



**Discomfort glare from daylight:
Influence of transmitted color and
eye's macular pigment**

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Bright Environments: Daylight in Sustainable Building Design,
ETH Zurich, 25 Aug 2023

Daylight in buildings?

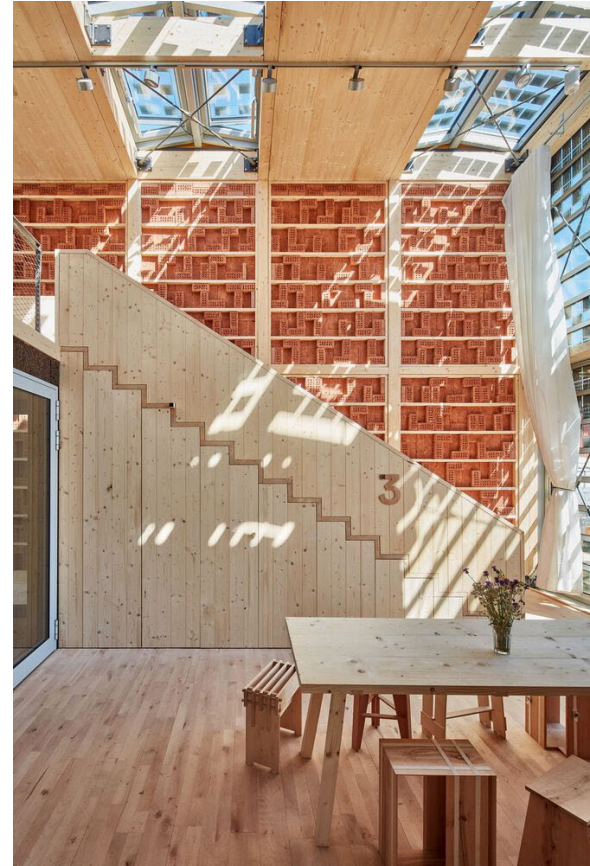
Energy efficiency

Comfort

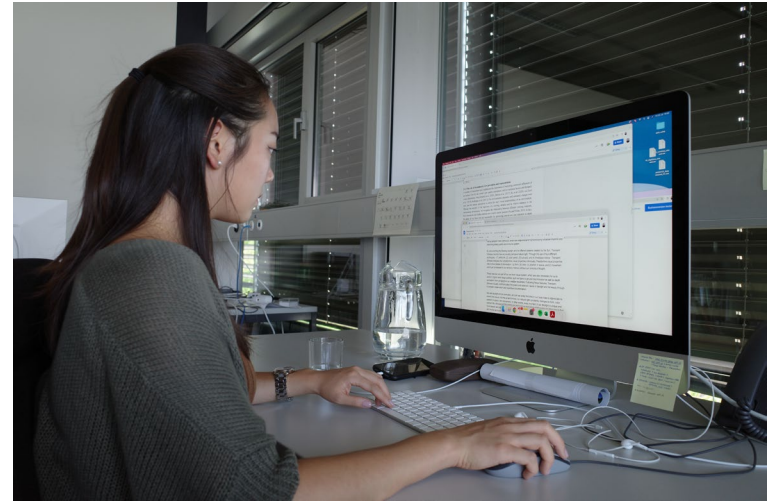
Health

Well-being

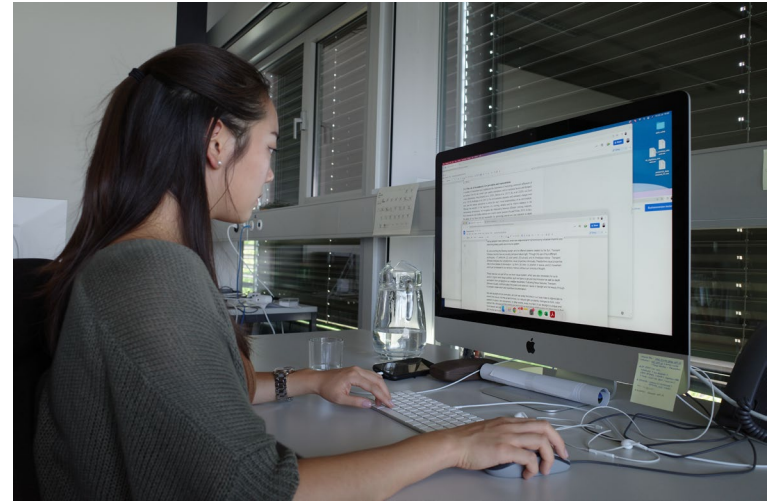
...



But also visual discomfort, *discomfort glare*



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Need to understand and quantify discomfort glare

Discomfort glare

Causes visual irritation or annoyance without necessarily impairing the vision [CIE, 1983].

■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment



How are the discomfort glare models derived?

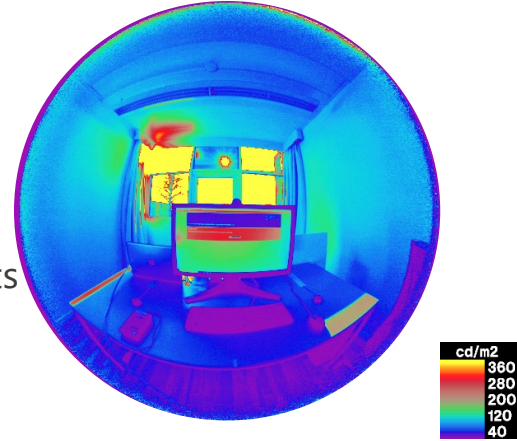


User assessment survey

HDR imaging



Photometrics measurements



Physical properties of the scene

How do you rate glare in the field of view?

