Collection:	JM
Methodology:	KH, JM	Original Draft:	JM
Apparatus:	JM	Review & Editing:	KH, JM

Study Artwork

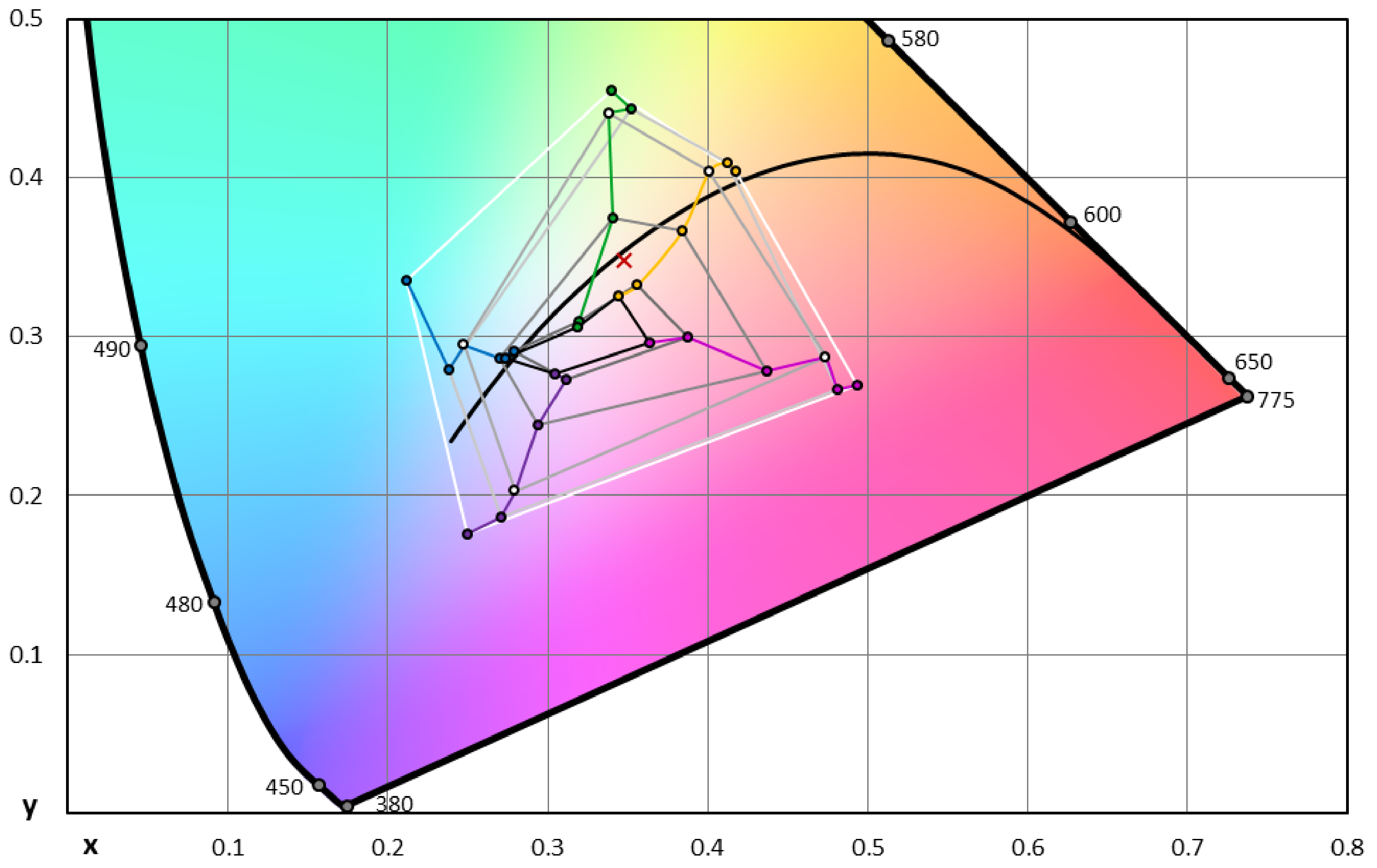
The heart of the experiment are the paintings upon which we paint our light. Artist James Whitbeck (top) adheres strictly to the traditional methods of 1600's Dutch baroque painter Johannes Vermeer. Artist Jim Mundinger (bottom) created saturated acrylic and watercolor paintings according to experimental specification. Together they set the field of color for participants to carefully consider.

Background

- Museum conservation guidelines restrict illuminance for sensitive artwork to levels that can cause color to be **perceived as less saturated**, a phenomenon known as the **Hunt Effect**. [*IES 2017, Hunt 1952*].

- For a dramatic though imperfect demonstration of the Hunt Effect, decrease your screen brightness while viewing the chromaticity plot at right. While an accurate replication of the Hunt Effect requires visual adaptation, the demonstration illustrates the desaturation of colors with decreasing illuminance.

- The chromaticity plot at right illustrates that **Hunt Effect** desaturation is **similar to reducing gamut**.

