Comparison of discomfort glare metrics for small, high-luminance light sources in outdoor nighttime environments

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Glare

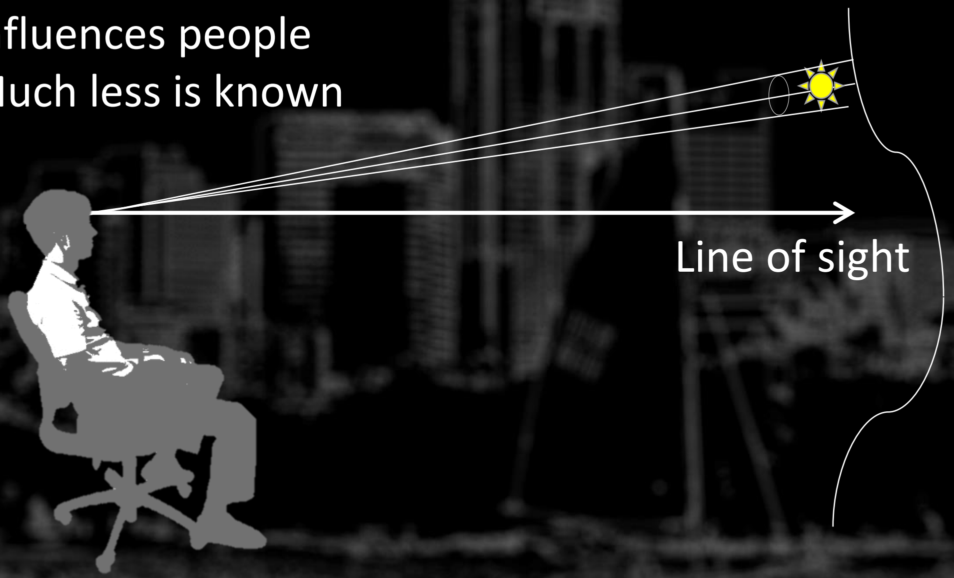
A condition of vision in which there is a feeling of discomfort and/or a reduction in visual performance. It occurs when the luminance or luminance ratios are too high.

Disability Glare

- Reduces visibility due to scattered light in the eye
- Depends on the quantity of light falling on the eye, and is largely independent of the source luminance
- Influences task performance
- Well understood

Discomfort glare (DG)

- Causes “a sensation of annoyance or pain caused by high luminances in the field of view” without necessarily impairing vision
- Determined mainly by the luminance of the source
- Influences people
- Much less is known



Outcome:
Discomfort glare is the focus of this research

Outdoor nighttime environments

- Low background luminances;
- High contrasts between lit and unlit surfaces;
- Small light sources in the field of view;
- High-luminance LEDs are becoming popular in outdoors;
- A single LED chip: $19*10^6$ cd/m^2 (Tyukhova and Waters 2014);
- The potential to cause more glare than conventional systems.

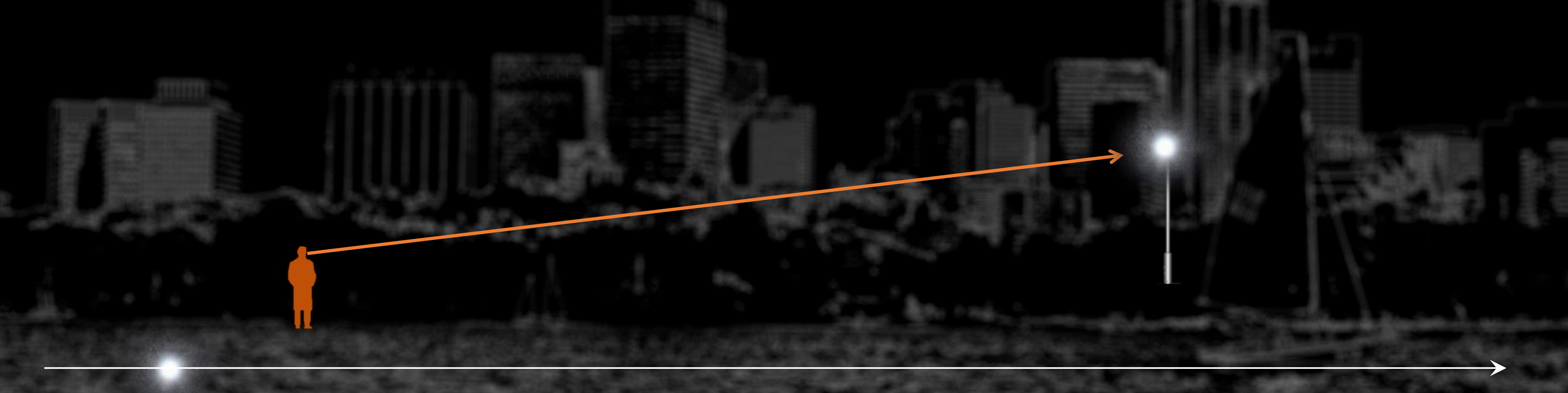
St. Petersburg, Russia

San Francisco, CA

Why do we care?

- We all have experienced discomfort glare before;
- It has been studied for decades;
- The cause is still not known;
- There's a high demand for predicting and eliminating glare;
- To quantify discomfort glare accurately for a given application;

- **To facilitate the calculation of discomfort glare – fill the existing research gaps.**



Research gaps

- Multiple metrics are available;
- However, discomfort glare is rarely calculated;
- Metrics have limitations.