- Imperceptible Noticeable Disturbing Intolerable

Limitations!

$$DGP = a \cdot E_v + b \cdot \log\left(1 + \sum \frac{L^{\exp 1 \omega}}{E_v^{\exp 2} p^{\exp 3}}\right) + c$$

Discomfort glare models

Limitations



Inability of models in capturing inter-individual variability



Goals

Unveiling physiological rationale behind discomfort glare.



Inability of models in capturing certain lighting environments



Extending the applicability of models in such scenarios, **e.g. scenes with colored glare sources**

Glare perception under colored daylight

■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment



Blue Electrochromic glazing



BIPV colored transparent façade

Research questions

Ocular Characteristics

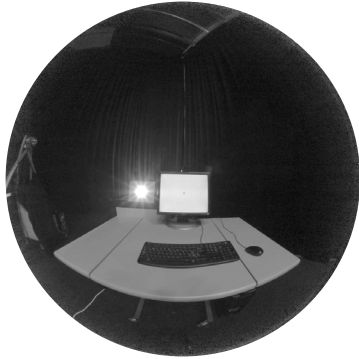
Is there an influence of eye physiology on discomfort glare from daylight?

Environmental Characteristics

Is there an influence of transmitted color on discomfort glare from daylight?

User studies

Experiment 0



Electric light

Pilot test

Experiment 1



Blue EC glazing

Electrochromic glazing



Glare protection

Laboratory of Nanostructured materials for solar energy, EPFL

Experiment 2



Color-neutral glazing

Eye physiology

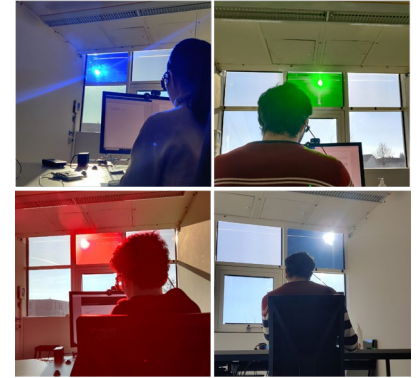


Glare sensitivity



Hôpital ophtalmique Jules-Gonin
Service universitaire d'ophtalmologie
Fondation Asile des aveugles

Experiment 3



RGB and neutral glazing

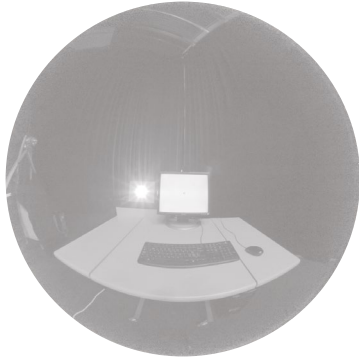
Color of sunlight



Glare sensitivity

User studies

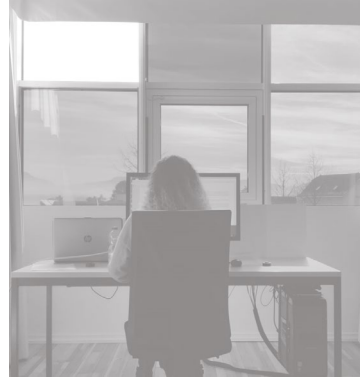
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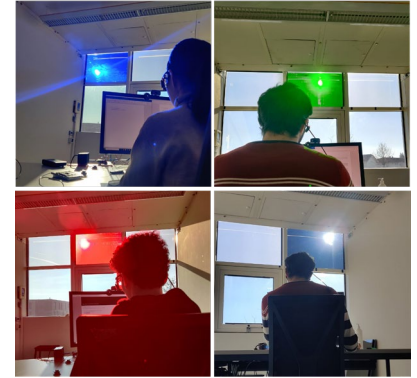


