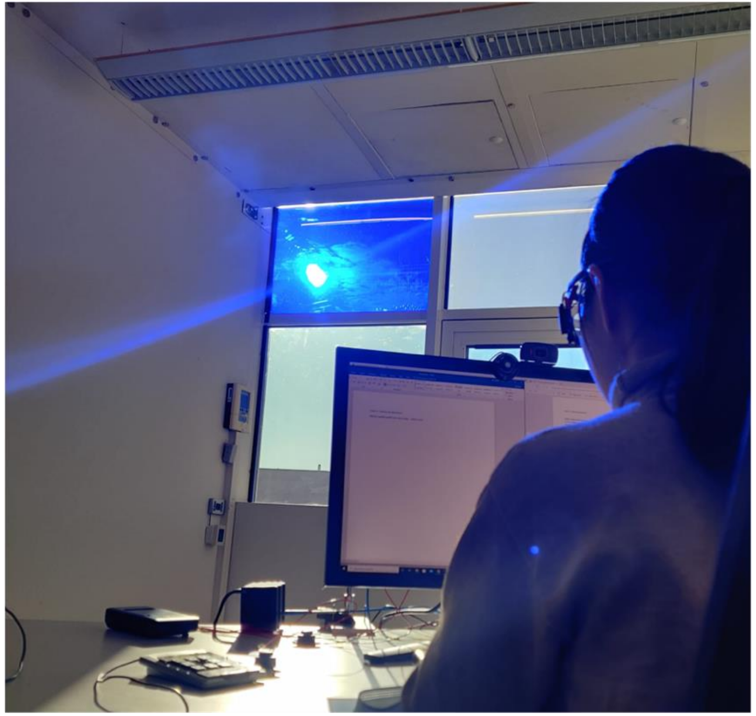
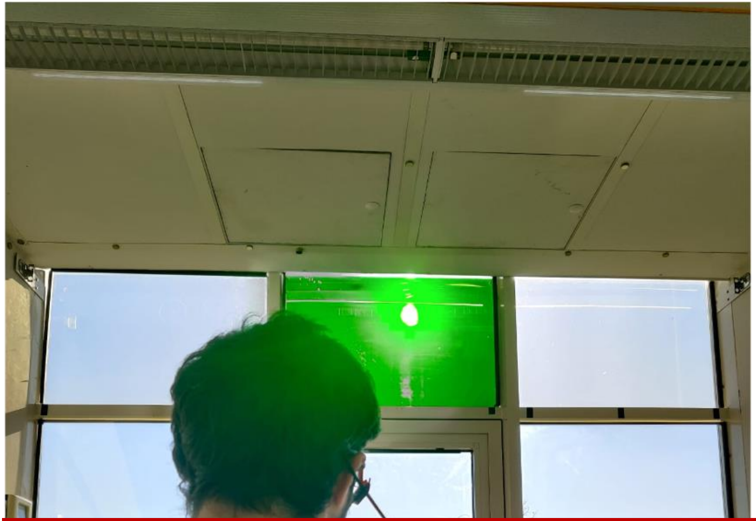
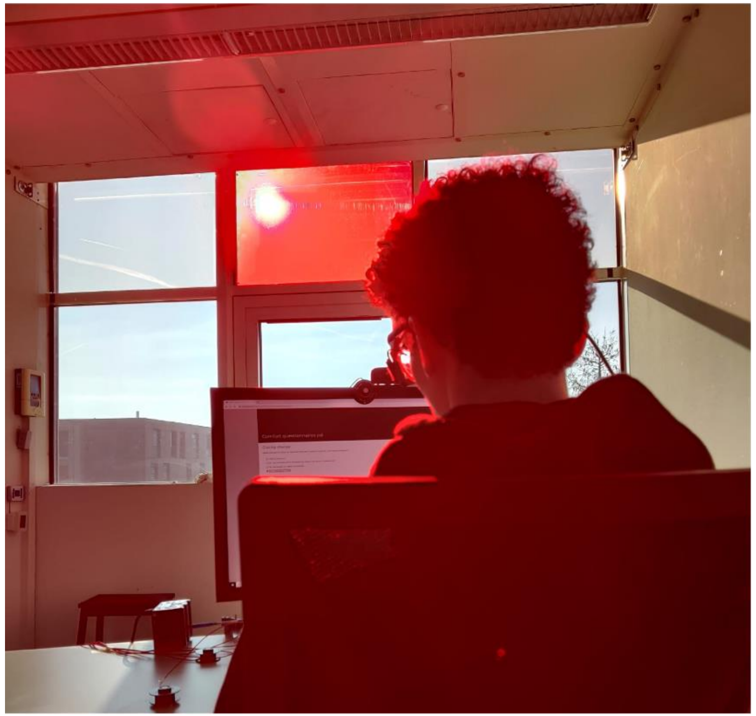
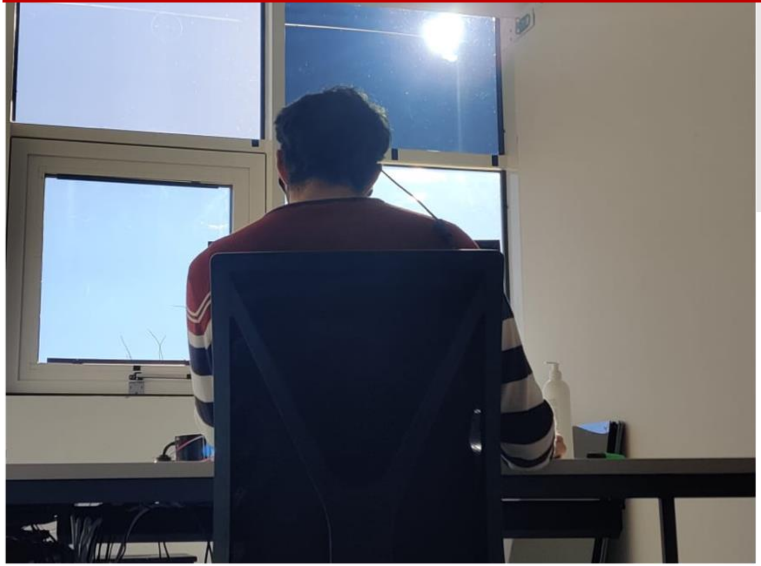




How to incorporate color influence in Discomfort Glare models

Sneha Jain, Postdoctoral Scholar, Stanford University





Radiance Workshop, Aug 27, 2024
Salt Lake City, Utah

Stanford University

EPFL

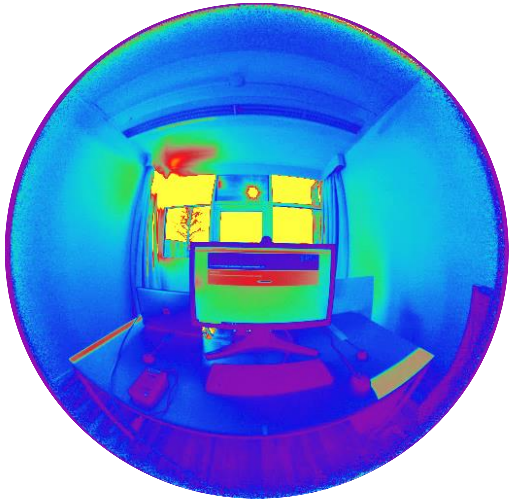
How is glare quantified?

Discomfort glare models

User assessment survey

HDR imaging

Photometrics measurements



Physical properties of the scene

How do you rate glare in the field of view?

- ❑ *Imperceptible*
- ❑ *Noticeable*
- ❑ *Disturbing*
- ❑ *Intolerable*

$$\boldsymbol{DGP} = a.\boldsymbol{E}_v + b.\log(1 + \sum \frac{\boldsymbol{L}^{\exp 1}\omega}{\boldsymbol{E}_v^{\exp 2} P^{\exp 3}}) + \mathrm{c}$$

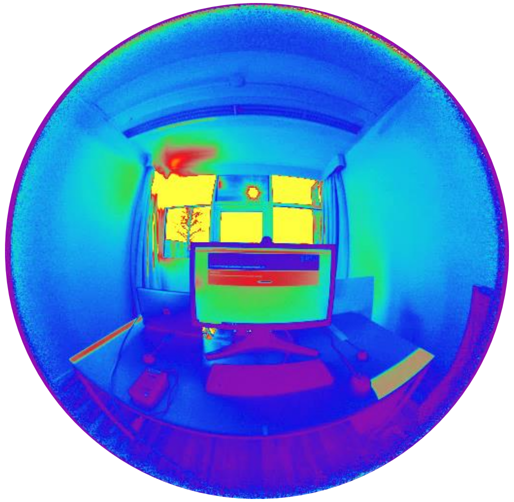
Daylight Glare Probability

How is glare quantified?

Discomfort glare models

HDR imaging

Photometrics measurements



User assessment survey

Physical properties of the scene

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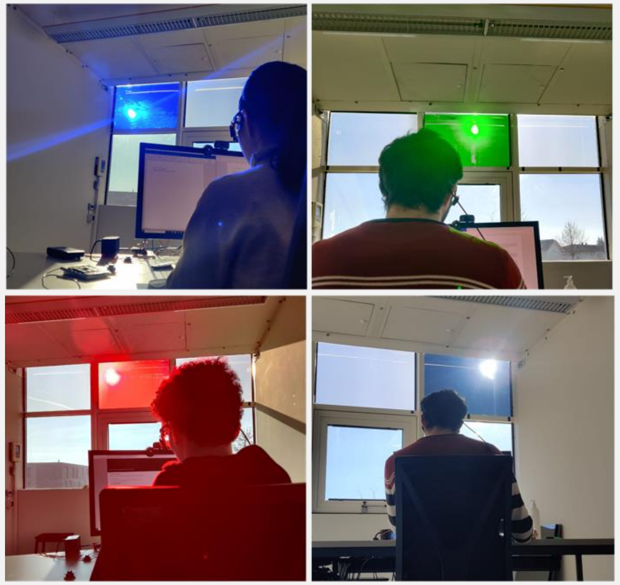
$$\boldsymbol{DGP} = a.\boldsymbol{E_v} + b.\log\left(1 + \sum \frac{\boldsymbol{L}^{\exp1}\omega}{\boldsymbol{E_v}^{\exp2} P^{\exp3}}\right) + c$$

Limitations!