Outdoor sports and area lighting metric
CIE 112-1994

Motor vehicle metric
Schmidt-Clausen and Bindels 1974

Outdoor lighting installations
Bullough et al. 2008, 2011

Unified Glare Rating small source extension
CIE 146,147-2002

Discomfort glare in outdoor sports and area lighting (CIE-112 1994)

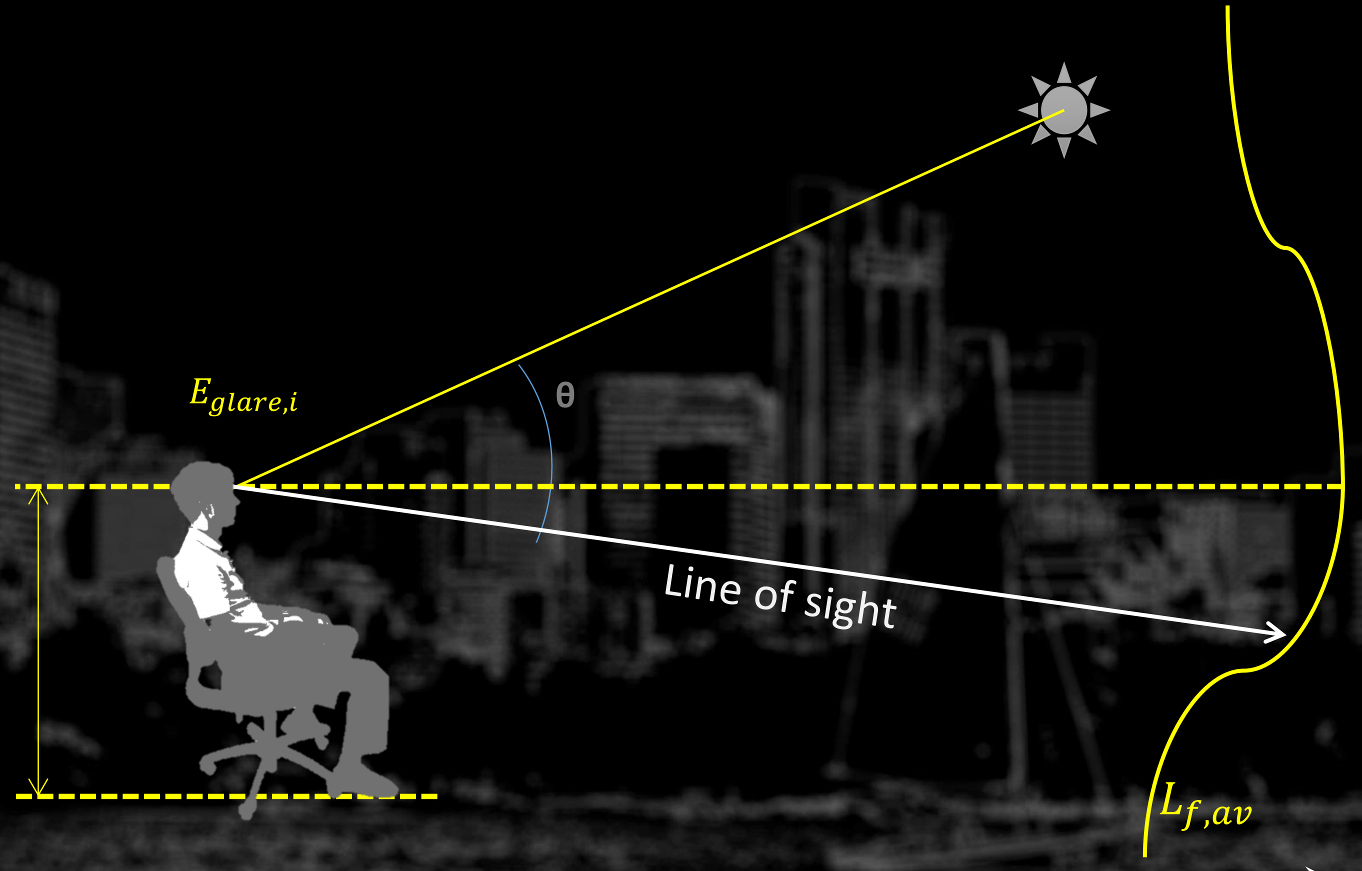
$$GR = 27 + 24\log\left(\frac{L_{vl}}{L_{ve}^{0.9}}\right)$$

$$L_{vl} = 10\sum_{i=1}^{n}\frac{E_{glare,i}}{\theta_i^2}$$

$$L_{ve} = 0.035 \times L_{f,av}$$

$$L_{f,av} = E_{hor,av} \times \frac{\rho}{\pi}$$

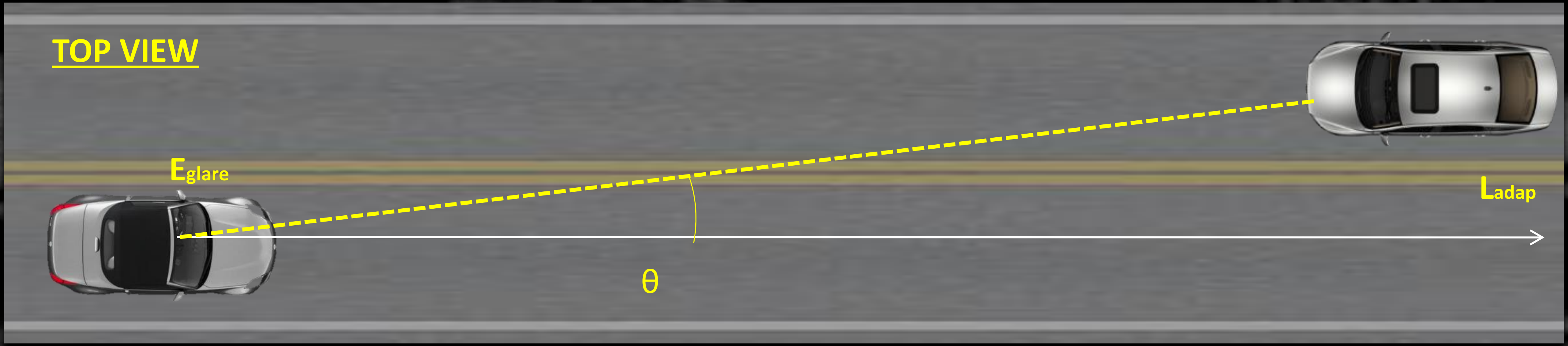
glare control mark *GF*		glare rating *GR*
1	unbearable	90
2		80
3	disturbing	70
4		60
5	just admissible	50
6		40
7	noticeable	30
8		20
9	unnoticeable	10



Discomfort glare in motor vehicle lighting (Schmidt-Clausen et al. 1974)

$$W = 5 - 2\log \frac{E_{glare}}{0.003\left[1 + \sqrt{\frac{L_{adap}}{0.04}}\right] \cdot \theta^{0.46}}$$

Assessment	Glare rating W
Unbearable	1 2
Disturbing	3 4
Just admissible	5 6
Acceptable	7 8
Noticeable	9