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RGB and neutral glazing

Color of sunlight



Glare sensitivity

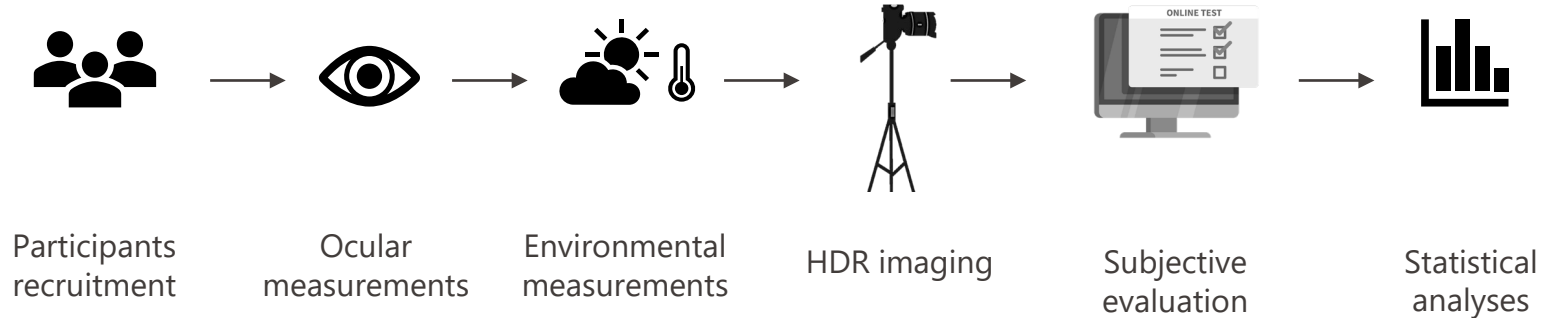
Method

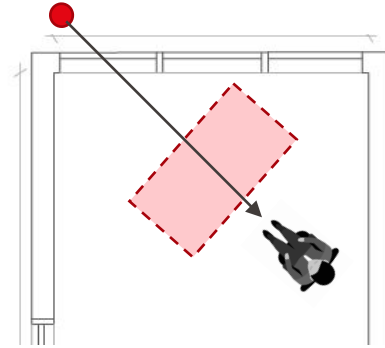
- **Psychophysiological approach**

Measuring the relationship between perception (discomfort glare) and physiological processes (filtering by macular pigment)

- **Psychophysical approach**

Measuring the relationship between stimuli (colored sun) and perception (discomfort glare)



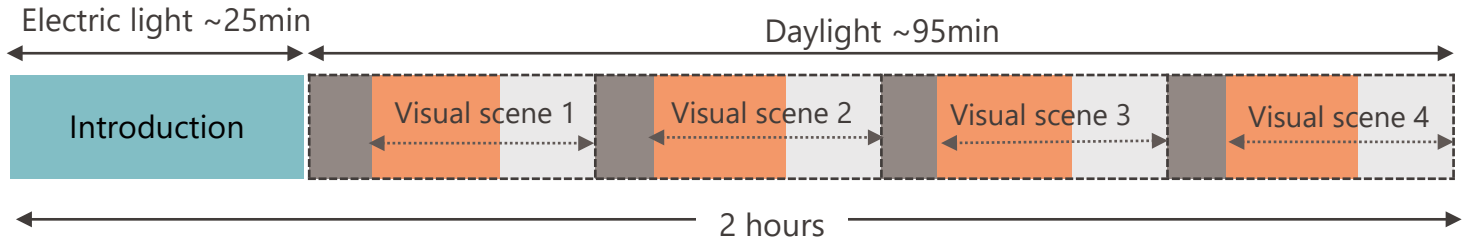


HDR camera with
illuminance sensor



Test room from outside

Test Procedure



Break ~ 5min

Task ~ 12mins

Comfort Q&A
~12mins

Randomization

- Participant relax with eye mask and headphones
 - Researcher does measurements and change of glazing
- Typing on the screen to adapt to the visual scene
- Participant rates visual and thermal comfort of the scene

Is there an influence of macular pigment density on discomfort glare from daylight?



Design of experiment

Participants	55 (18-31 years)
Study design	Between subject
Response variable	Glare sensitivity
Independent variable	Macular pigment Optical Density (MPOD)

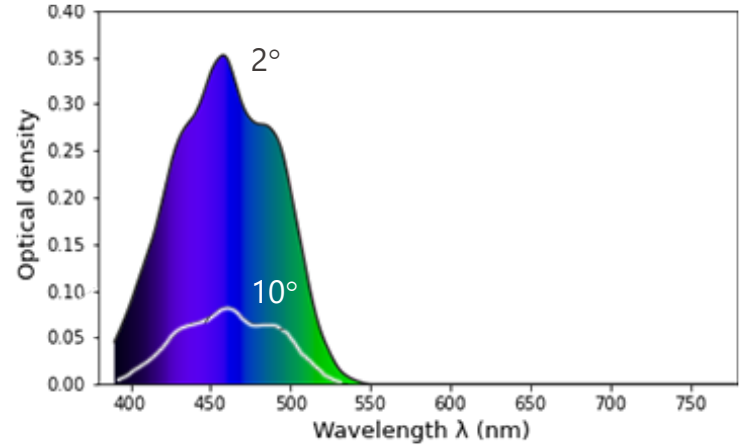
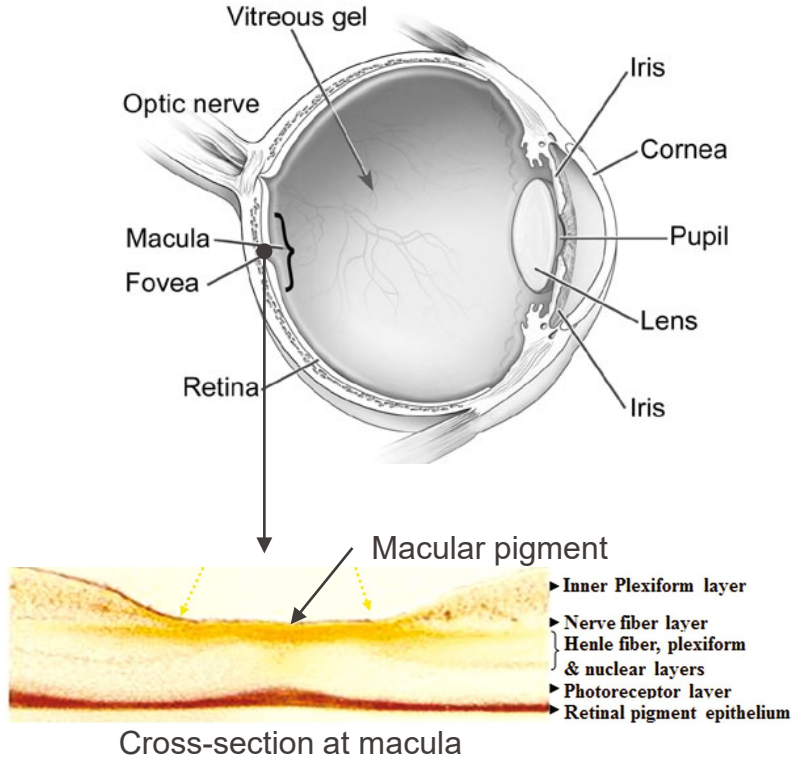