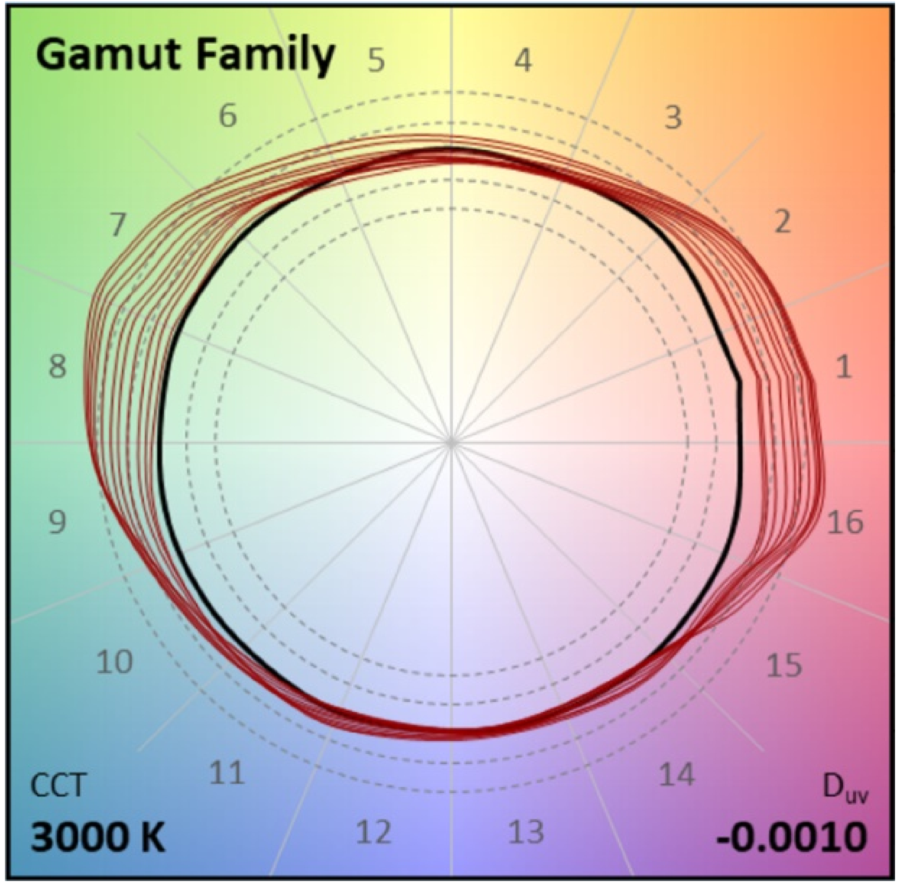


Binocular Match Gamuts at Various Luminance Levels [*Hunt 1952*]

Binocular matches are reproduced above for the first 6 adapting luminance levels (L_A) and the 5 test colors (violet, blue, green, yellow and magenta) that were replicated across both observers. Results of each match are averaged across the two observers to simplify the plot. Grayscale pentagons represent the gamuts bounded by the averaged matches made at each included L_A. Each series of matches begins with L_A = 100 cd/ft^2 (white gamut line) and ends with L_A = 0.007 cd/ft^2 (black gamut line). The white markers in each series denotes the match made at the L_A = 0.75 cd/ft^2, which was also the luminance of the matching field. The red X represents the chromaticity of standard illuminant B, which provided the L_A for both the matching and test color fields [*Hunt 1952*]. Line and marker colors represent but are not meant to accurately portray the test colors. The spectrum locus, blackbody locus, and purple line are marked with black lines. Reference wavelengths are denoted by grey makers along the spectrum locus.

Project Objectives

- Previous IES TM-30 research has identified **red saturating gamuts** that consistently increase perceived saturation and personal preference. [*Esposito 2016, Royer 2018, Bao and Wei 2019*]
- The shape and size of experimental gamuts were constrained such that their TM-30 gamut scores were used as unique identifiers (R_g^*), over a range of **96 ≤ R_g^* ≤ 124**.
- The primary objective was evaluating the red saturating gamut's ability to **compensate for the Hunt Effect** in an art gallery setting.
- Spectral optimization and live spectral feedback controlled gamut shape, chromaticity, and illuminance to more than an order of magnitude below the just noticeable difference.



Experimental Gamut Family

The experimental red saturating gamut family is illustrated by a simplified TM-30 Color Vector Graphic (CVG). The CVG includes 11 gamuts within the family across a range of 105 < R_g^* < 125. Similar results can be produced by LED arrays with as few as five color channels.

Experimental Chamber

The experiment was set in a mock art gallery. The LEDCube-11 near the top of the image is shown illuminating the gamut-illuminance study paintings. A Konica-Minolta CL-500A spectrophotometer is mounted between the paintings.

Experimental Methods

- A pair of studies was conducted in series. Elements common to both studies are presented along the center line that divides the distinct elements.