Unable to predict glare in certain light scenarios including colored lighting

Is there an influence of the color of daylight (filtered by glazing color) on discomfort glare?



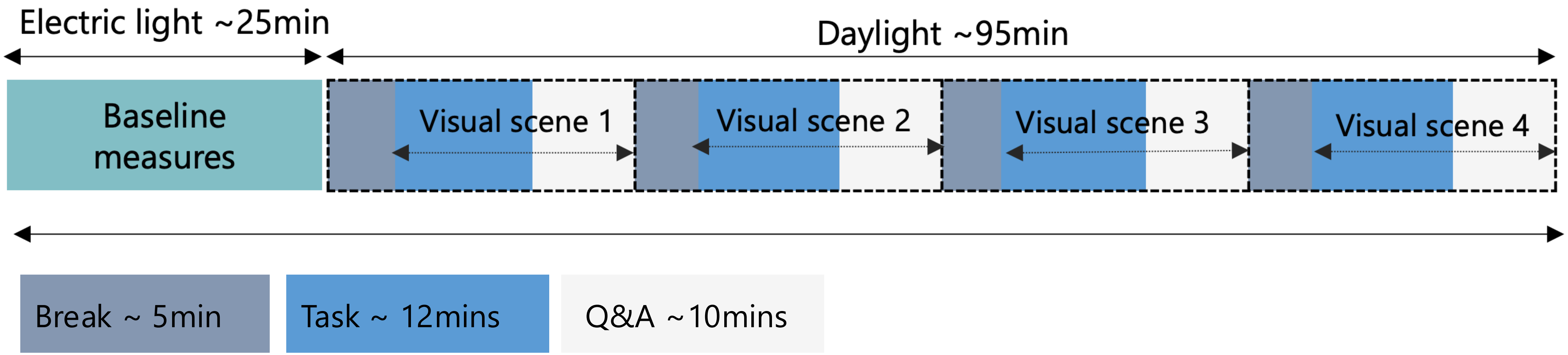
Design of experiment

Participants	55 (18-31 years)
Study design	Within-between mixed factorial design
Dependent variable	Discomfort glare perception
Independent variable	Glare source colour *(within subject variable)* Glare source luminance *(between subject variable)*

Experiment protocol

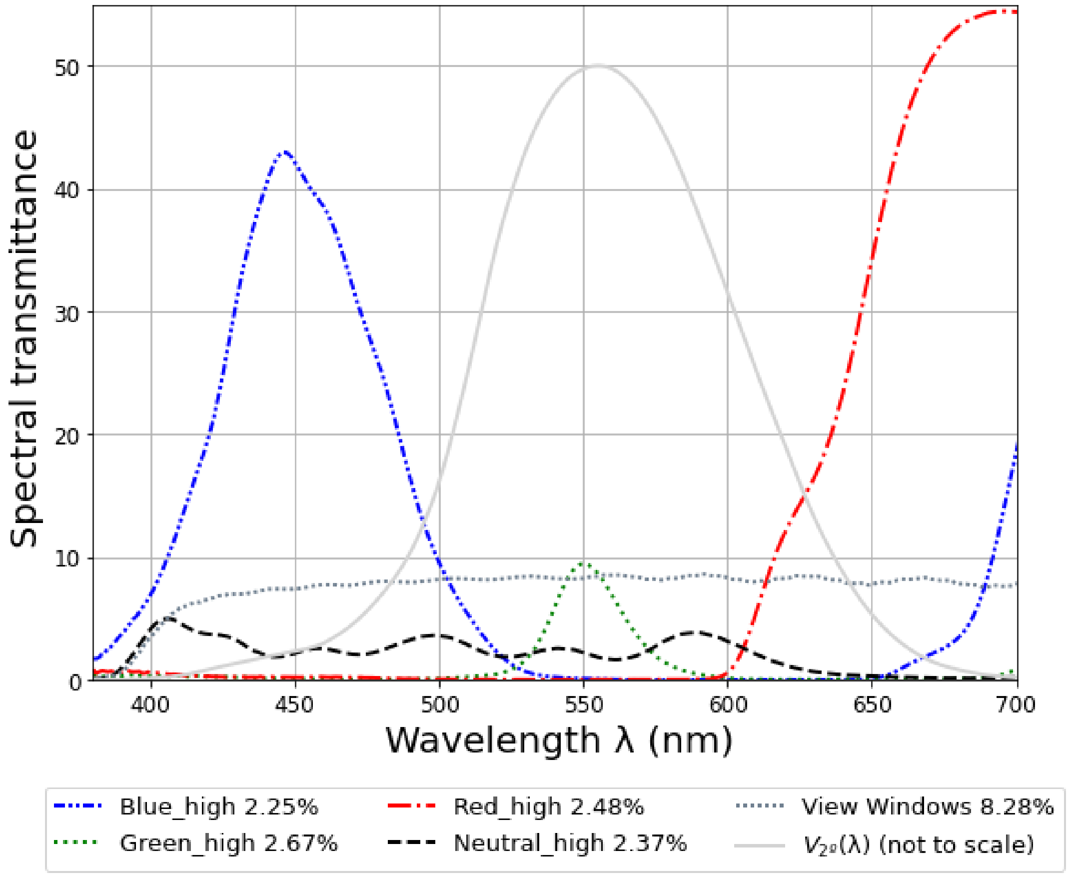
	Blue	Green	Red	Grey	No. of participants
Transmittance high (~2.5%)					28
Transmittance low (~0.37%)					28

Total datapoints: 224

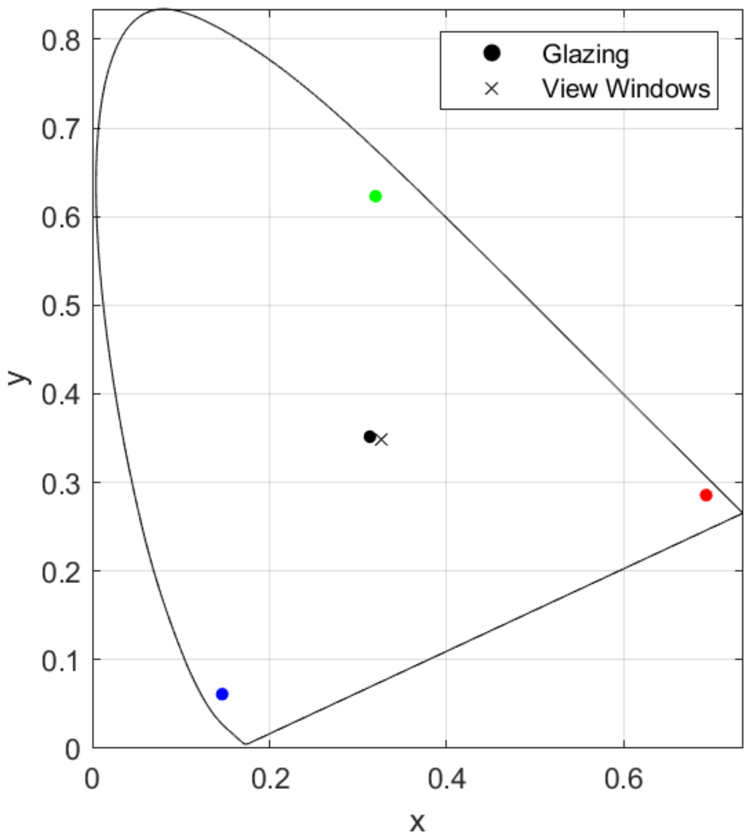


Glazing transmittance

Glazing	Visible light Transmittance ($t_{v,n-h}$) weighted over V(l)
Blue_low	0.39%
Green_low	0.40%
Red_low	0.33%
Neutral_low	0.38%
Blue_high	2.25%
Green_ high	2.67%
Red_ high	2.48%
Neutral_ high	2.37%
View windows	8.28%



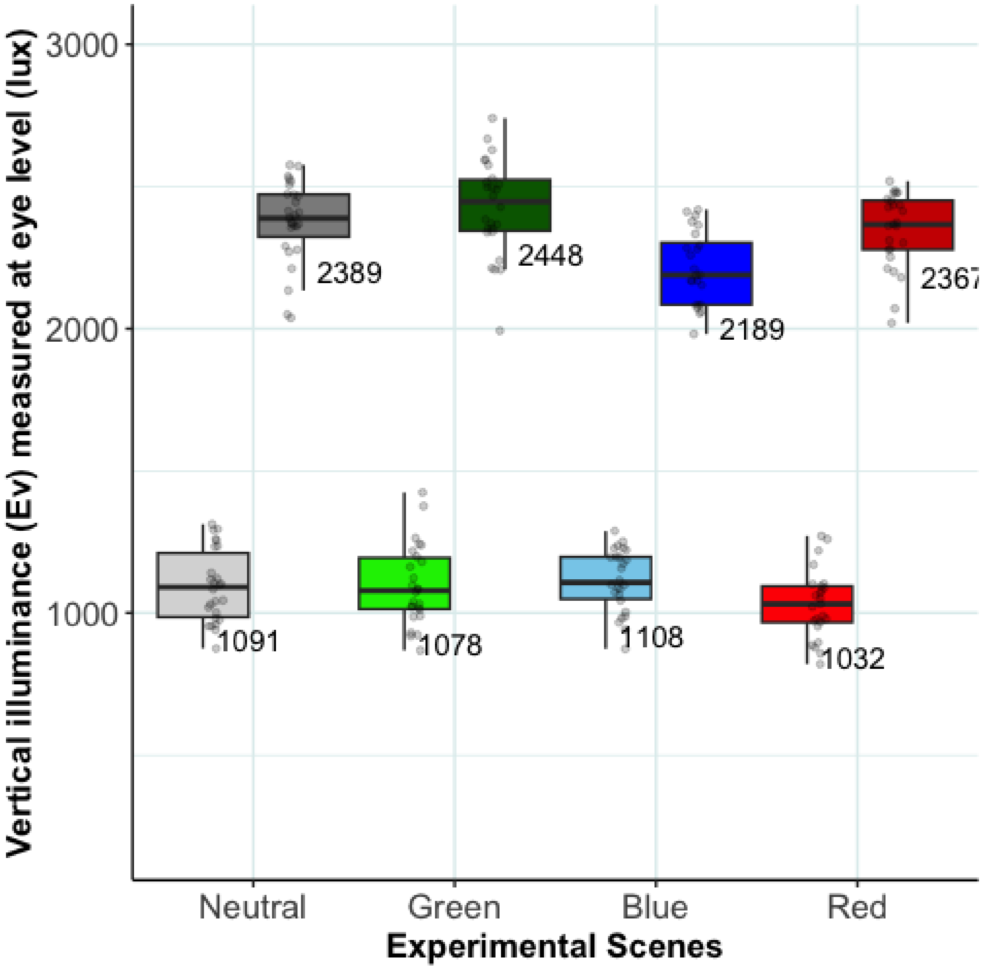
Glazing color



CIE xy chromaticity coordinates of the glazings.