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Macular pigment

■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment



Absorption spectrum of macular pigment and optical density for a 2° and 10° field size

Experimental conditions

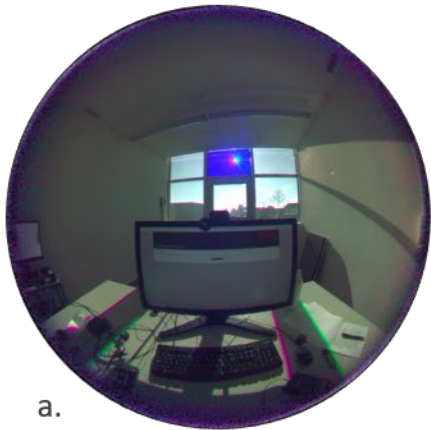


Color-neutral glazing
N=55
Four experimental conditions

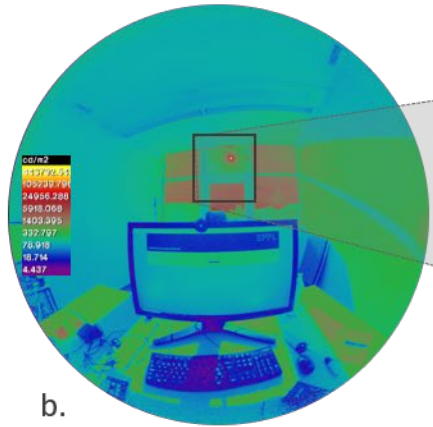


Saturated Blue-tinted glazing
N=55
Two experimental conditions

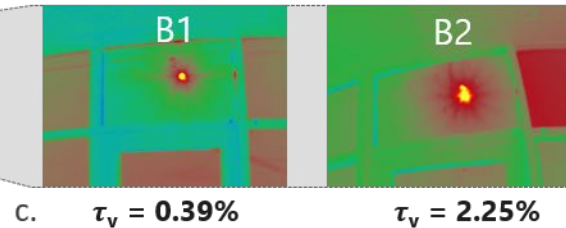
Experiment II Blue-colored glazing



a.



b.



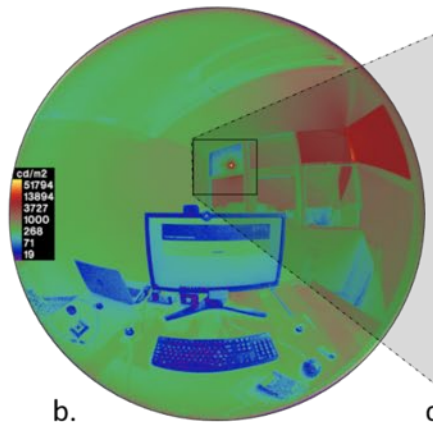
c.

 $\tau_v = 0.39\%$ $\tau_v = 2.25\%$

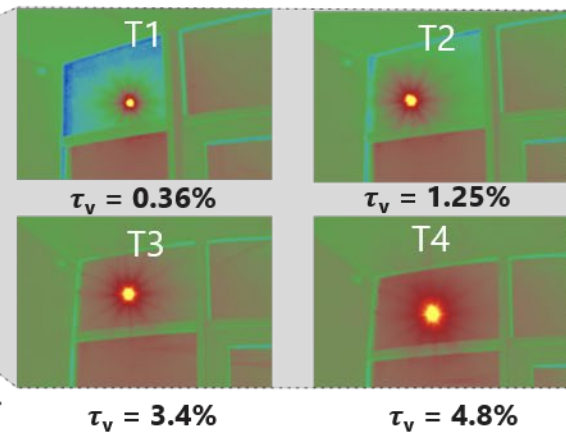
Experiment I Color-neutral glazing



a.