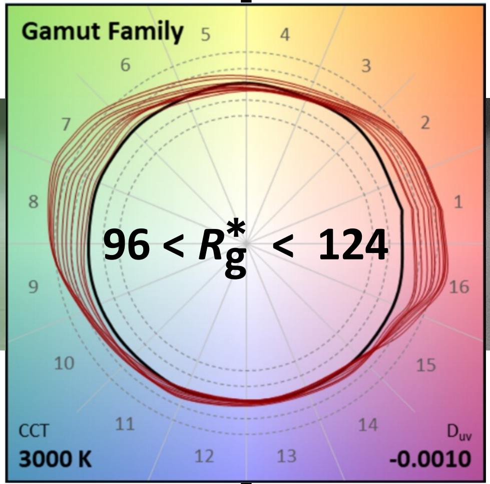
- The **Gamut-Tint Study** investigated the interaction between R_g^* **and tint (*D_{uv}*)** at a conservation light level of 50 lux.

- The **Gamut-Illuminance study** investigated the Hunt Effect via the interaction between R_g^* **and average painting illuminance (*Log Lux*)**.

- Paintings were evaluated in pairs under the various lighting conditions along 6-point semantic scales corresponding to **preference, saturation, and naturalness**.

Gamut-Tint Study	Gamut-Illuminance Study

$-0.0211 < D_{uv} < 0.0036$



25 lux < *Log Lux* < 100 lux

3000 K, 50 lux

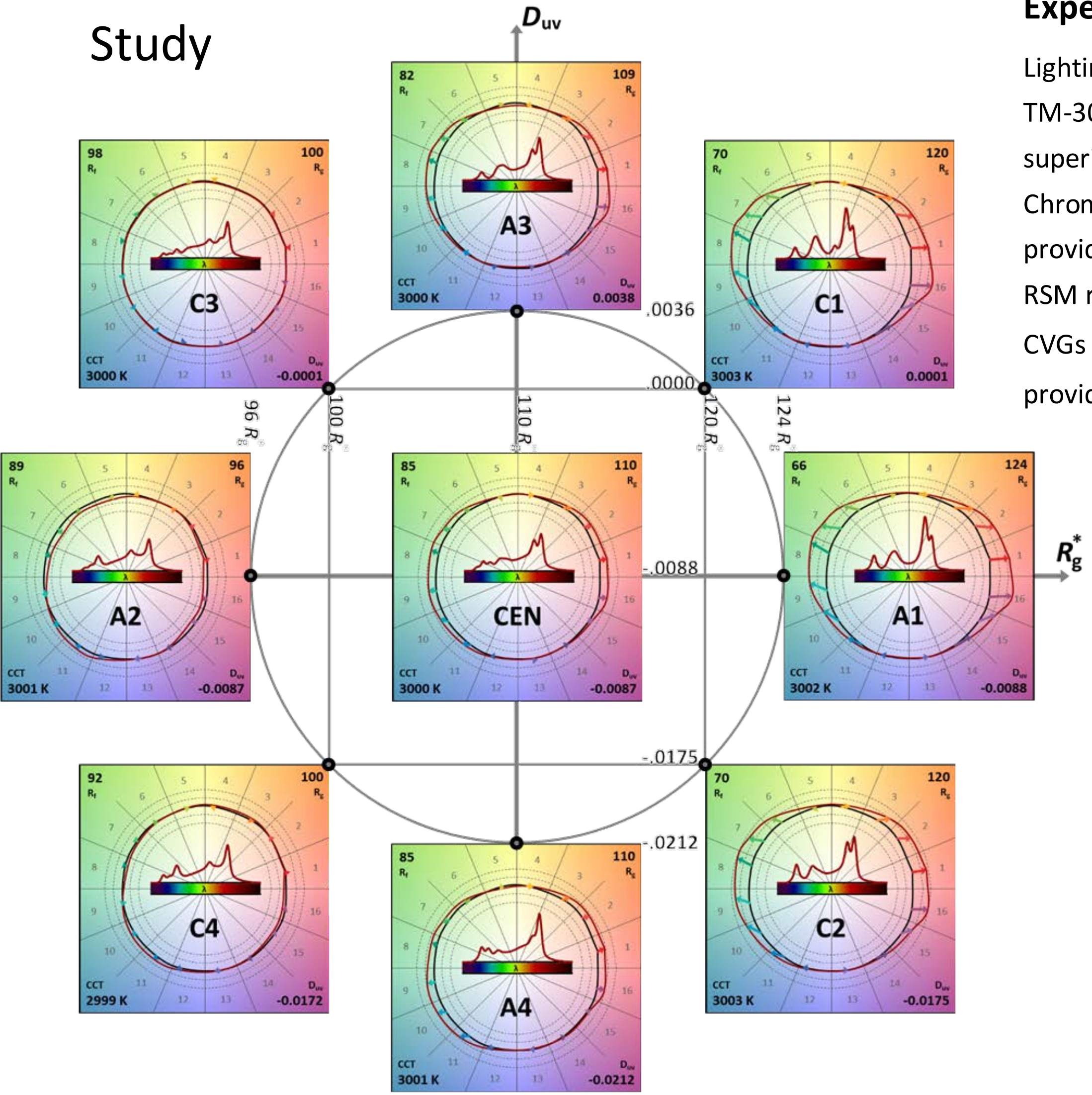
3000 K, -0.0075 D_{uv}

31 naïve participants

Preference
Saturation
Naturalness

36 naïve participants

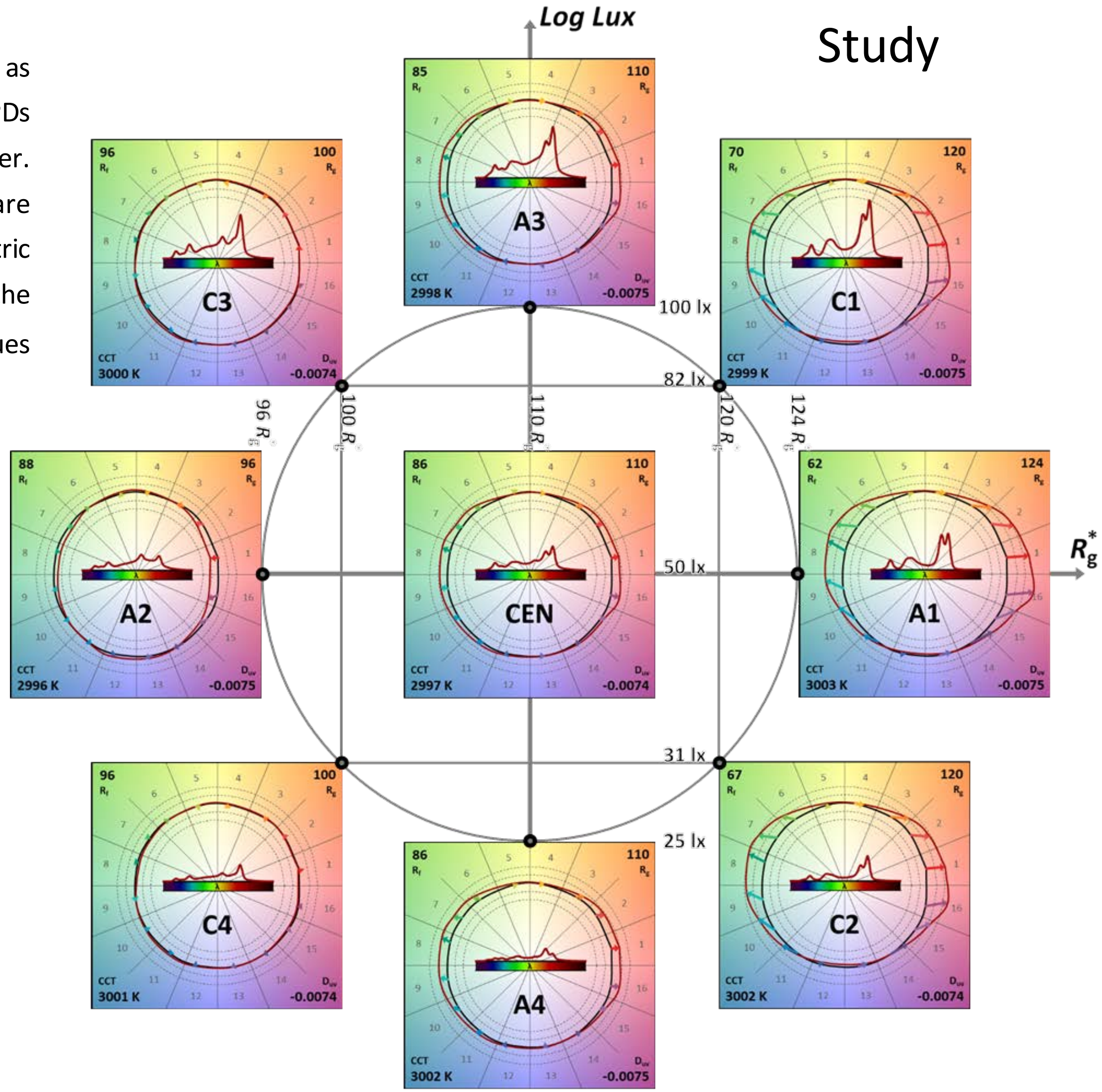
Gamut-Tint Study



Experimental Search Space

Lighting conditions are presented as TM-30-15 CVGs with associated SPDs superimposed in the center. Chromaticity and TM-30 R_f and R_g are provided on each CVG. The geometric RSM relationship is shown behind the CVGs with target R_g^* and D_{uv} values provided for reference.

Gamut-Illuminance Study



Experimental Methods

- R_g^*, D_{uv} and *Log Lux* were systematically varied according to response surface methodology (RSM), designed to map 2nd order terms and interactions
- Each participant evaluated a pair of paintings under nine independently presented lighting conditions

Hypotheses

- The studies shared core *a priori* hypotheses.
- Hypotheses highlighted in green are supported by results presented on the following slides; those in red are not supported.