Sneha Jain | Stanford University

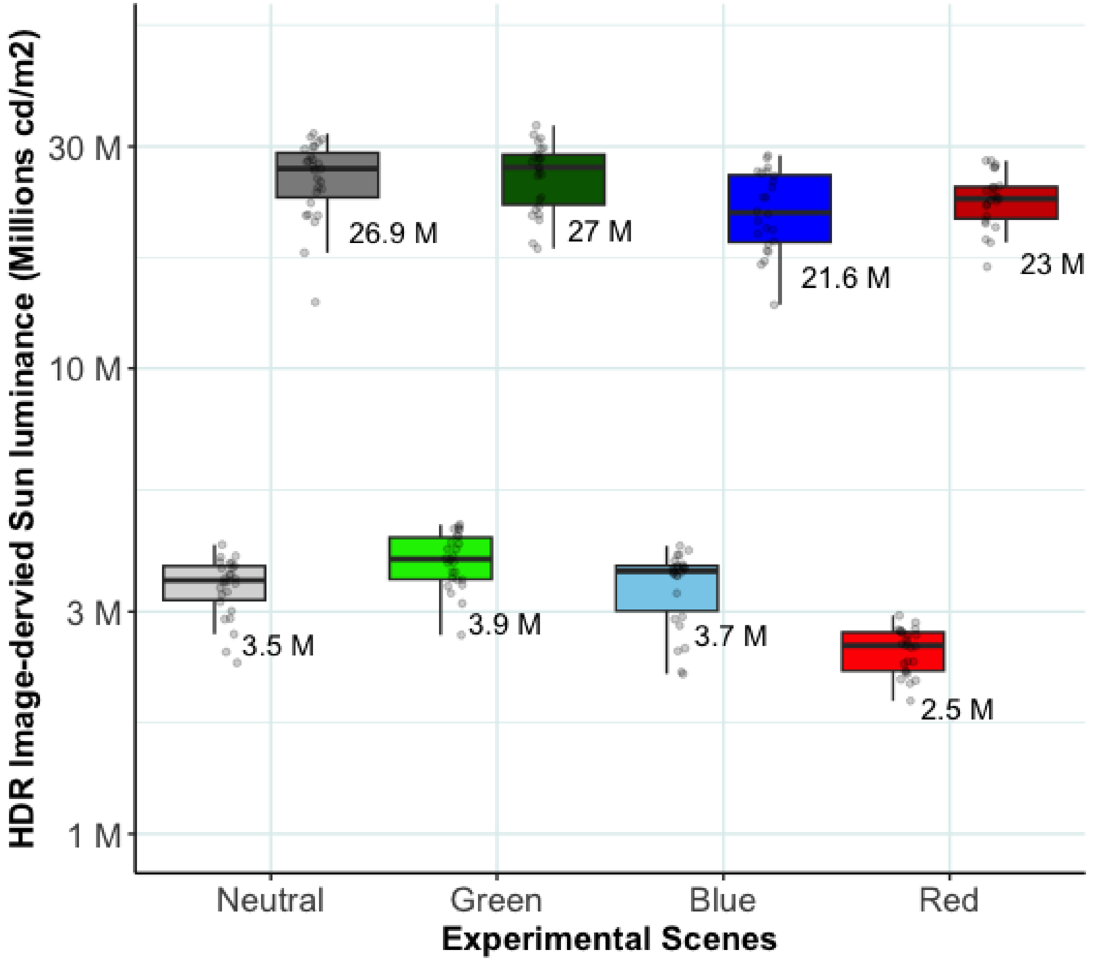
Daylight Conditions: Vertical illuminance levels