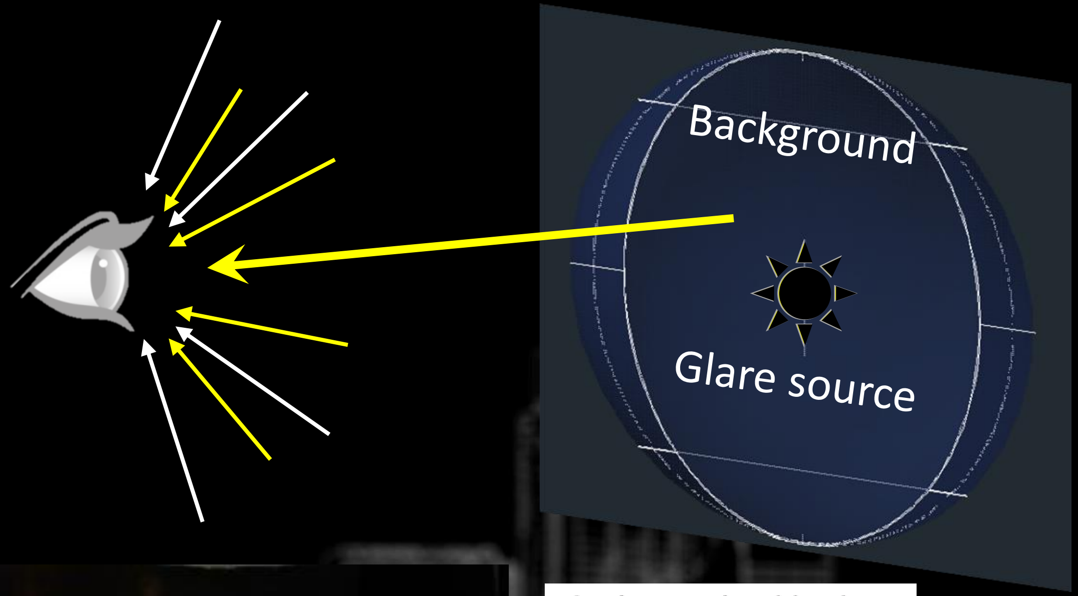
Outdoor discomfort glare models (Bullough et al. 2008 and 2011)

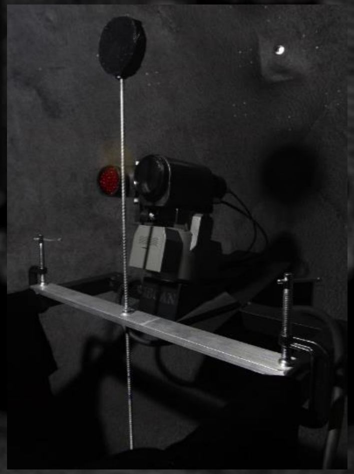
$DB = 6.6 - 6.4\log DG$

For a glare source of 0.3° or more in angular size:

$DB = 6.6\log DG + 1.4\log(50{,}000/L)$

$$DG = \log(E_l + E_s) + 0.6\log\left(\frac{E_l}{E_s}\right) - 0.5log(E_a)$$

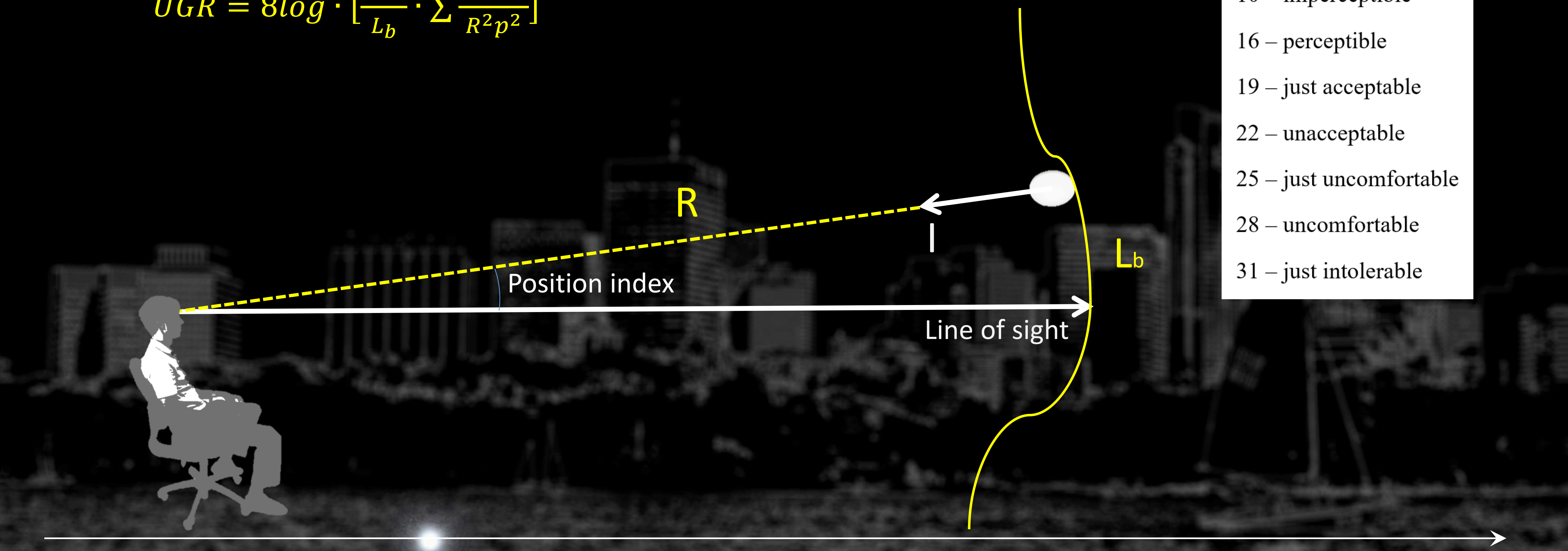




9	just noticeable glare
8	
7	satisfactory
6	
5	just permissible
4	
3	disturbing
2	
1	unbearable