Gamut-Tint Study

A. Participants will have preferred levels for D_{uv} and R_g^*

B. Perceived saturation increases with R_g^* not with D_{uv}

C. The paintings won't be judged differently

Gamut-Illuminance Study

A. Participants will prefer the maximum *Log Lux*

and have a preferred level for R_g^*

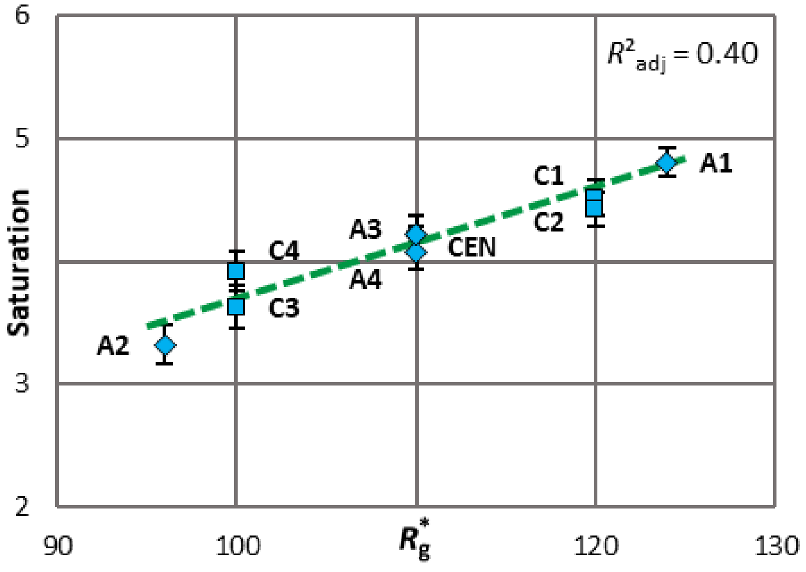
B. Perceived saturation increases with R_g^* and *Log Lux*

C. The paintings won't be judged differently

Results – Saturation

- Results for saturation aligned with *a priori* expectations for all variables.
- **Increasing *Log Lux* increased perceived saturation**, suggesting the Hunt Effect was clearly seen by participants with the experimental range of 25 lux ≤ *Log Lux* ≤ 100 lux.
- **Increasing R_g^* also increased perceived saturation.**
- The omitted single factor plot is not provided because **D_{uv} was not a significant predictor of saturation.**

Gamut-Tint Study



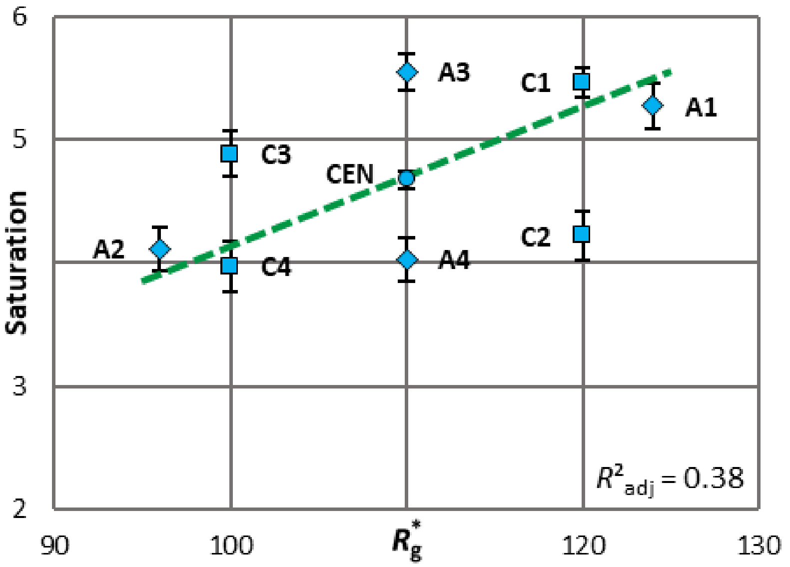
R_g^* as a Predictor of Saturation

Single Factor Plots – Saturation

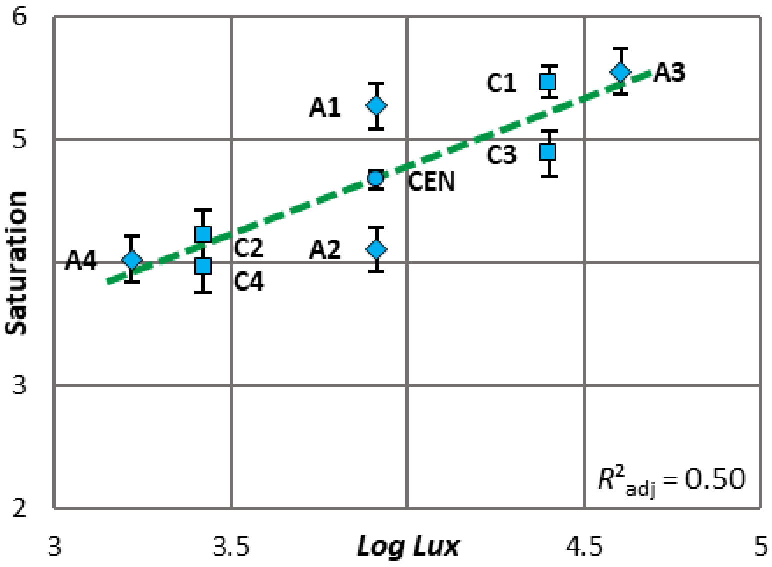
Single factor regression plots are provided for significant predictors. Regression models are represented by dashed green lines. Mean response levels for each experimental scene are marked with by blue shapes. Error bars represent ±1 standard error. Adjusted R^2 values are provided in plot corners.