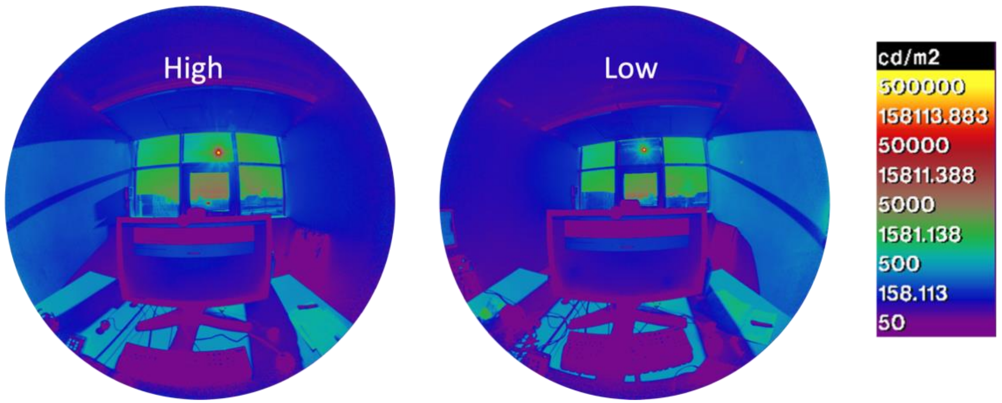


Influence of color on discomfort glare, **Radiance Workshop 2024**

Sneha Jain | Stanford University

Daylight Conditions: Luminance values





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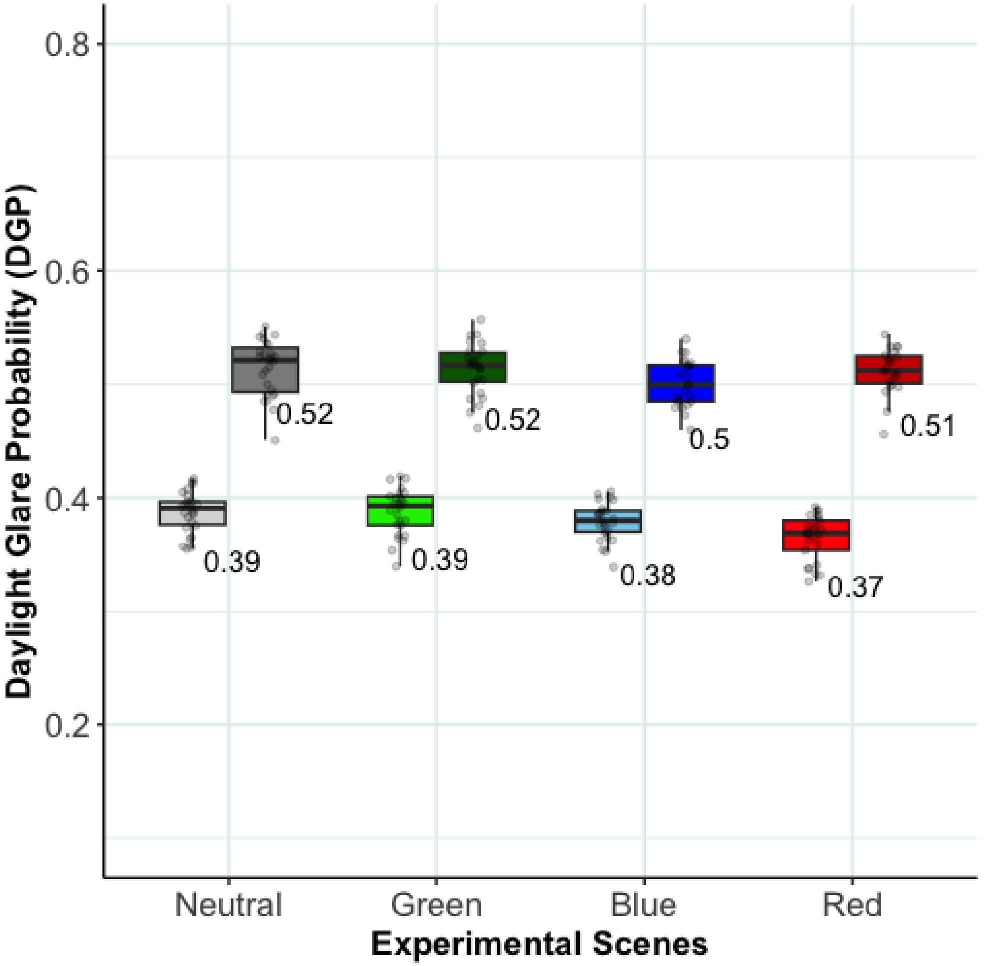
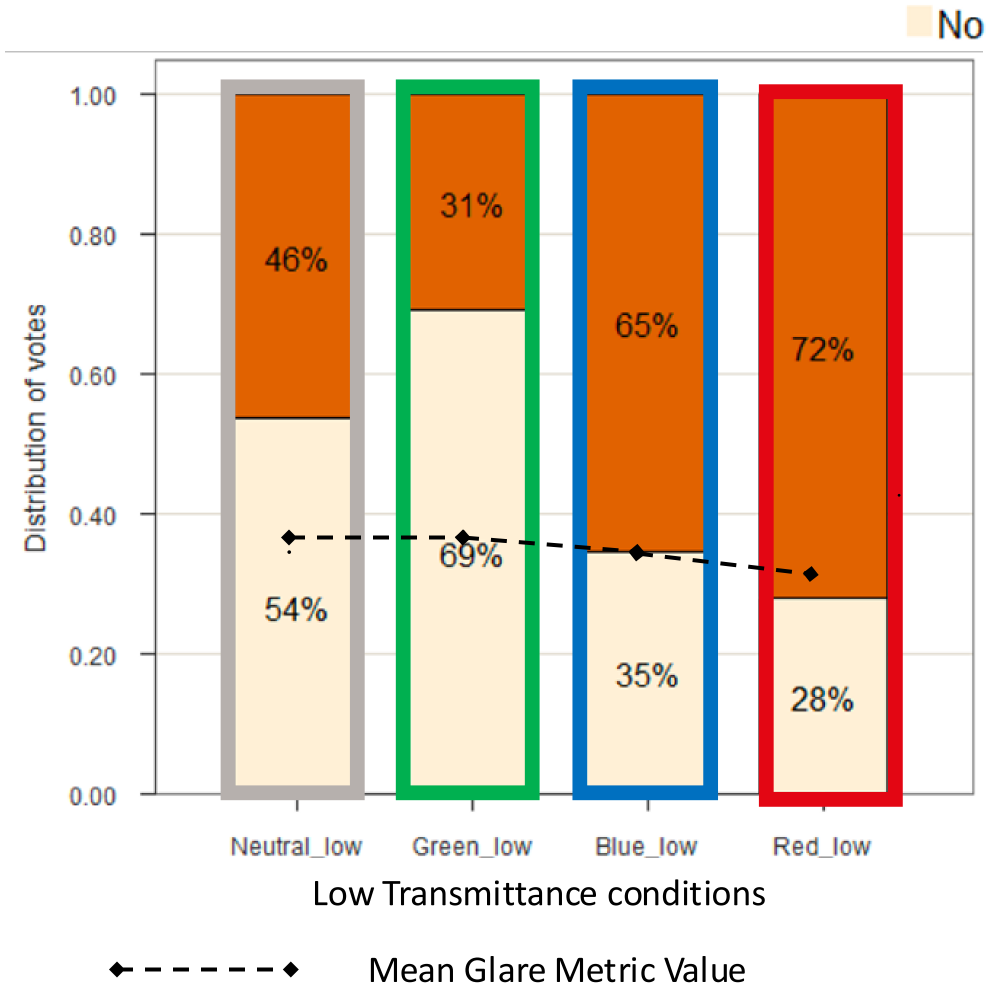
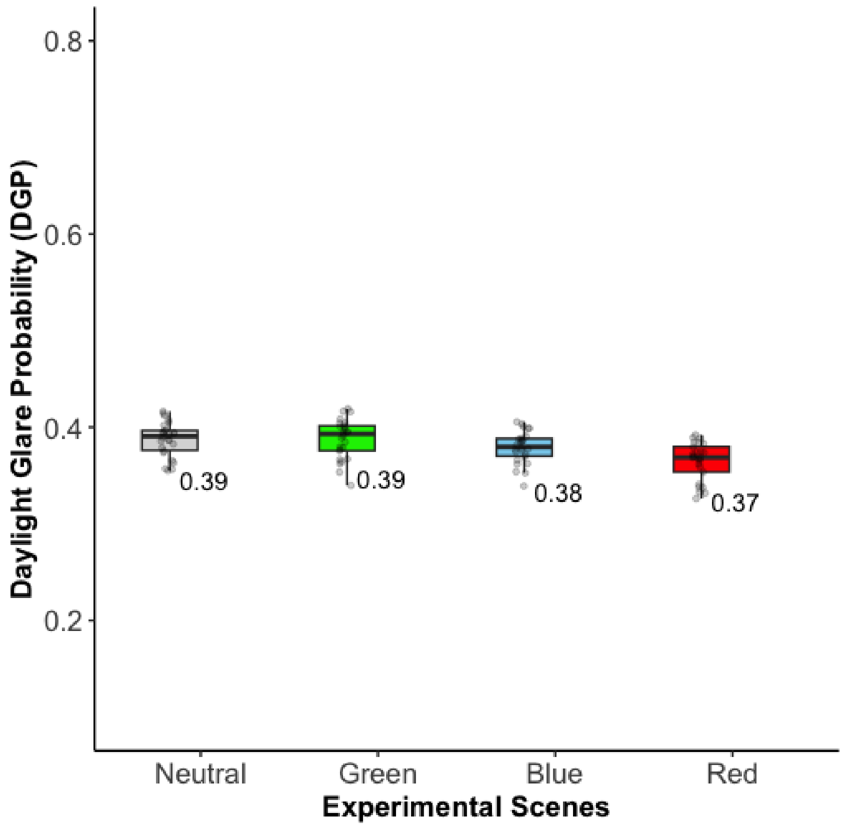
Daylight Conditions: Glare metric values



Subjective glare responses

Are you experiencing any discomfort due to glare at the moment?





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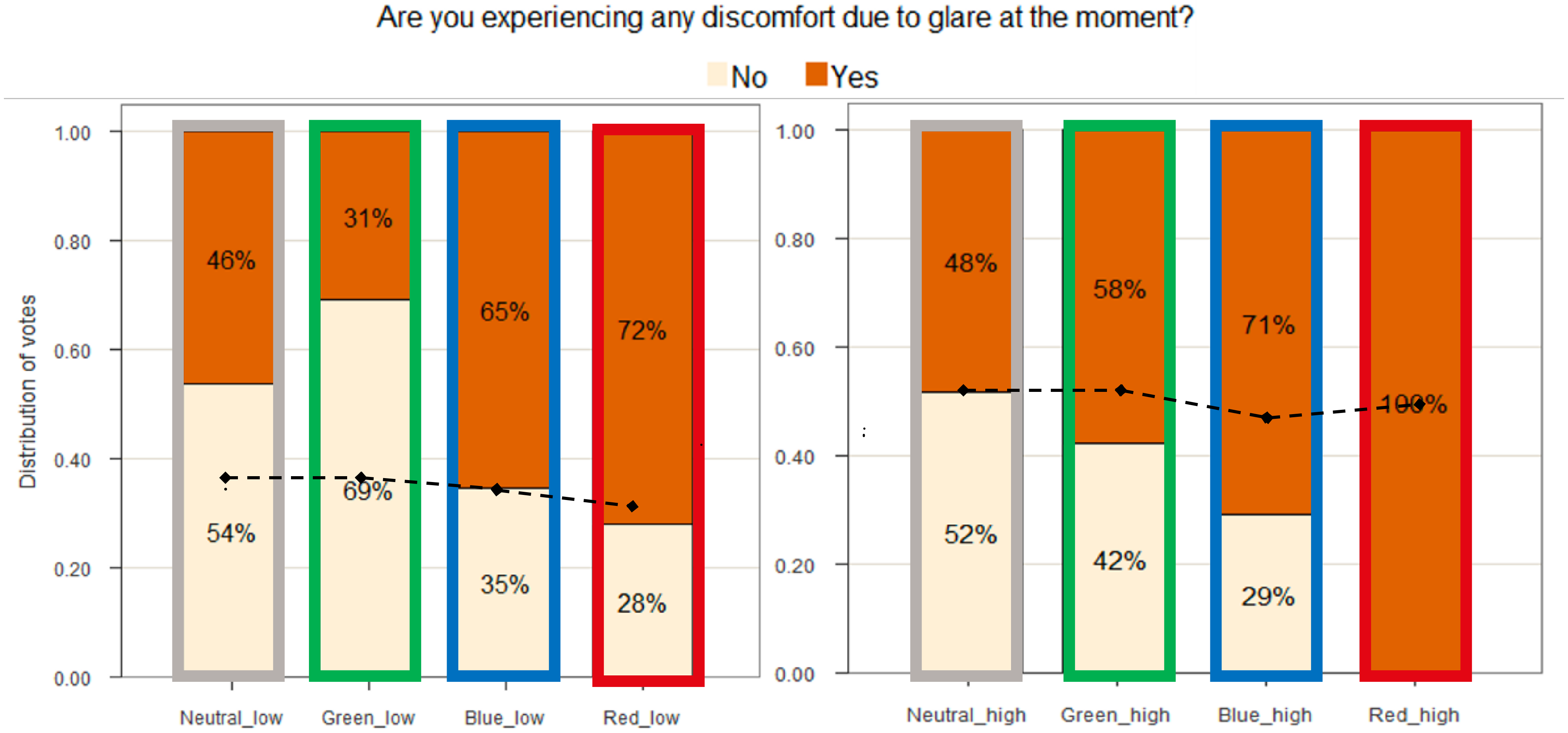
Subjective glare responses