UGR extension for small glare sources (CIE-146,147 2002)

$$UGR = 8log \cdot [\frac{0.25}{L_b} \cdot \sum \frac{200 \cdot I^2}{R^2 p^2}]$$



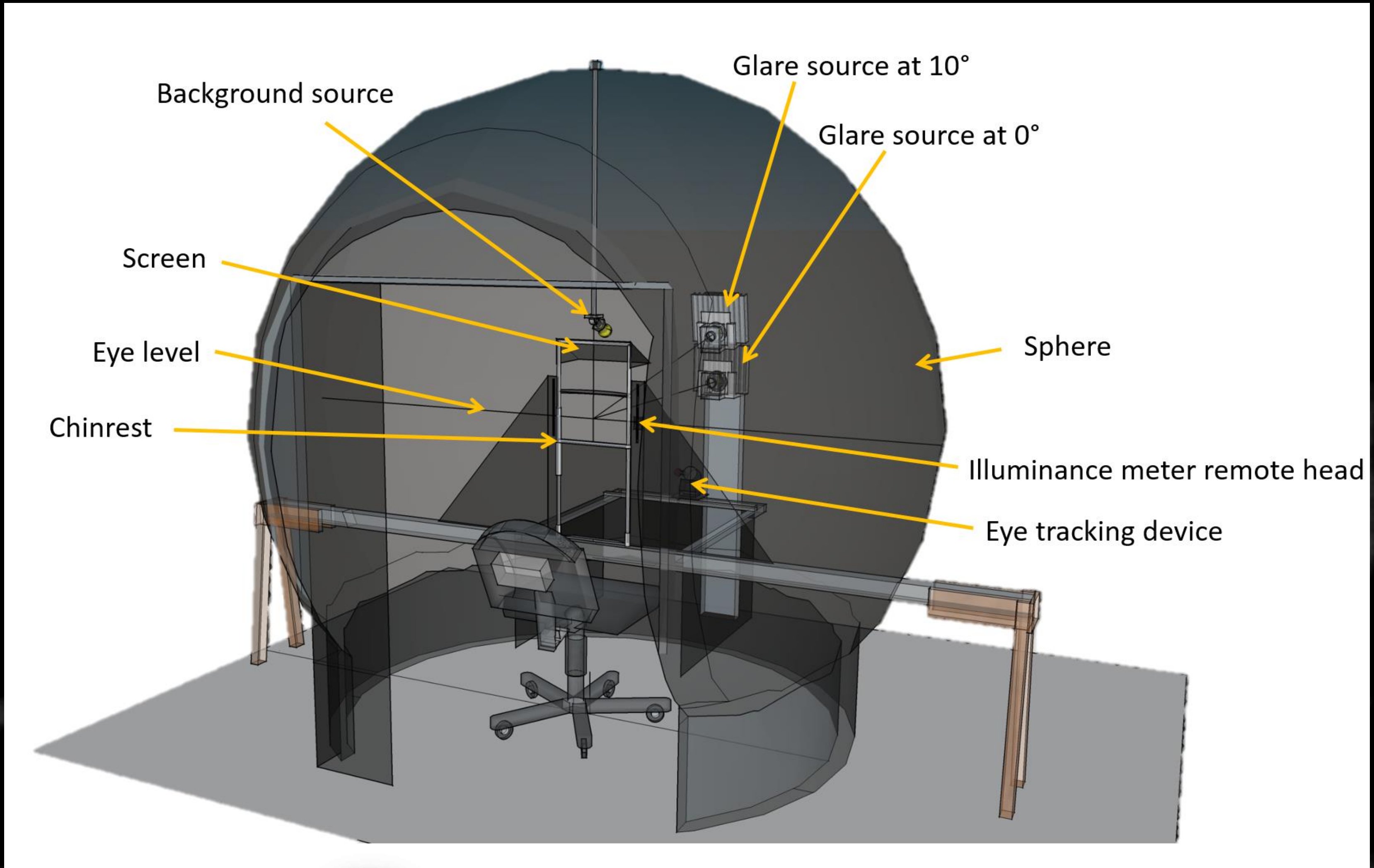
10	– imperceptible
16	– perceptible
19	– just acceptable
22	– unacceptable
25	– just uncomfortable
28	– uncomfortable
31	– just intolerable

Intention of this research

Determine which existing metric predicts discomfort glare most accurately in this application.

Apparatus and procedure

Lab experiment



Methodology. Variables and levels

Four variables (36 experimental conditions)

Glare source luminance (20,000; 205,000; 750,000 cd/m^2)

Position (0°and 10°)

Solid angle (10^{-5} and 10^{-4} sr)

Background luminance (0.03; 0.3; 1 cd/m^2)

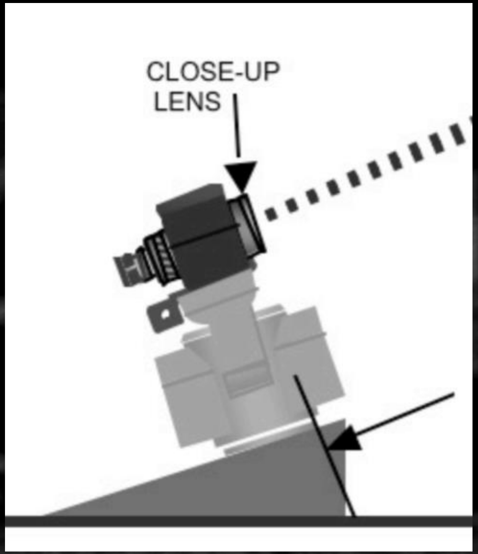
A subjective measure

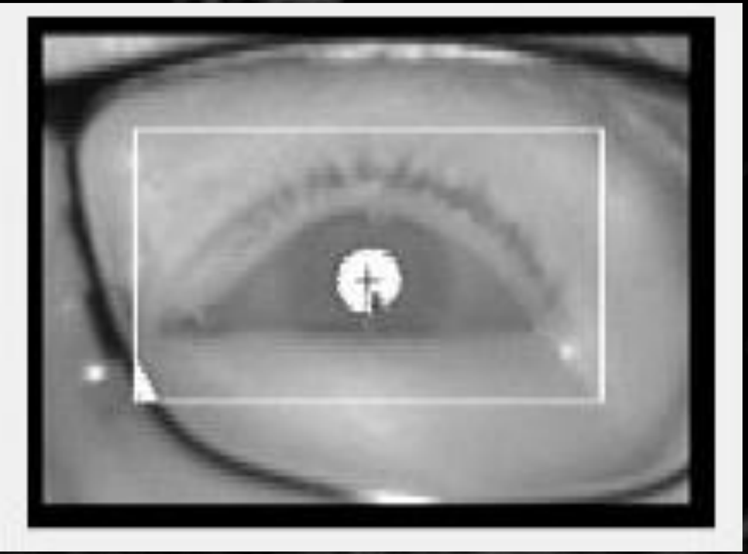
Rating scale used in this study from Fischer's paper (1991)

