Glare and visibility by headlamps with different control strategy

Fudan University
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Introduction

Introduction

Light sources

- Excessive contrast
- Inappropriate distribution

Human

- Glare
- Visibility

Influence

- Disturbs the observer
- Limit the ability to distinguish
- Visual fatigue

Disability glare

- Physiological response
- Expressing loss of visibility
- Easily to address

Discomfort glare

- Irritating
- Distracting
- Painful sensation
- Psychological response
- Difficult to address

Boyce P R. Human factors in lighting[M]. CRC Press,2003.

Glare

Introduction

VISIBILITY is a measure of the distance at which an object can be clearly discerned

VISIBILITY depends on the weather and the contrast between the target and background

$$contrast = \frac{L_T - L_B}{L_T}$$

In night driving, the luminance of the target (pedestrians, slogans) is related to the illuminance on it. Assuming there is diffuse reflection on the surface of the pedestrian, the relationship between the luminance and illuminance is:

$$L = \frac{\rho E}{\pi}$$

The illuminance obeys the law of inverse square: $E = \frac{I}{d^2}$

Introduction

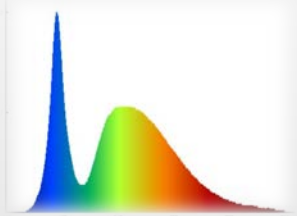
Influence factors of Glare

CERTAIN

Luminance of the glare source 、Adaptation level、
Solid angle of the glare source、the Position index

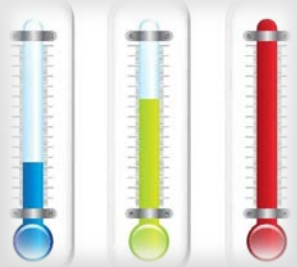
LIKELY

Time of the day、Season、Culture、Age、
Spectrum of light 、View direction



UNCERTAIN

Room temperature 、Questionnaire and rating
scale、Contrast sensitivity、Emotional state



Pierson C, Wienold J, Bodart M. Discomfort glare perception in day lighting: influencing factors[J]. Energy Procedia, 2017,
P. Petherbridge, R.G. Hopkinson, Discomfort Glare and the Lighting of Buildings, Lighting Research and Technology, 15 (1950).
S. Berman et al., The Influence of Spectral Composition on Discomfort Glare for Large-Size Sources, in: IESNA Conf., 1995.
J. Yamin Garretón et al., Effects of perceived indoor temperature on daylight glare perception, Building Research & Info.,2015.