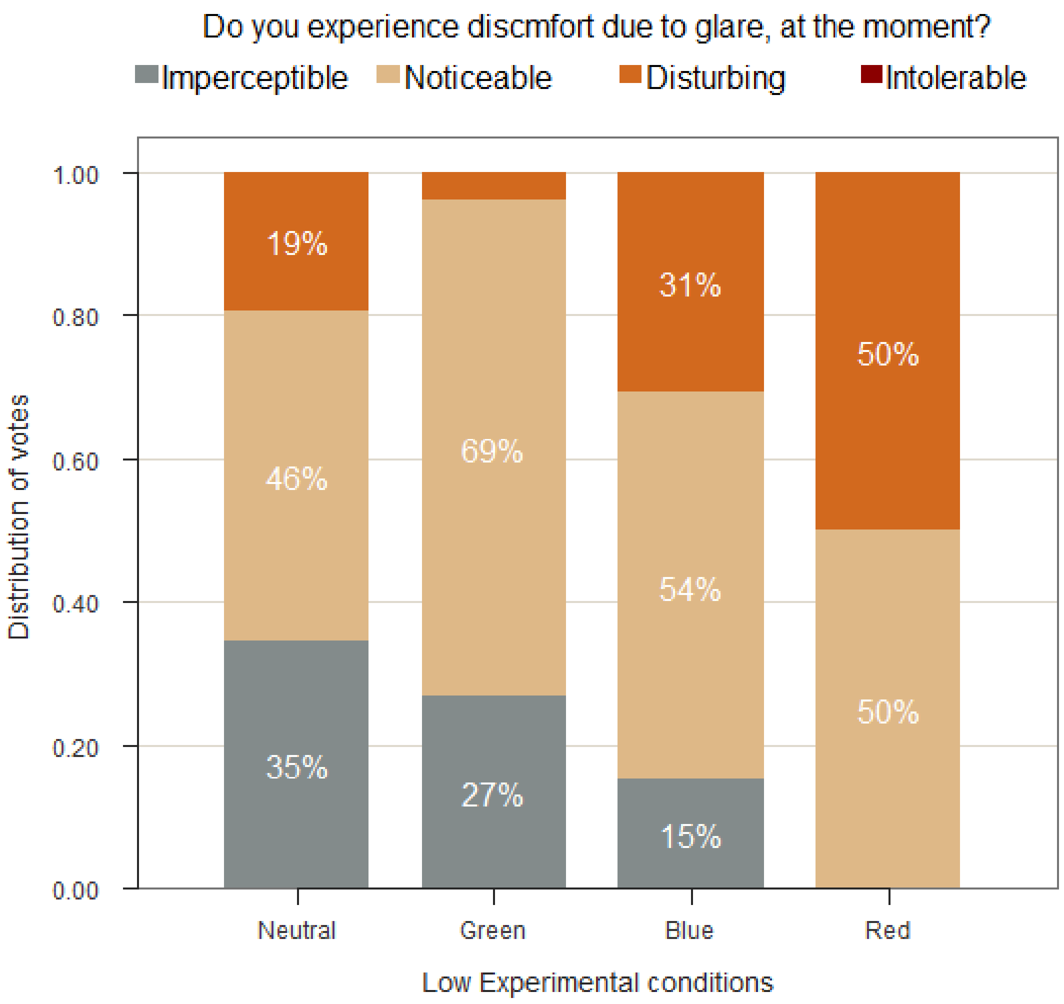


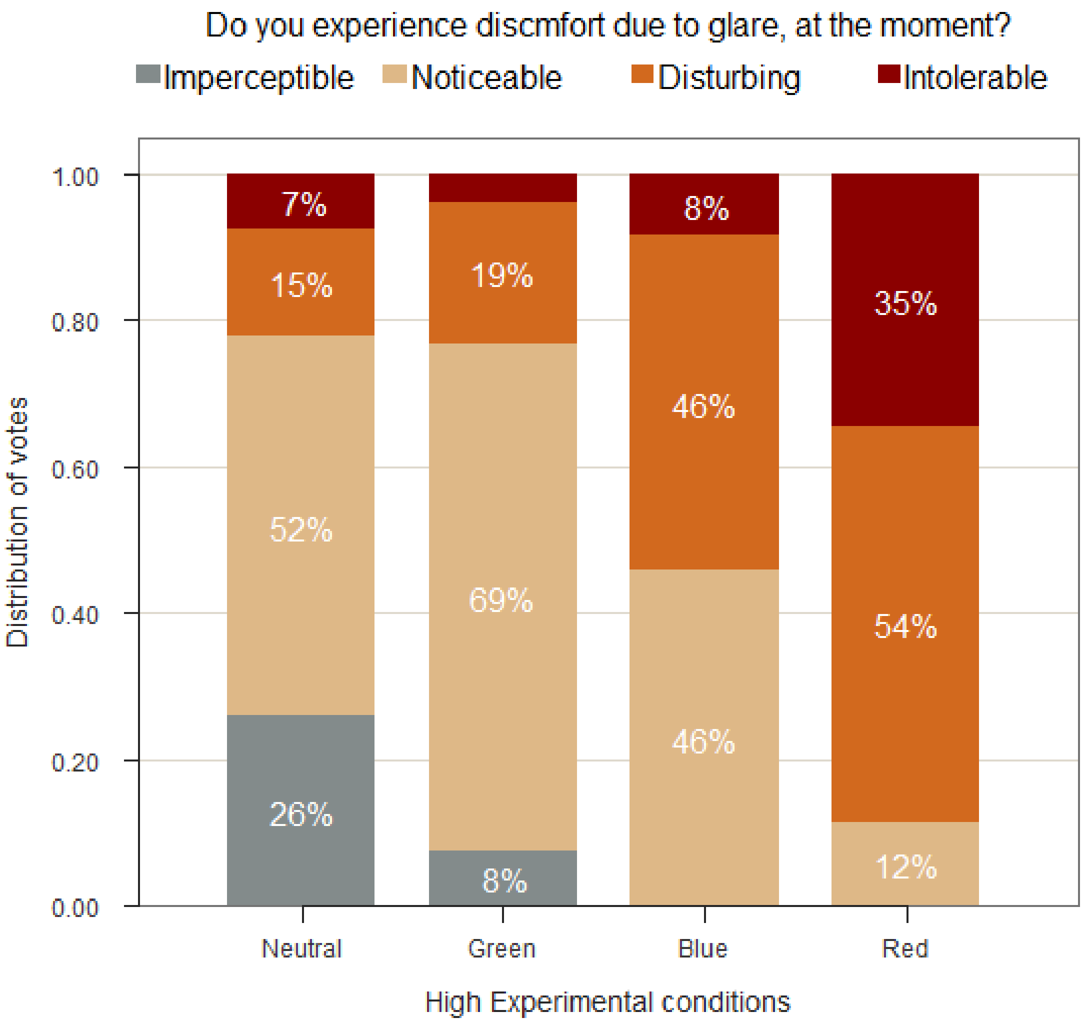
Low Transmittance conditions

High Transmittance conditions

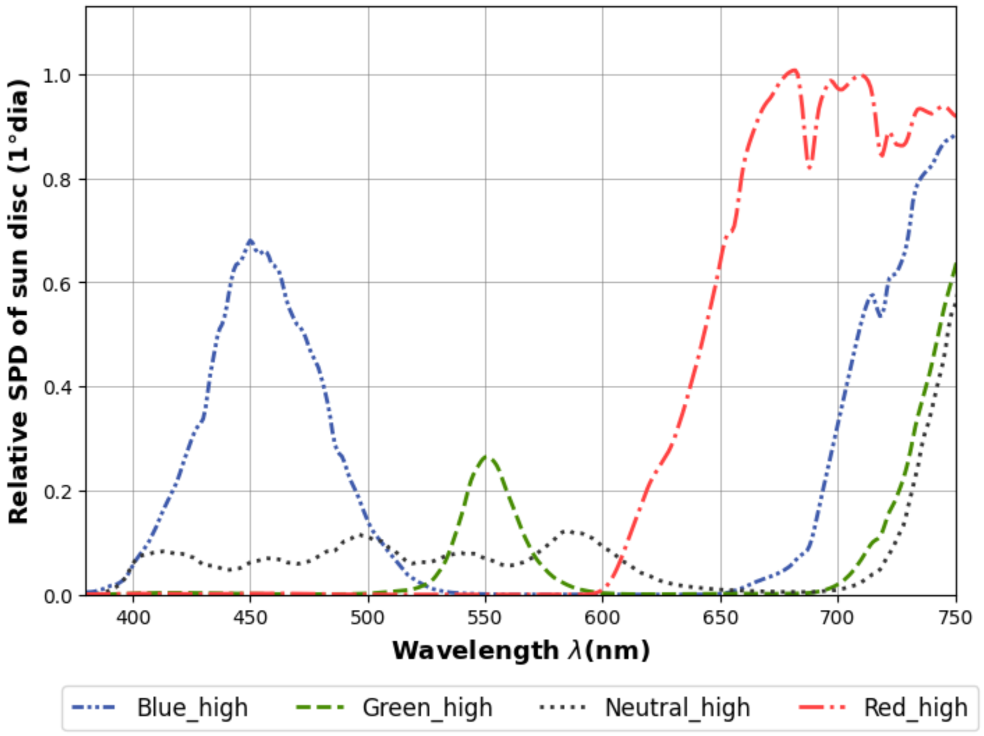
Mean Glare Metric Value

Subjective glare responses

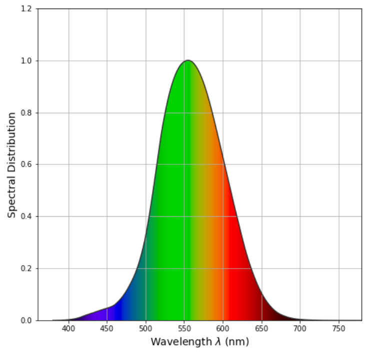


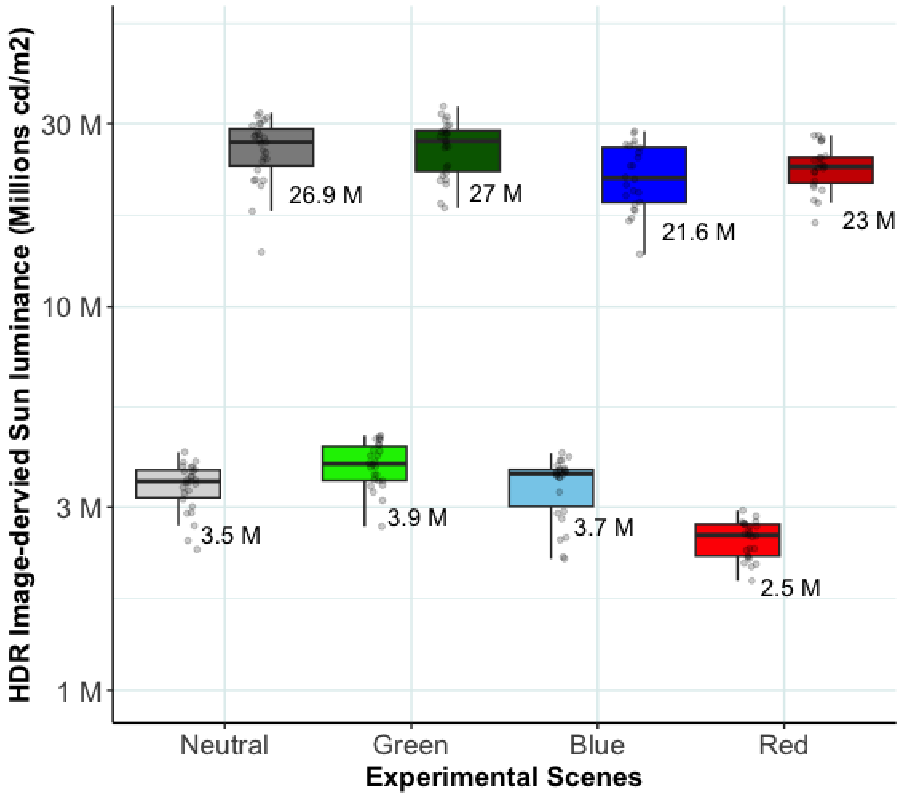


V(λ) Spectral Weighting doesn't work here



Spectral weighting function V(λ)