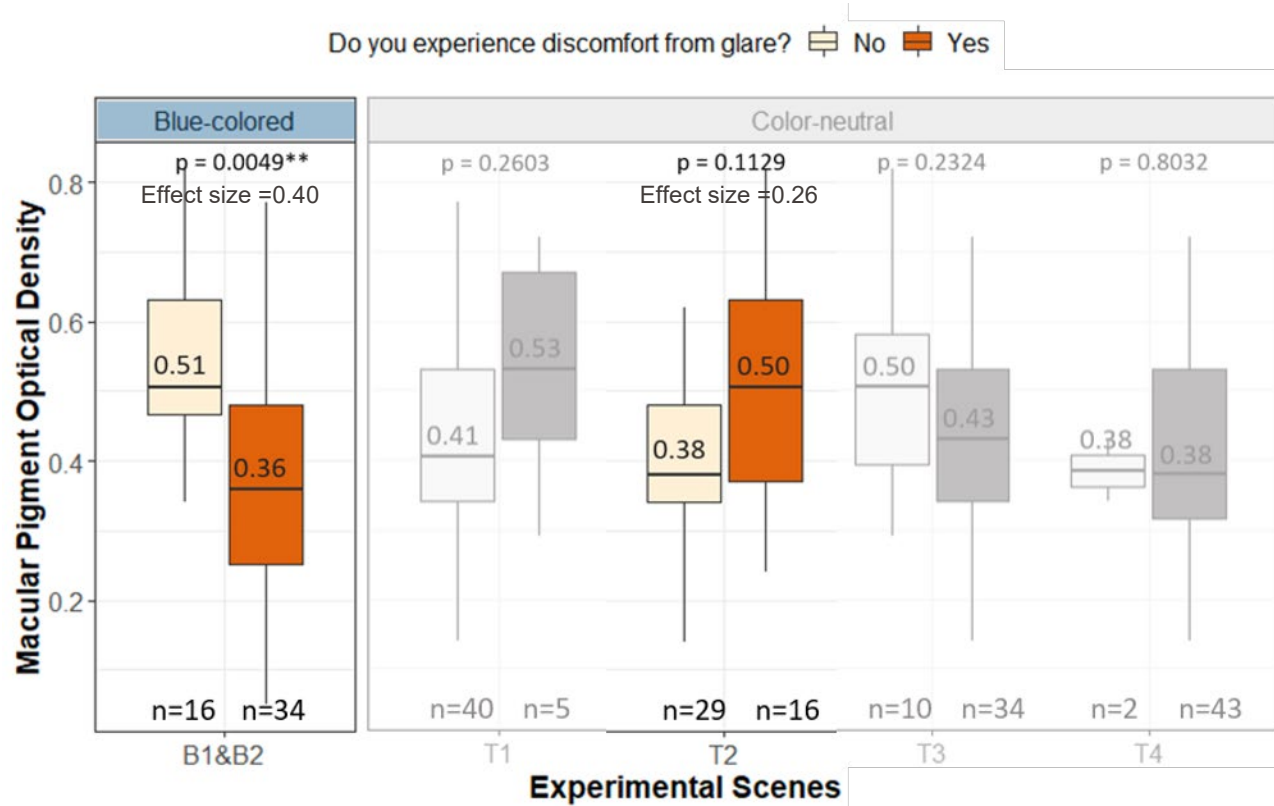
b.



c.

 $\tau_v = 0.36\%$ $\tau_v = 1.25\%$ $\tau_v = 3.4\%$ $\tau_v = 4.8\%$

Influence of MPOD on glare perception



Key findings

- No influence of MPOD in neutral indoor daylight scenarios with typically off-fovea light source.
- Strong influence of MPOD under blue colored sun disc in the near peripheral field.
- Participants with higher MPOD were better able to tolerate the glare under blue glazing.

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

Response variable Discomfort glare perception

Independent variable
 Glare source colour (*within subject variable*)
 Glare source luminance (*between subject variable*)

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



Design of experiment

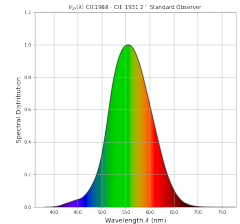
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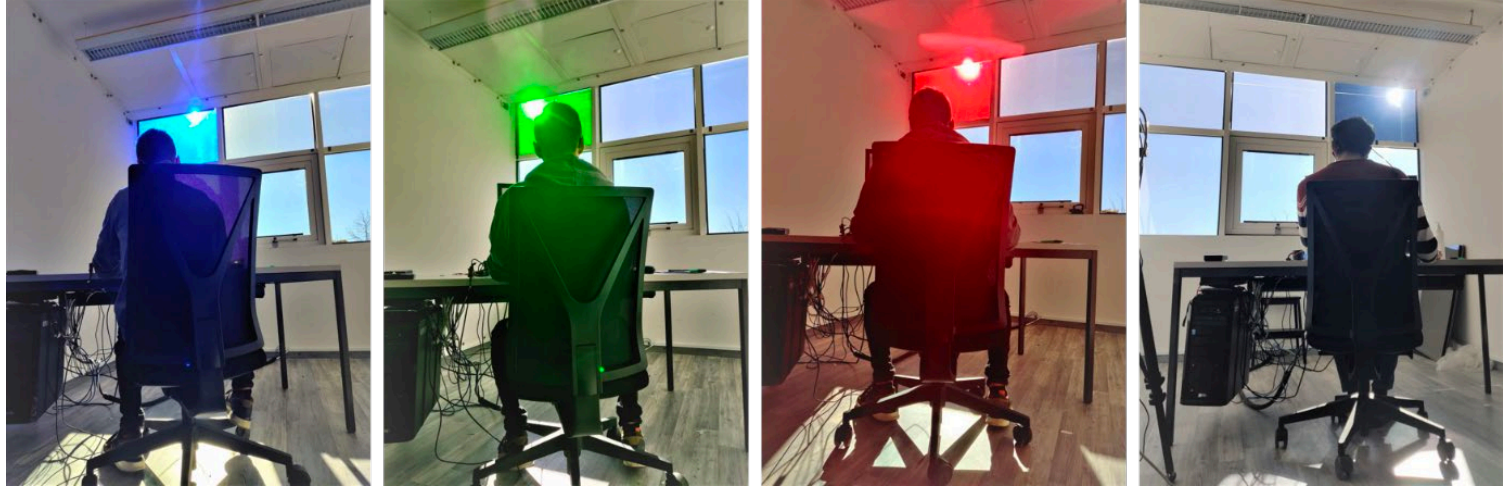
Response variable Discomfort glare perception