Gamut-Illuminance Study

R_g^* as a Predictor of Saturation



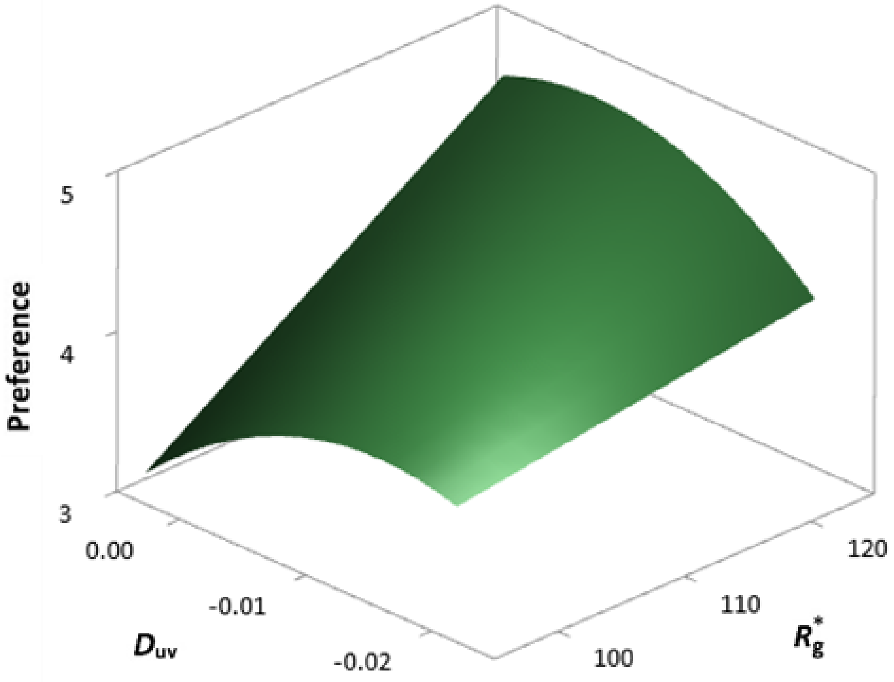
***Log Lux* as a Predictor of Saturation**



Results – Preference

- **Increasing R_g^* reliably increased personal preference** in all models across both studies.
- Both studies found **no evidence of decreased preference for R_g^* > 115,** contrary to previous studies. [*Esposito 2016, Royer 2018, Bao and Wei 2019*]
- The gamut-tint studied identified a valid response surface that maps an **interaction between R_g^* and D_{uv}** predicting the preferred level for D_{uv} varies with R_g^*:
    - D_{uv} = -0.013 at R_g^* = 100
    - D_{uv} = -0.005 at R_g^* = 120

Gamut-Tint Study



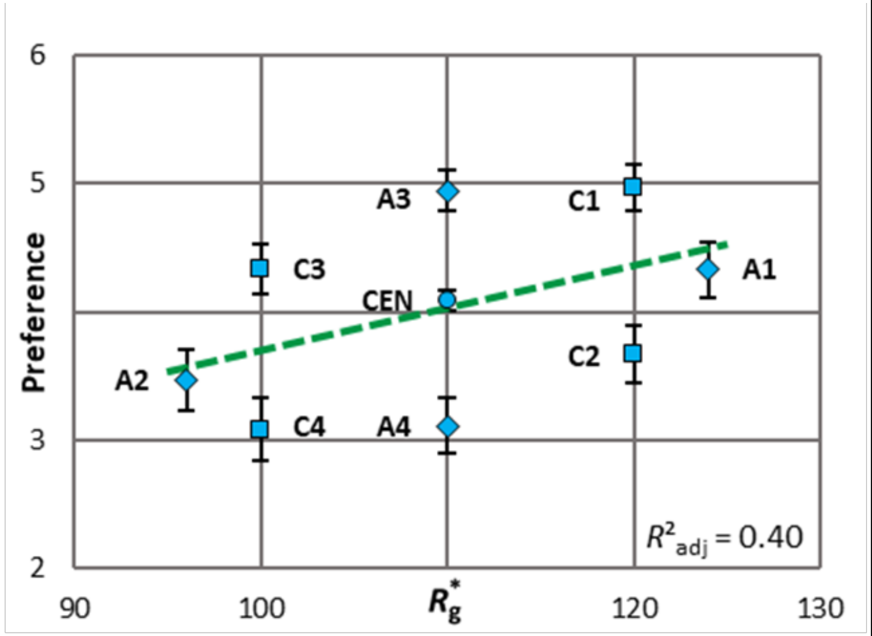
Response Surface for Preference

The response surface maps an interaction between R_g^* (x-axis) and D_{uv} (y-axis) for preference (z-axis). Lowest preference coincides with low R_g^* and high D_{uv}. Highest preference coincides with high R_g^* and moderately negative D_{uv}.