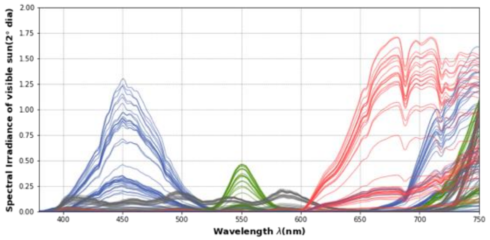




Getting sun (glare source) spectra

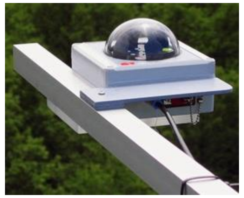
On-site Measurements | **Processing -- Output** | **Spectral Bandwidth**

Spectroradiometer

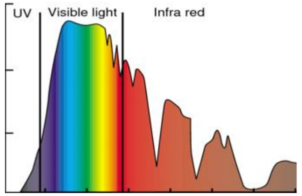


Measured Sun spectra

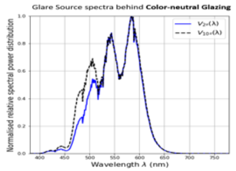
5nm
80 channels



Solar irradiance

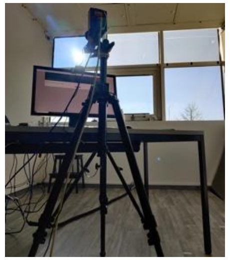


Reference solar spectra ASTM G173-03 scaled to match measured DNI



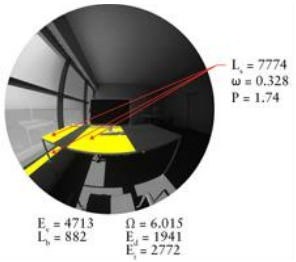
Integration of solar spectra to measured glazing spectral transmittance

1nm
400 channels



HDR capture of the test scenes

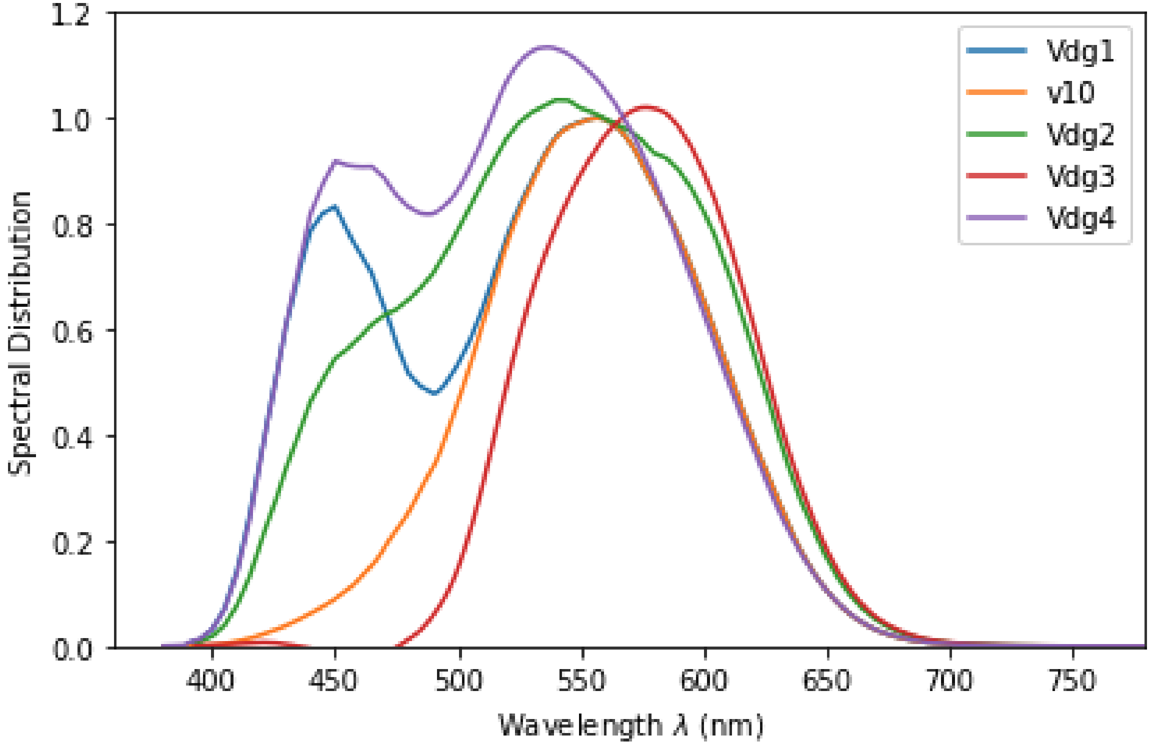
Color HDR images



Radiance: Using evalglare (zonal calculation), and rcomb

X, Y and Z camera filters
3 channels

Applying VDGs from Literature:
(V(λ) for Discomfort Glare)



None of these functions were able to accurately capture the subjective responses.

VDG_1 (λ)-10º = V10º (λ) + (0.75 S(λ))

VDG_2 (λ)-10º = {0.606*V'(λ)+ 0.157*[1.62L(λ)+M(λ)]} + 0.751*[L(λ)-M(λ)] + 0.109*[(1.62L(λ)+M(λ))-(-2.3452)*S(λ)]*

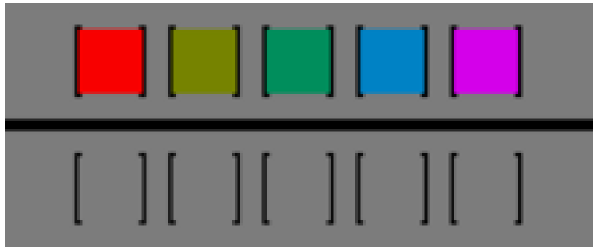
*VDG_3 = V(λ) + 0.578 * L(λ)-1.235*M(λ)+0.182S(λ)+ 0.02 * L(λ)+M(λ)-5.835S(λ)

VDG_4 = B(λ) = V(λ)+ 0.5 Mel(λ)+ 0.6S(λ)

Y. Yang, R.M. Luo, W. Huang, Assessing glare, Part 3: glare sources having different colours, Light. Res. Technol., 50 (2018),

Using Brightness instead of Luminance

Helmholtz-Kohlrausch effect (H-K effect)
Saturated colors appear to glow stronger compared to their equiluminant but less saturated counterparts



Applying Color Appearance Models (CAM)* that accounts for H-K effect

CAM15u (Withouck et al., 2015)
Based on unrelated stimuli

CAM18sl (Hermans et al., 2018)
Based on unrelated self-luminous stimuli

CIECAM16 (revised version by Hellwig et al., 2024)
General purpose CAM model recommended by CIE

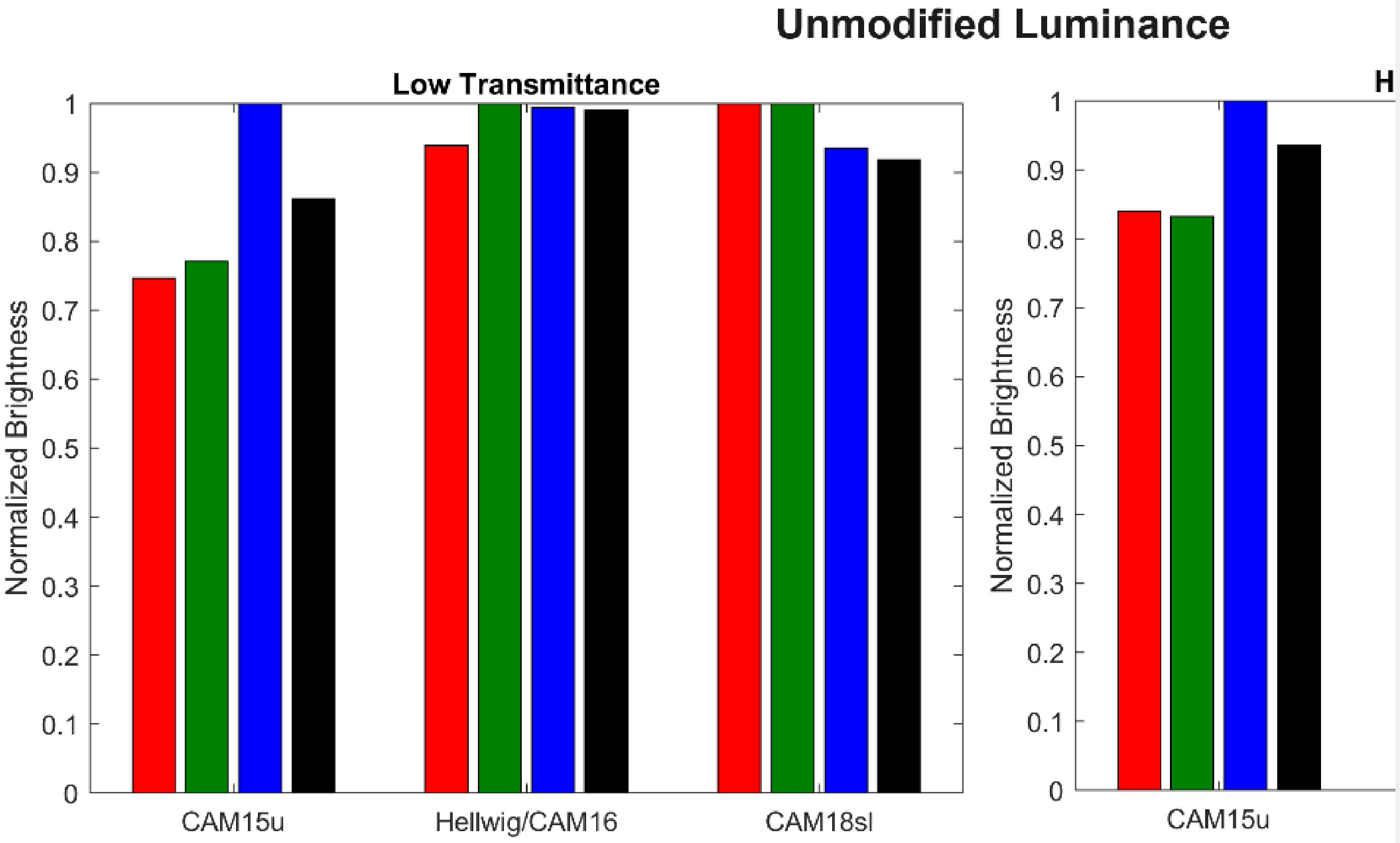
*CAM model predicts the appearance, represented by perceptual attributes of brightness, colorfulness, hue, saturation, and whiteness.