Independent variable
 Glare source colour (*within subject variable*)
 Glare source luminance (*between subject variable*)

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

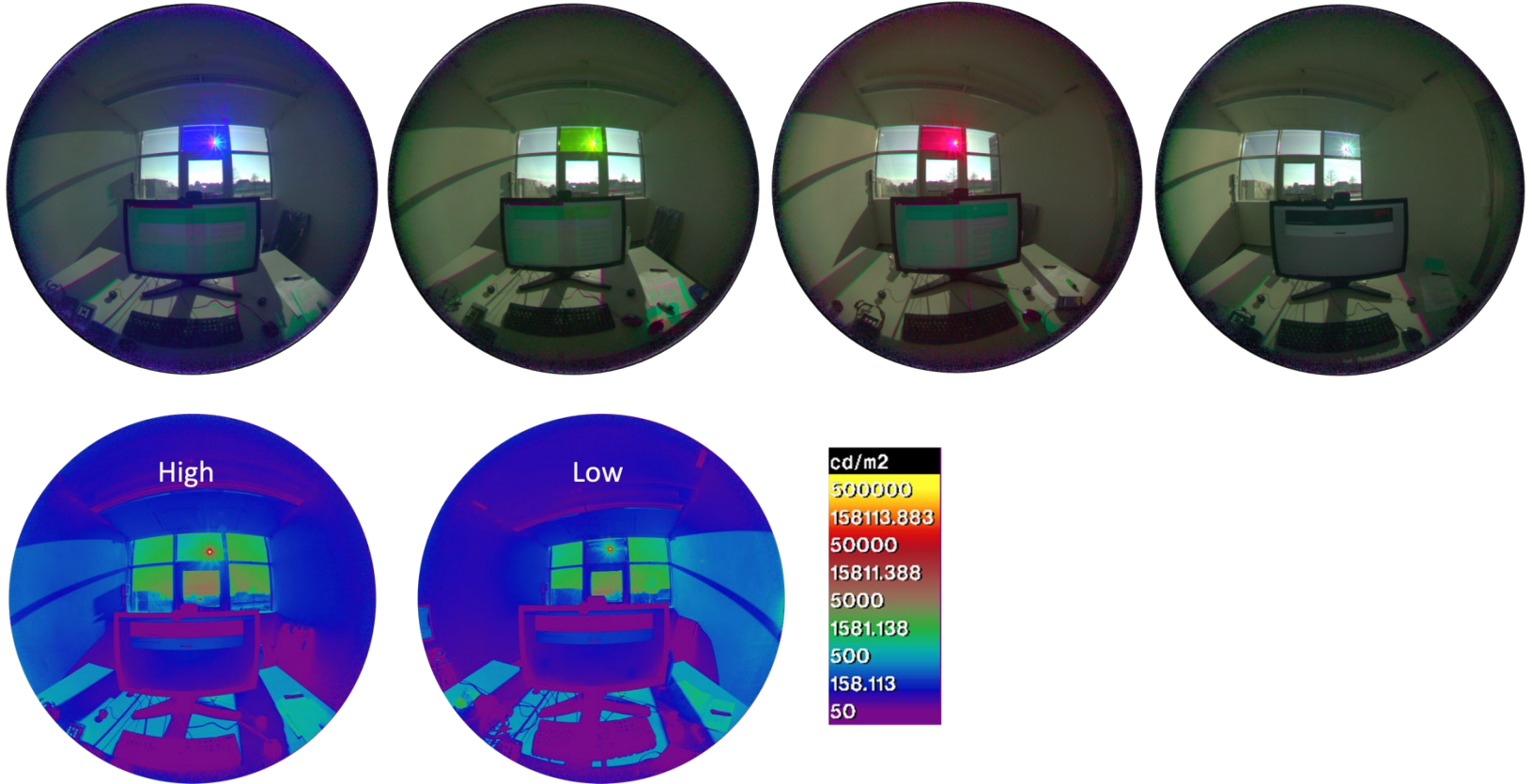


■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment



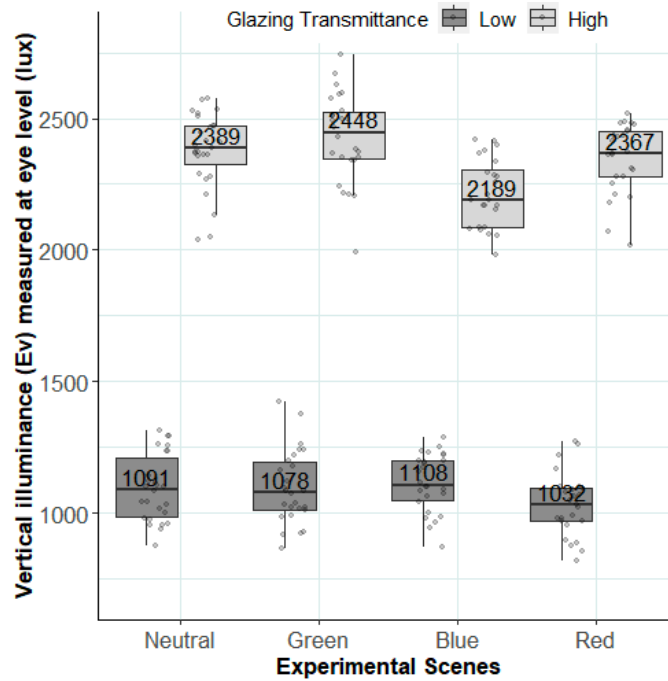
	Blue	Green	Red	Colour-neutral	No. of participants