0 - No discomfort glare
1 - Glare between non-existent and noticeable
2 - Glare noticeable
3 - Glare between noticeable and disagreeable
4 - Glare disagreeable
5 - Glare between disagreeable and intolerable
6 - Glare intolerable

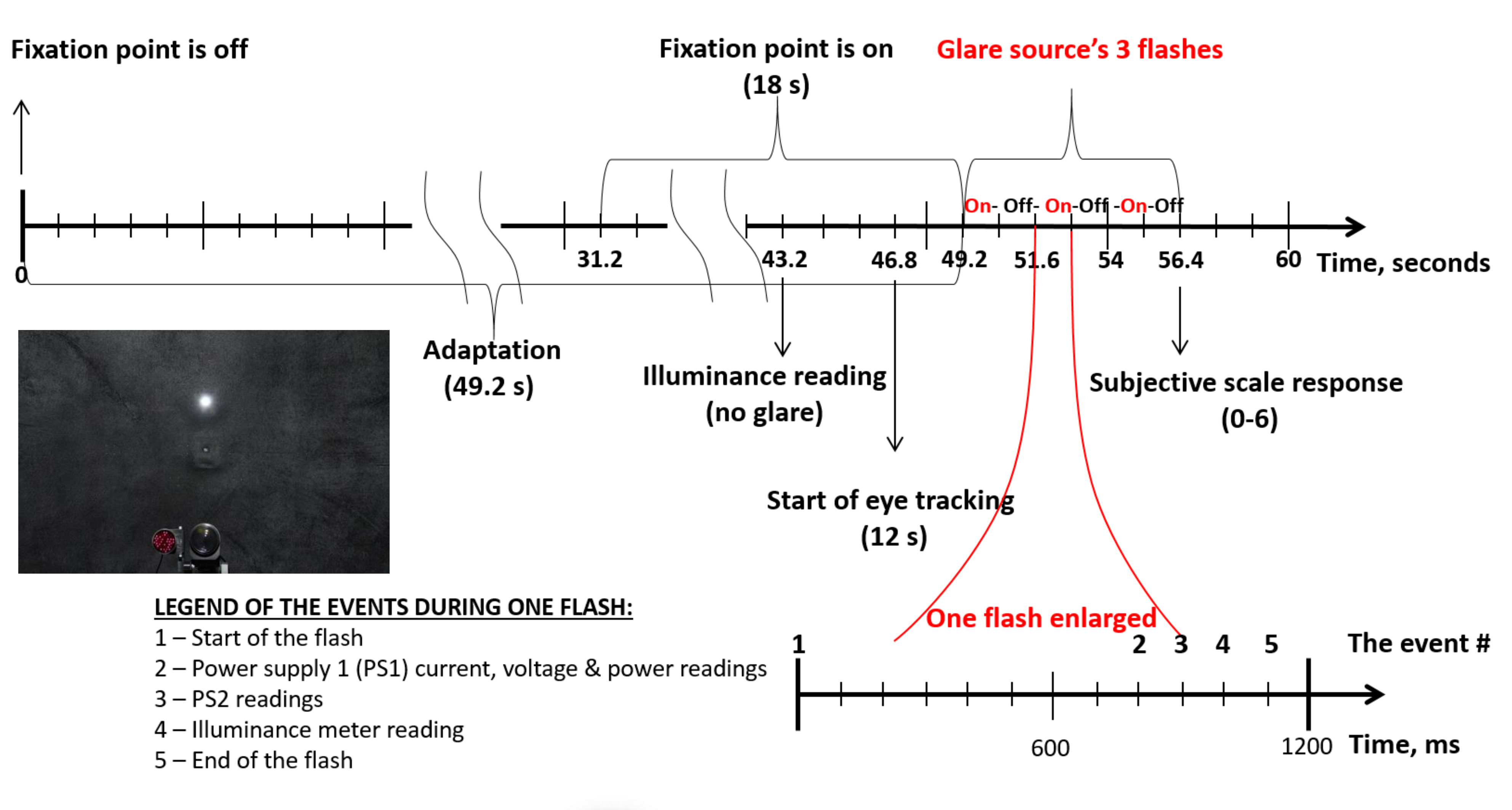
An objective measure

Pupil diameter





Simplified timeline of one experimental condition



Glare

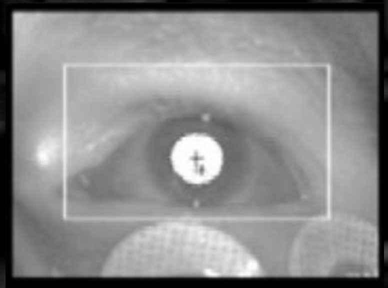
Fifty-six participants
Female 16, male 31;
Average age 39.3 years (from 20 to 76)

Custom-designed apparatus
Methodology

Subjective responses
on a seven-point rating scale

Glare
0….6

Objective (physiological) measure
pupil diameter



Discomfort glare metrics

Which metric predicts DG most accurately compared to subjective responses in this study?