Gamut-Illuminance Study

Single Factor Plot – R_g^* as a Predictor of Preference

A single factor regression plots is provided for R_g^*. *Log Lux* was also significant. The regression model is represented by a dashed green line. Mean response levels for each experimental scene are marked with by blue shapes. Error bars represent ±1 standard error. Adjusted R^2 values are provided in plot corners.



Results – Paintings

- No significant differences between paintings were seen for either R_g^* or D_{uv} in the gamut-tint study

- Significant differences between the paintings were seen throughout the gamut-illuminance study for both R_g^* and *Log Lux*.

- **It may not be possible to specify a particular level of R_g^* that is broadly effective for all artwork at a particular light level.**

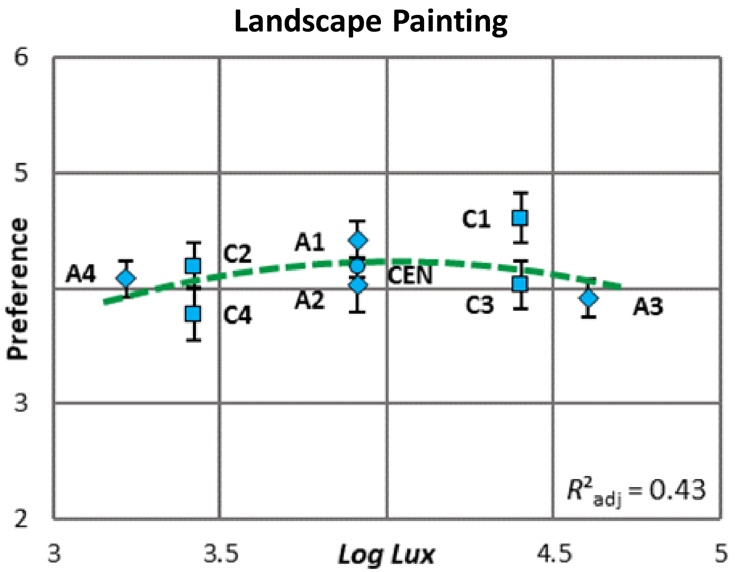
- **Style** (baroque realism *versus* modern abstract) **and color palette** (moderately saturated natural color *versus* high saturation abstract color) **may lead to distinct perceptual outcomes**. The results of these and other studies are generalizable only to the types of paintings presented.

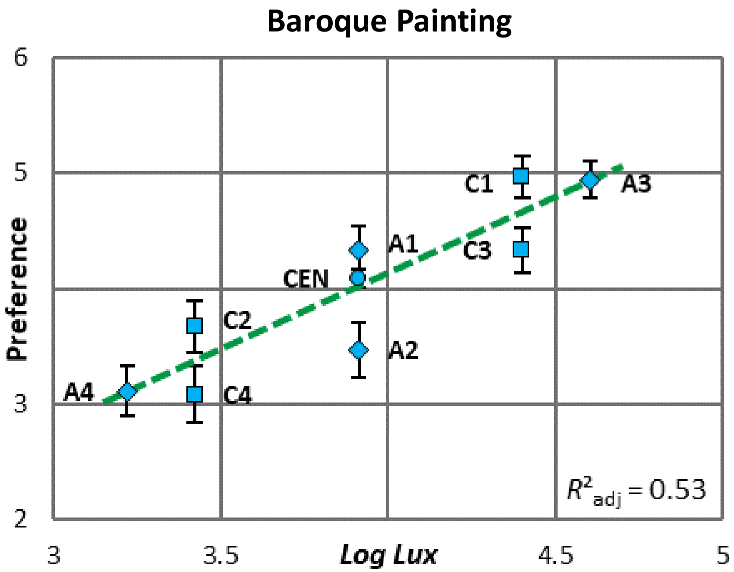
Gamut-Tint Study

Gamut-Illuminance Study

Single Factor Plots – ***Log Lux*** **as a Predictor of Preference**

Separate single factor regression plots are provided for *Log Lux* for both paintings. The regression models are represented by dashed green lines.