Transmittance high (~2.5%)					28
Transmittance low (~0.37%)					28

HDR luminance imaging



Results: Maintaining similar daylight levels

■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment



Measured Vertical illuminance

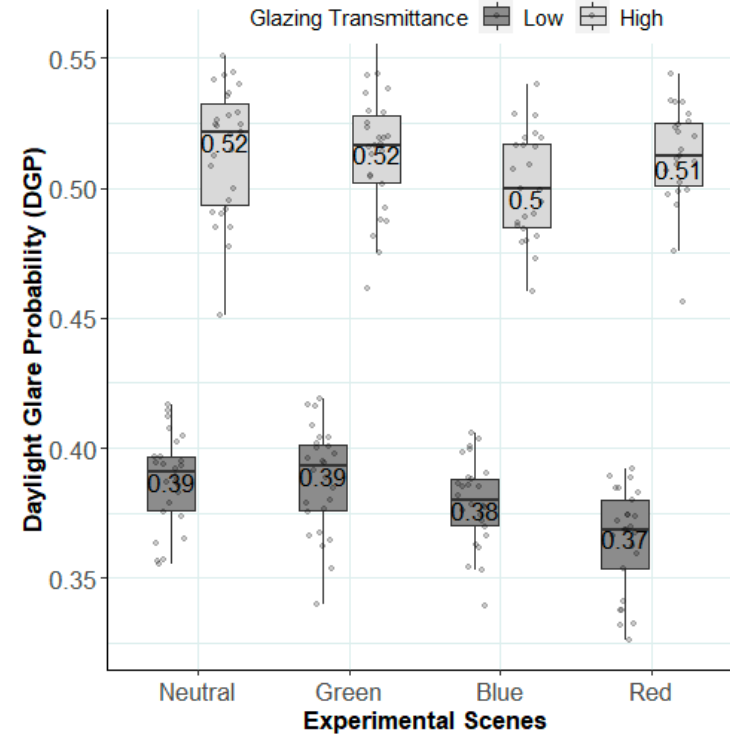
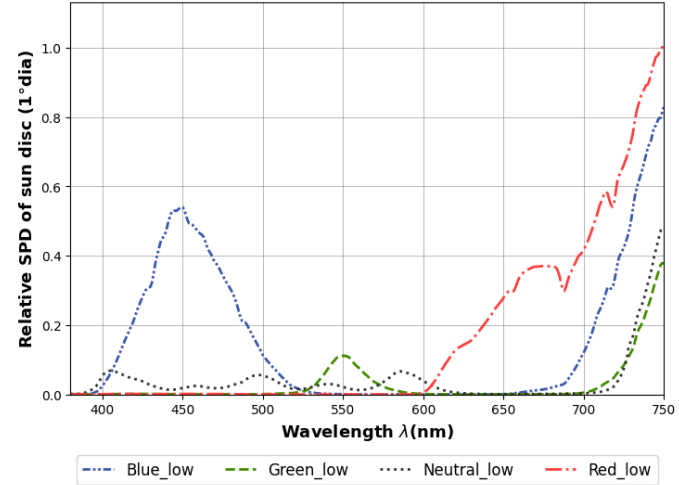
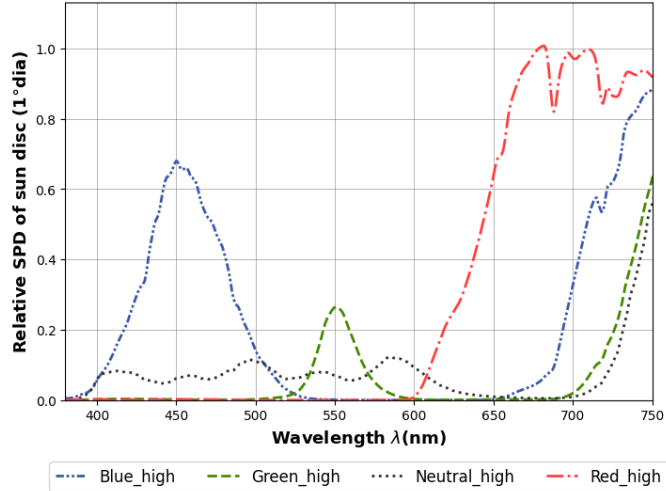