Apparatus measurements averaged over time

Calculations of DG in each of the 36 conditions

- Outdoor Sports and Area Lighting (CIE 112-1994)
- Motor Vehicle Lighting (Schmidt-Clausen and Bindels 1974)
- Combo of two Bullough's et al. outdoor metrics (2008, 2011)
- UGR_{small} (CIE 146, 147 – 2002)

Correlation

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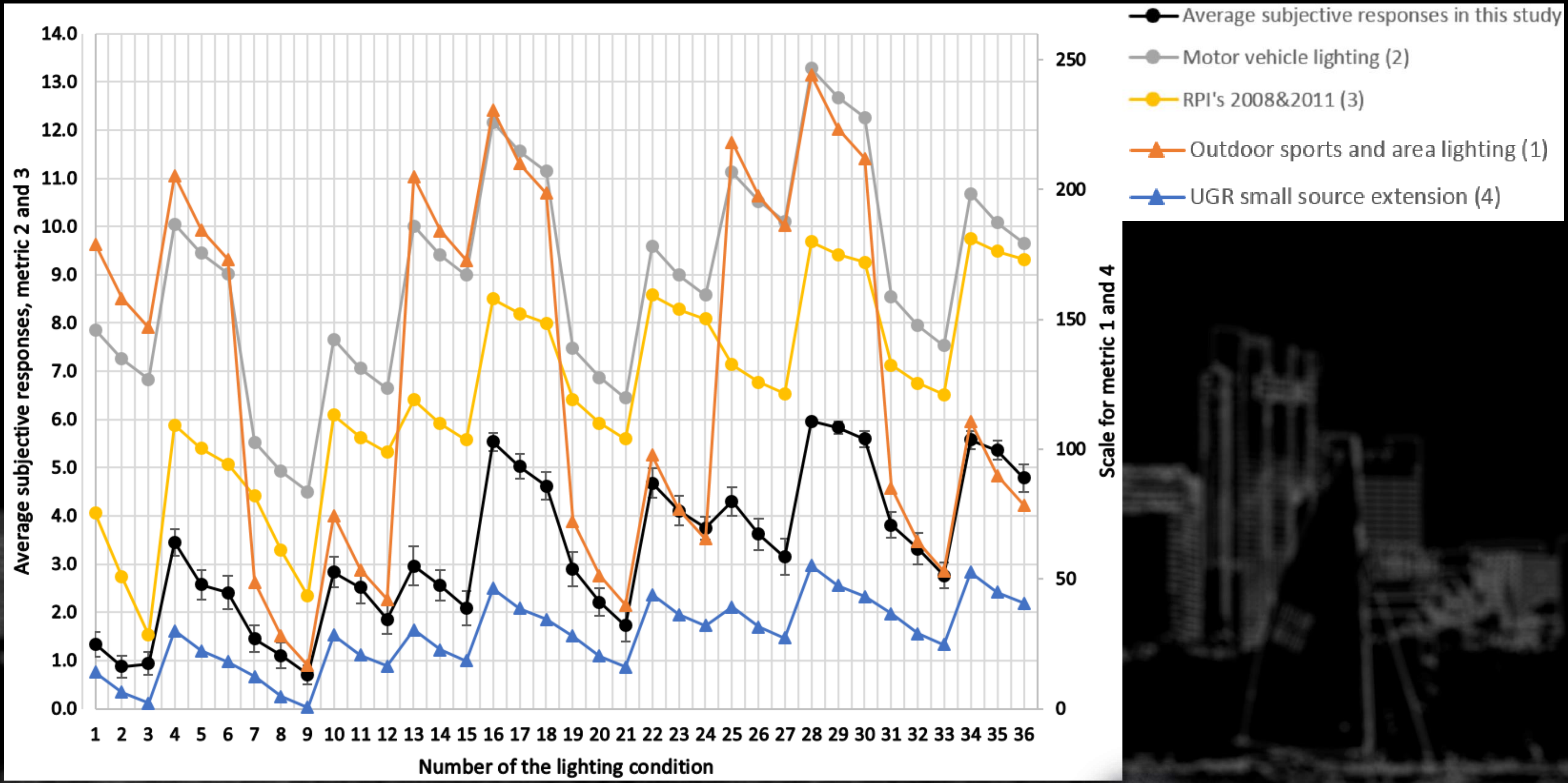
Subjective ratings by each of 47 subjects for all 36 conditions

Discomfort glare metrics and subjective data for 36 conditions

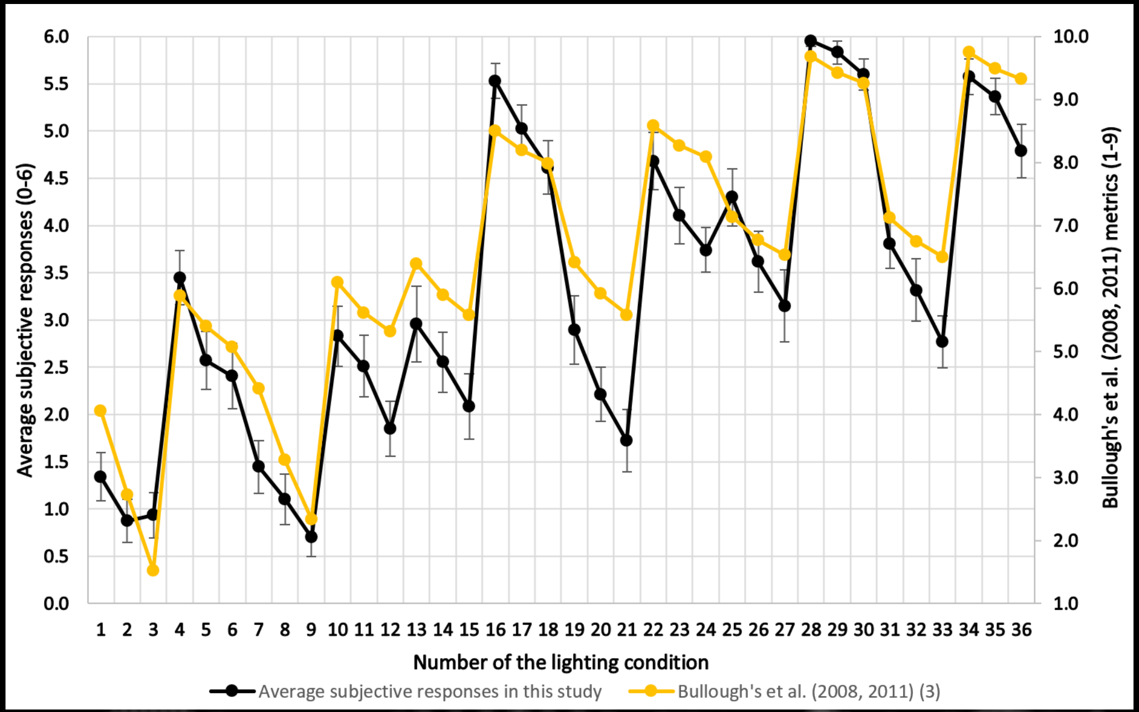
#	Average subjective rating	Outdoor sports and area lighting metric 1994	Motor vehicle lighting metric 1974	Outdoor lighting installation metric 2008 & 2011	UGR small source extension 2002
	This research	$GR = 27 + 24\log\left(\frac{L_{vl}}{L_{ve}^{0.9}}\right)$	$W = 5 - 2\log\frac{E_{glare}}{0.003\left[1+\sqrt{\frac{L_{adap}}{0.04}}\right]\cdot\theta^{0.46}}$	$DB = 6.6 - 6.4\log DG$ $DB = 6.6 - 6.4\log DG + 1.4\log(50{,}000/L_L)$	$UGR = 8\log\cdot\left[\frac{0.25}{L_b}\cdot\sum\frac{200\cdot I^2}{R^2p^2}\right]$
	0 – no DG 1 – between non-existent and noticeable 2 – noticeable 3 – between noticeable and disagreeable 4 – disagreeable 5 – between disagreeable and intolerable 6 – intolerable	10 – unnoticeable 20 30 –noticeable 40 50 – just admissible 60 70 - disturbing 80 90 - unbearable	INVERTED 1 – noticeable 2 3 – acceptable 4 5 – just admissible 6 7 – disturbing 8 9 – unbearable	INVERTED 1–just noticeable 2 3 – satisfactory 4 5 – just permissible 6 7 – disturbing 8 9 – unbearable	10 – imperceptible 16 – perceptible 19 – just acceptable 22 – unacceptable 25 – just uncomfortable 28 – uncomfortable 31 – just intolerable (1999 Mistrick)
1	1.3	***179***	7.9	4.1	14.0
2	0.9	***158***	7.3	2.7	6.3
..					
36	4.8	78	***9.7***	***9.3***	***40.6***