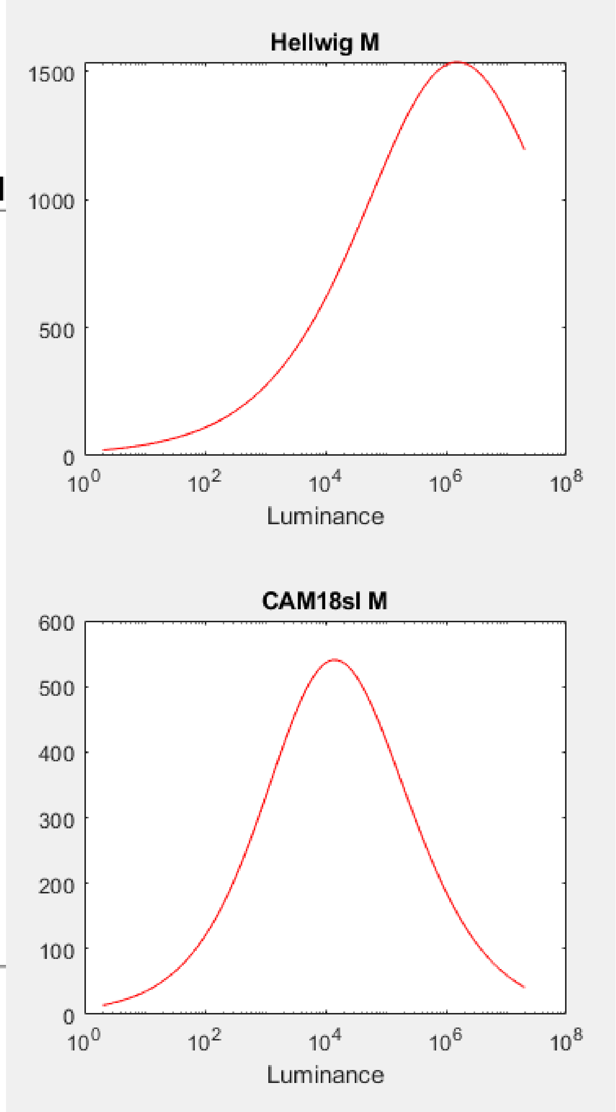
Ref: Kindlmann G, Reinhard E, and Creem S 2002 Face-based luminance matching for perceptual colormap generation, presented at IEEE Visualization 2002, Boston, Massachusetts, USA, 27 October -1 November, 2002.

Sneha Jain | Stanford University

Applying Brightness Models

Normalized Brightness of Experiment Scene compared across three models





Influence of color on discomfort glare, **Radiance Workshop 2024**

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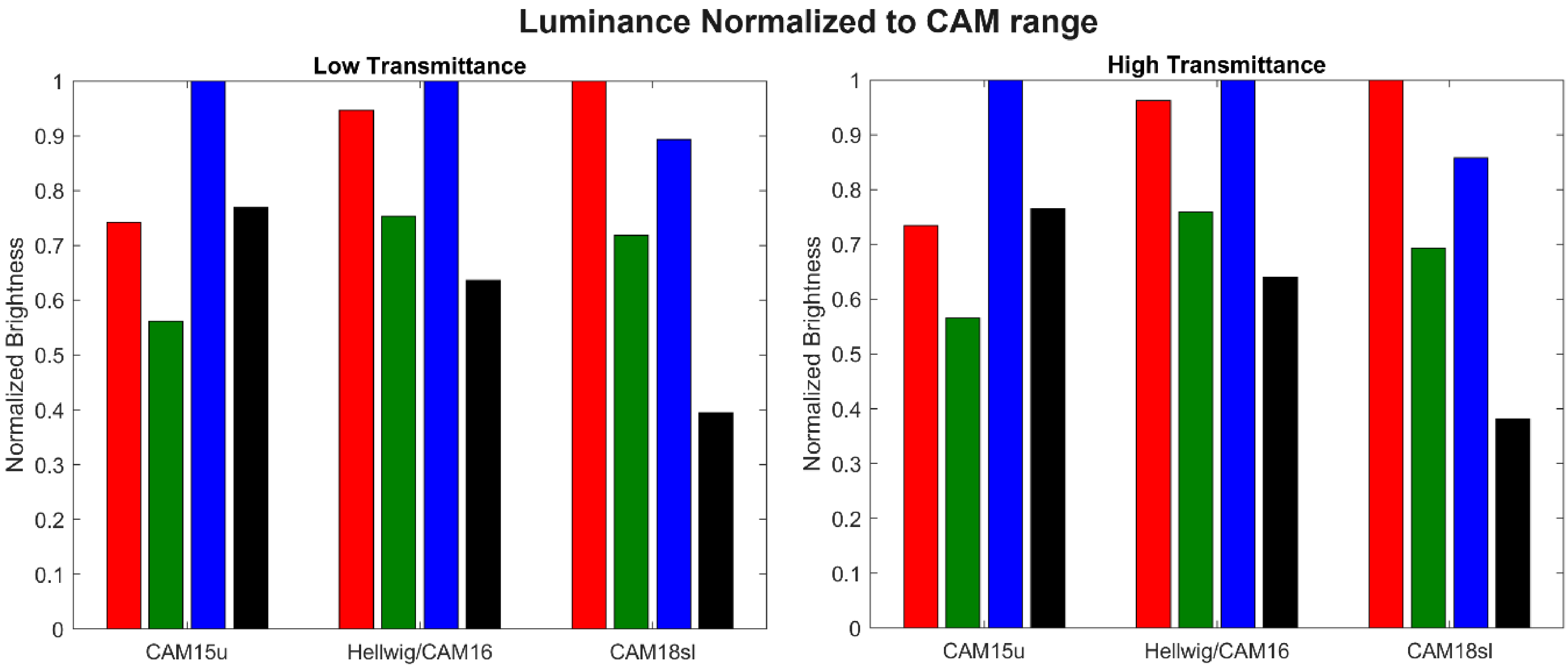

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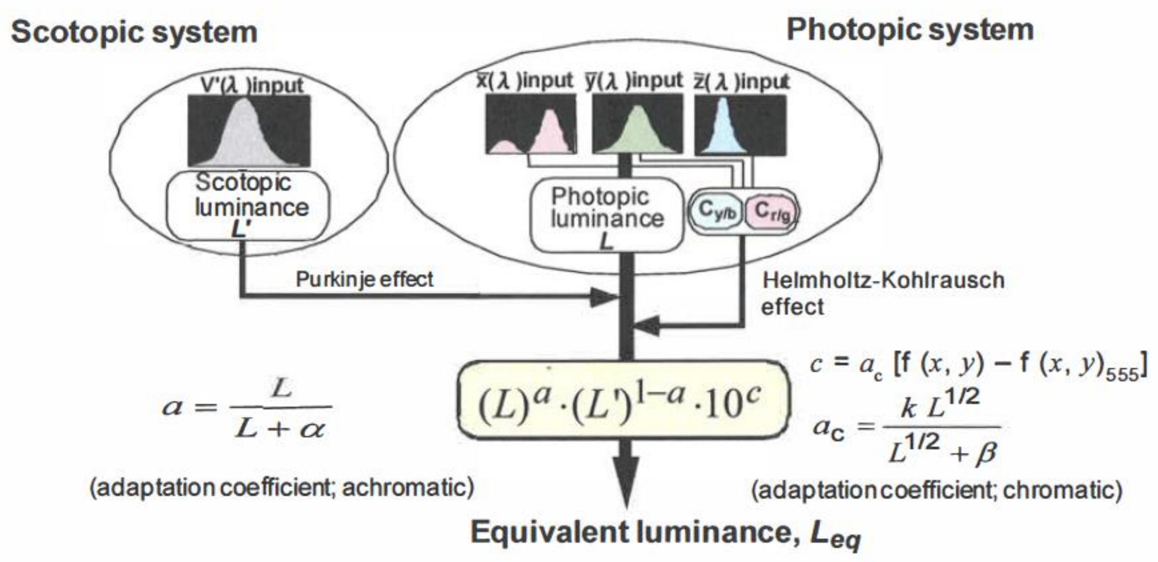
Applying CIE Supplementary Photometry