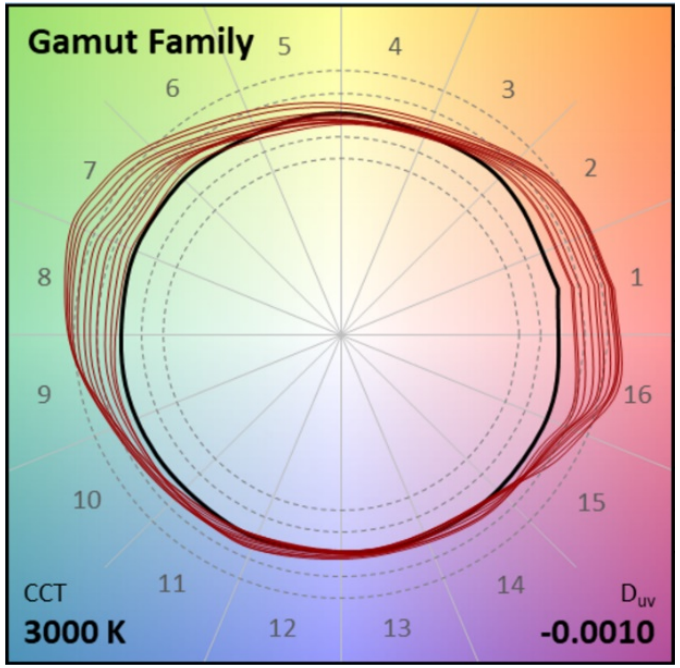


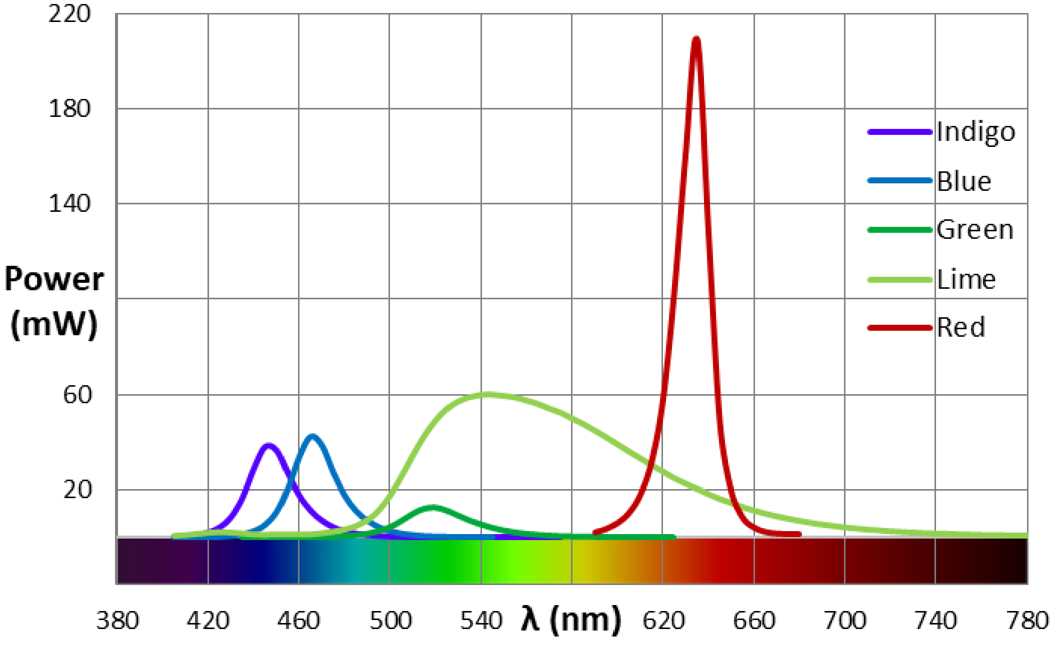
Future Work

- The **red saturating gamut family reliably increased both personal preference and perceived saturation** for all three paintings and across a range of D_{uv} and *Log Lux*.

- LED sources capable of providing a range of high performance gamuts are already available. Such sources only require one broad-band emitter along with three emitters corresponding to the **prime color regions (450 nm, 530 nm, 610 nm)**. [Thornton 1999]

- Making a red saturating gamut family available on those sources would provide lighting designers with a powerful new tool for fine-tuning the visual environment, with cross-over applications in fine dining, hospitality, theatre and more.





Realistic LED Array

The presented SPDs were extracted from Luxeon C datasheets. This five-channel array is similar to several commercially available systems and produced the gamut family shown at right.

References

[IES] Illuminating Engineering Society. 2017. RP-30-17 Recommended Practice for Museum Lighting. New York (NY): Illuminating Engineering Society. 141 p.

Hunt R. 1952. Light and dark adaptation and the perception of color. Journal of the Optical Society of America. 42(3)190-199.

Esposito T. 2016. Modeling color rendering and color discrimination with average fidelity, average gamut, and gamut shape. PhD Thesis, Penn State University, PA. 190 p.

Royer M, Wilkerson A, Wei M. 2018. Human perceptions of colour rendition at different chromaticities. Lighting Research & Technology. 50(7)965-944.

Bao W, Wei M. 2019. Change of gamut size for producing preferred color appearance from 20 to 15000 lux. Leukos. 17(1)1-22.

Thornton WA. 1999. Suggested optimum primaries and gamut in color imaging. Color Research and Application. 25(2)148-150.