20,000 cd/m^2; 0^{o}; 0.3 cd/m^2; 10^{-5} sr

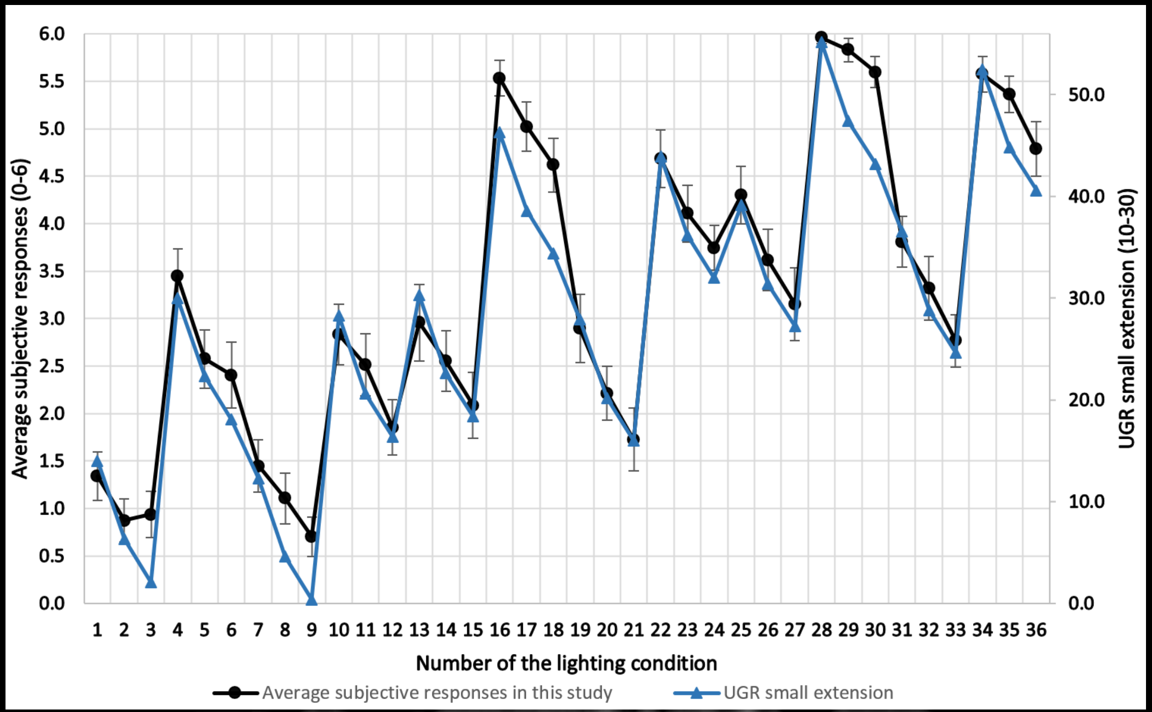
Discomfort glare metrics calculations and subjective data



Correlation analysis



Bullough et al. (2008, 2011)



UGR_{small}

Metric	Correlation with subjective responses, r
Outdoor sports and area lighting (1)	0.405
Motor vehicle lighting (2)	0.792
Bullough’s et al. metrics (3)	0.860
UGR small source extension (4)	0.879

Outcome: The metric that most accurately predicts discomfort glare in the tested ranges is the UGR small source extension.

Conclusions of this study

UGR_{small} was developed for interior lighting, but predicted DG most accurately compared to the outdoor metrics tested.

UGR_{small} was significantly better than other three tested metrics.

It validates and extends UGR_{small} to outdoor nighttime environments in the ranges tested in this study.