Equivalent Luminance as defined by CIE200:2011



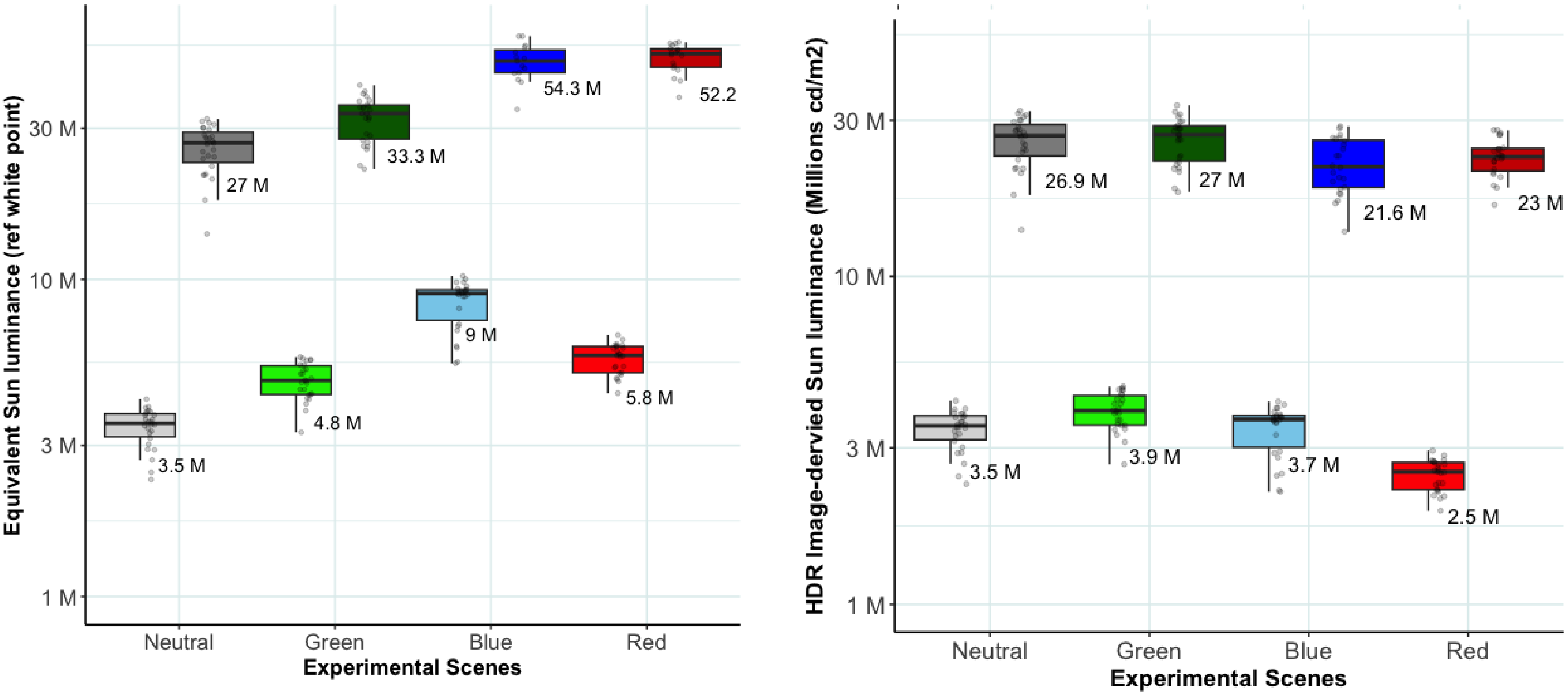
Parameters:

α = 0,05 cd·m^{-2}; β = 2,24 cd·m^{-2}; k = 1,3;

and f (x, y) is the chromatic contribution at a moderate photopic luminance level that is formulated by using only the chromaticity coordinates of the object or light, x and y, as follows (Nakano et al.,1999):

$$f(x,y) = 1/2 \log[-0{,}005\,4 - 0{,}21\,x + 0{,}77\,y + 1{,}44\,x^2 - 2{,}97\,x\,y + 1{,}59\,y^2 - 2{,}11\,(1 - x - y)\,y^2] - \log y \quad (5)$$

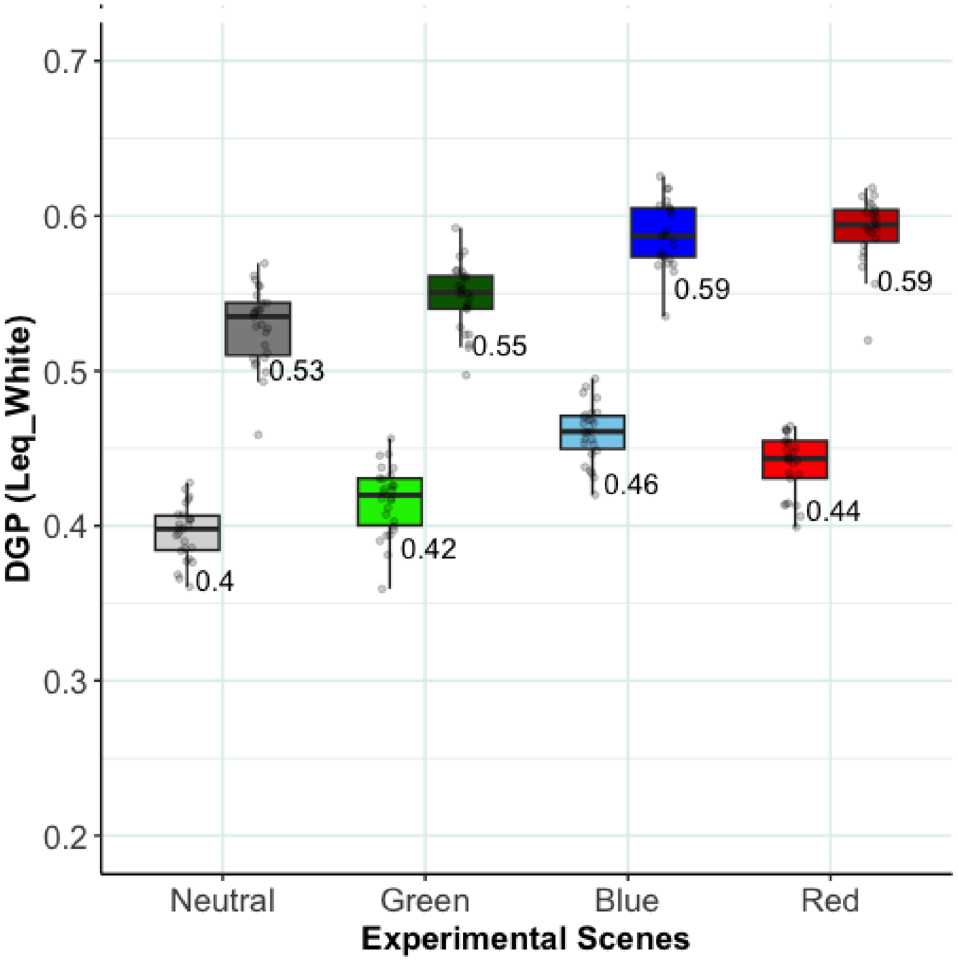
Comparing Equivalent luminance



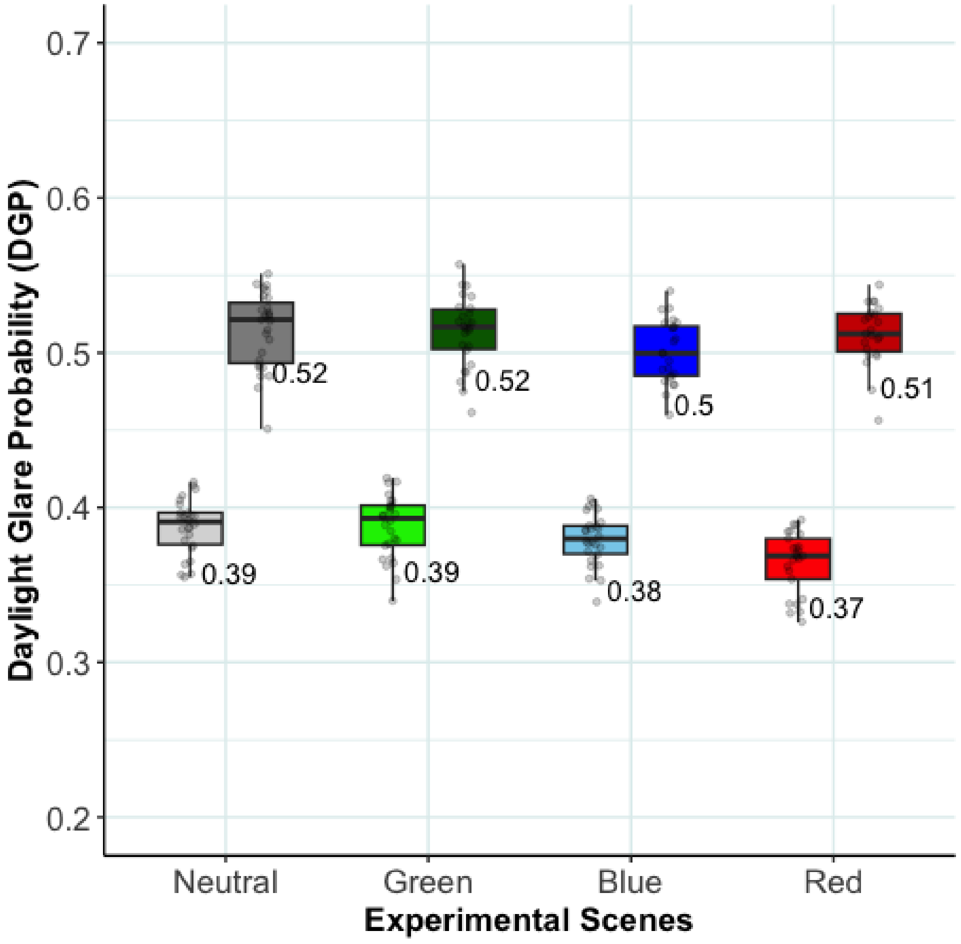
Modified

Original

Comparing modified DGP



Modified



Original

Summary

- Red glazing is most disturbing, closely followed by blue glazing in creating discomfort glare. While Color-neutral as well as the green glazing are more comfortable ones.
- Spectral weighting V(λ) is not suitable to characterize luminance (or glare) under brightly lit colored lighting conditions- need to consider H-K effect.
- Models which account for the H-K effect were better at predicting the perceived glare from colored sources where metrics based solely on luminance would fail.
- CAM models have a limited range of luminances over which they can accurately predict the H-K effect, more refinement is needed to predict glare of very high luminance stimuli.
- Additional extensive experiments are needed to validate, adjust, or develop a new glare model.

Acknowledgements

Stanford | Doerr
School of Sustainability

EPFL

Swiss National Science Foundation