Image derived glare metric values

Mean relative SPD of sun disc

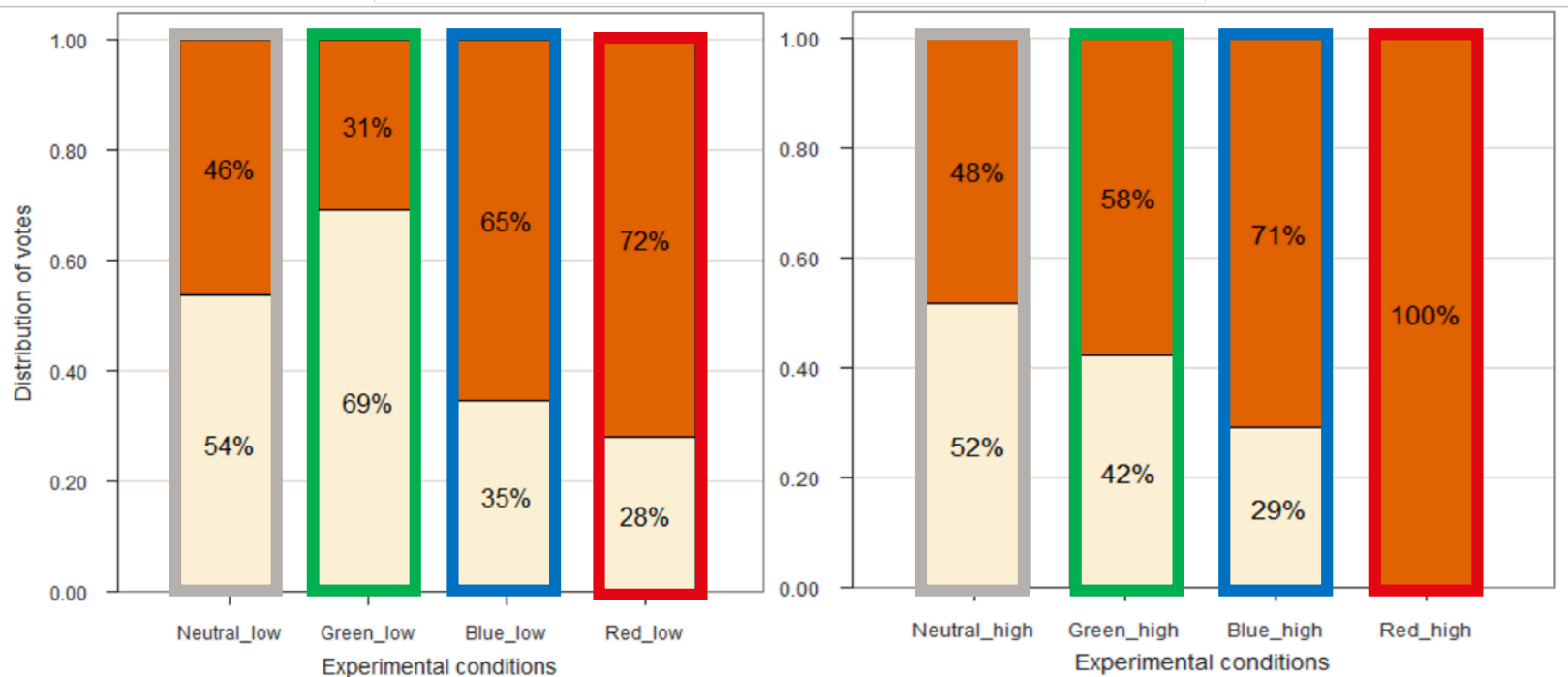
■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment



Subjective discomfort glare rating

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

No Yes



Influence of color of daylight on glare perception

■ Discomfort glare from daylight: influence of transmitted color and eye's macular pigment

Group1	Group2	p-value (Bonferroni adjusted)	Effect size	Magnitude
Neutral	Green	1	0.05	small
Neutral	Blue	0.012	0.30	moderate
Neutral	Red	1.99E-06	0.53	large
Green	Blue	0.01	0.31	moderate
Green	Red	1.57E-06	0.57	large
Blue	Red	0.065	0.26	small

Key findings

- Red glazing is most disturbing, closely followed by blue glazing in creating discomfort glare.
- Color-neutral as well as the green glazing are more comfortable ones.
- $V(\lambda)$ is not suitable to characterize luminance under brightly lit colored daylight conditions.
- Spectral weighting in glare models need modifications for such conditions.
- Smart glazing technology should be developed to have neutral tints for better glare protection.

Overall Conclusions

Ocular Characteristics

Is there an influence of macular pigments on discomfort glare from daylight?

Research Question. 1



No influence of macular pigment on glare in neutral daylit conditions but strong influence under blue-colored glare source.

Environmental Characteristics

Is there an influence of the color of daylight on discomfort glare from daylight?

Research Question. 2



Strong influence of color of daylight transmitted through colored glazing on discomfort glare.

Acknowledgements

The EPFL logo is rendered in a large, bold, red, sans-serif font.

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Thank you for listening 😊