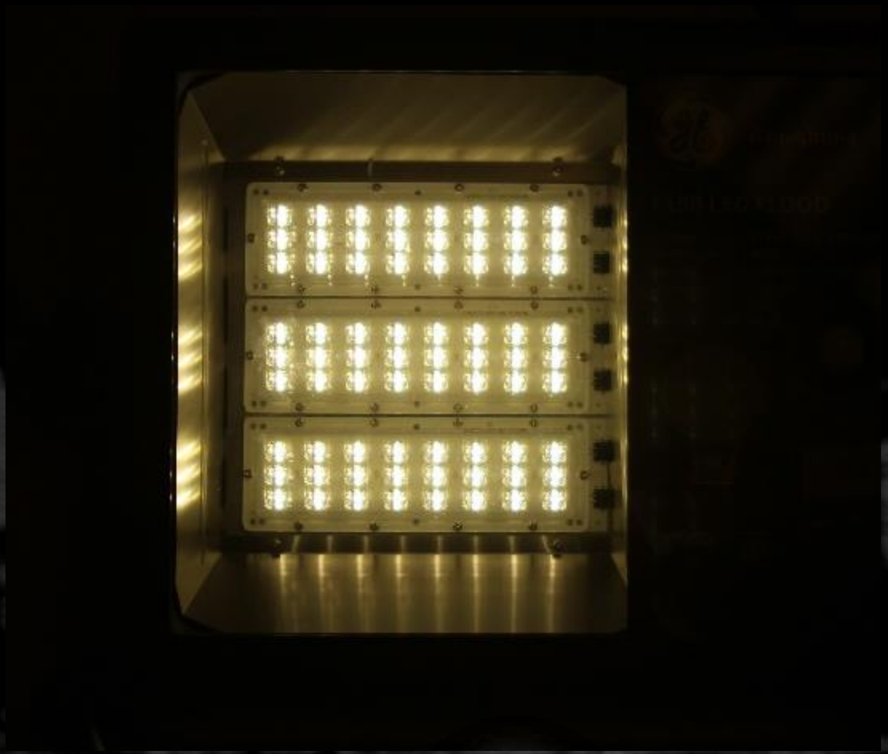
Future research

- Improve the UGR small source extension metric to achieve higher predictability;

- Study multiple sources (e.g. banks of light sources on a pole, or a source with a grid of LEDs in one luminaire);

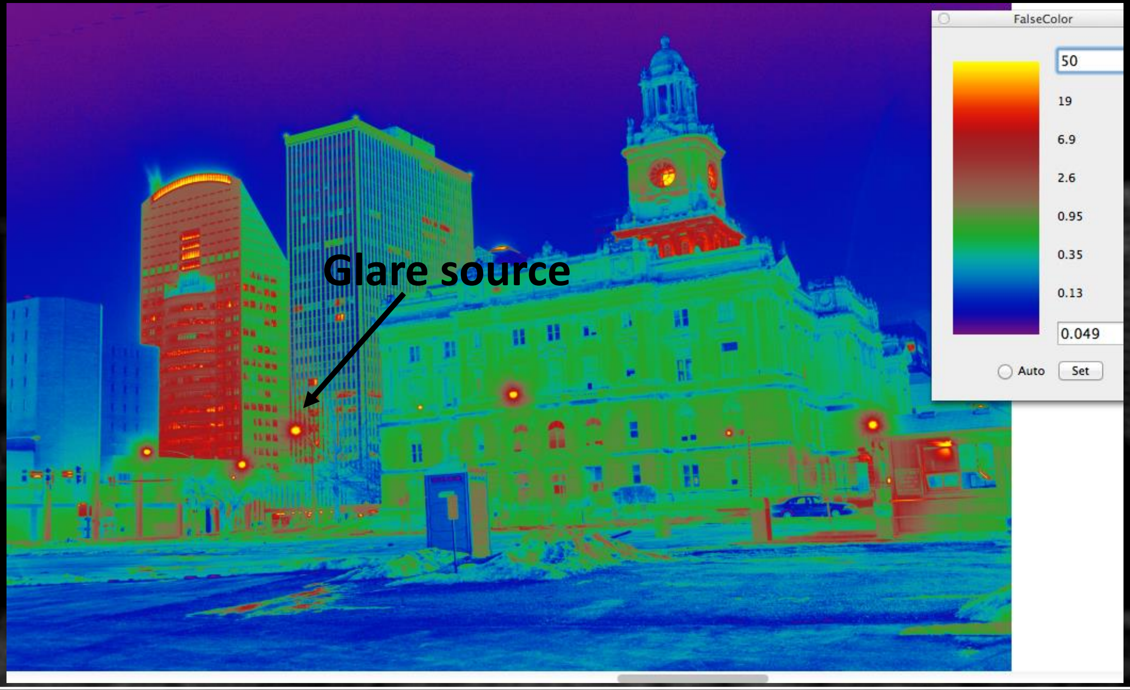
- We need to have a metric in place;

- We need to have a convenient method of assessing glare.



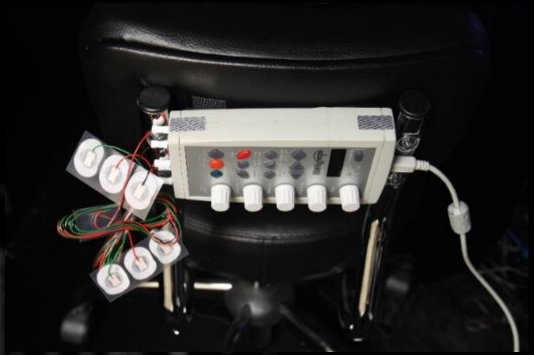
A possible method of glare analysis

High dynamic range imaging



A long-term vision

Most existing DG research is based on subjective measures; objective measure is highly desired.

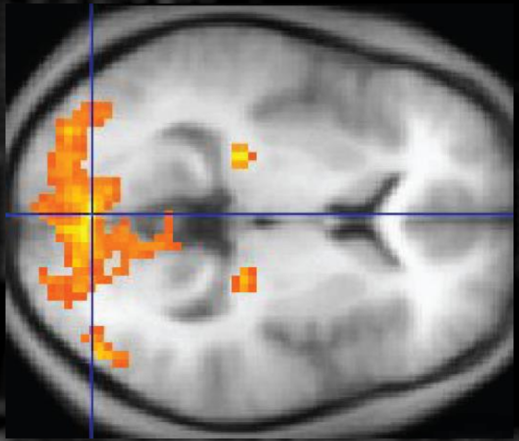


<u>Understand the underlying mechanisms and cause of discomfort glare</u>

- Study various physiological measures simultaneously (e.g. pupil diameter, blinking rate, EMG of extraocular muscles);

- Use function magnetic resonance imaging to measure brain activity in humans in response to glare stimuli;
    - Gratings with different orientations (Kamitani and Tong 2005)
    - Pictures of faces and other objects (Kanwisher et al. 1997)

- Attention can influence physiological responding (Goldstein 2014);
    - Womelsdorf el al. (2006) showed that attention can cause a monkey's receptive field to shirt toward the place where attention is directed.



Yellow areas show increased activity
Source: Wikipedia

Thank you

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