Introduction

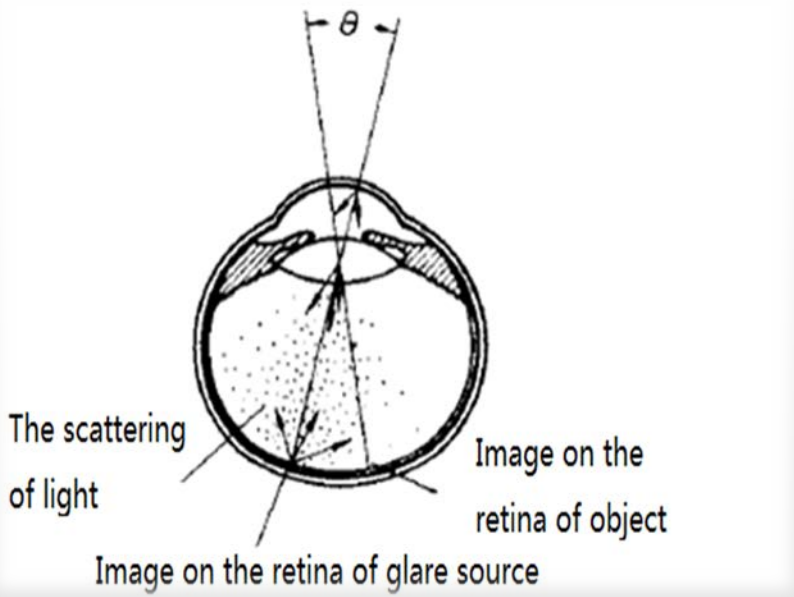
Physiological causes of glare

Pupil ↓ → Brightness ↑

Cornea / Lens → Scattering light → Light curtain

Retina → High Brightness → Destroying adaption state

How Glare affect Visibility

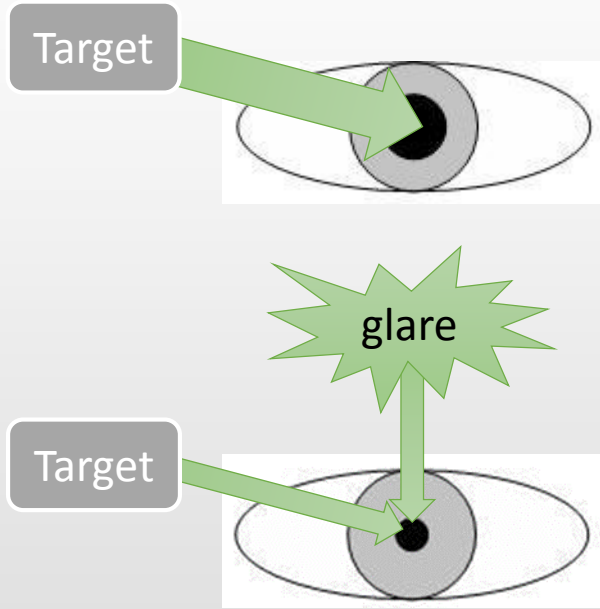


Light curtain ↑ / Background luminance ↑ → Luminance contrast of objects around light source ↓ → Detection capability (Visibility) ↓

Introduction

How does glare affect the visibility?

Disability glare is often caused by the inter-reflection of light within the eyeball, reducing the contrast between task and glare source to the point where the task cannot be distinguished



New

illuminate + −

add glare + −

$$contrast = \frac{L_T - L_B}{L_T}$$

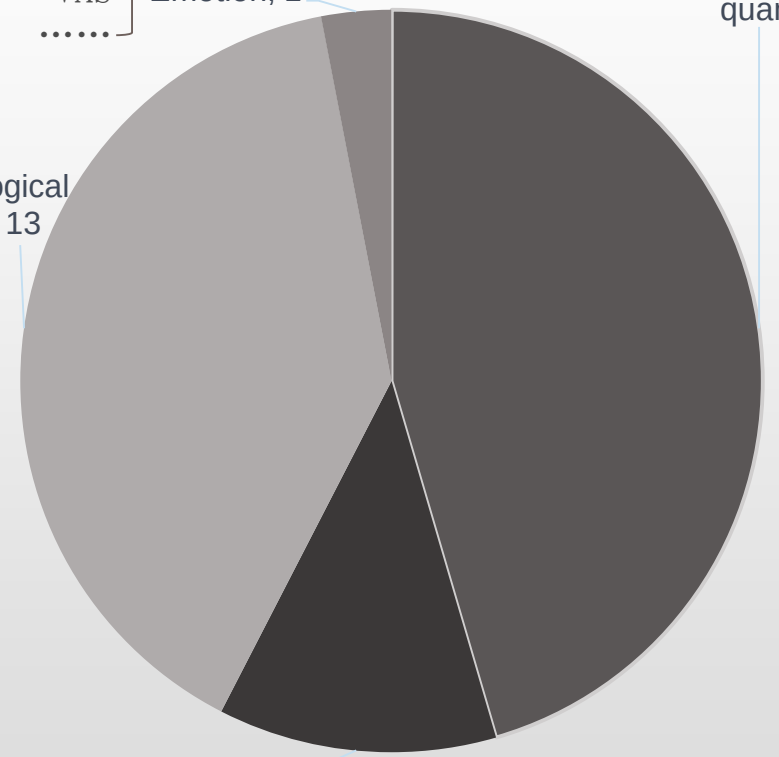
2

Review on past research: glare and visibility

Review on past research: glare & visibility

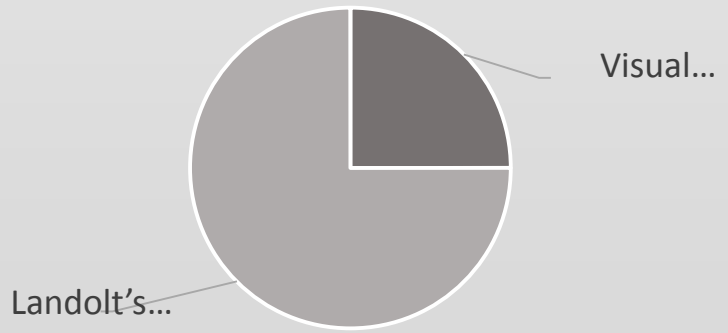
Methodology

Human body effect experiment related to glare



Scale of discomfort glare appraisal (G)	
Unbearable	1
Disturbing	3
Just admissible	5
Satisfactory	7
Unnoticeable	9

Work performance experimental method



Review on past research: glare & visibility

Methodology

Visual accuracy

Landolt’ s ring

Visual chart

Recognition distance

Traffic sign recognition

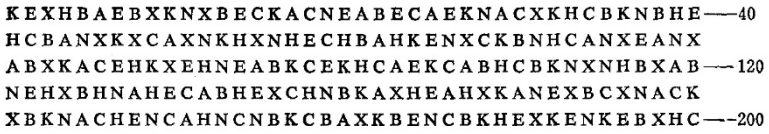
Moving target calibration

Different aspects

Work performance

Ann Fermo J correction table

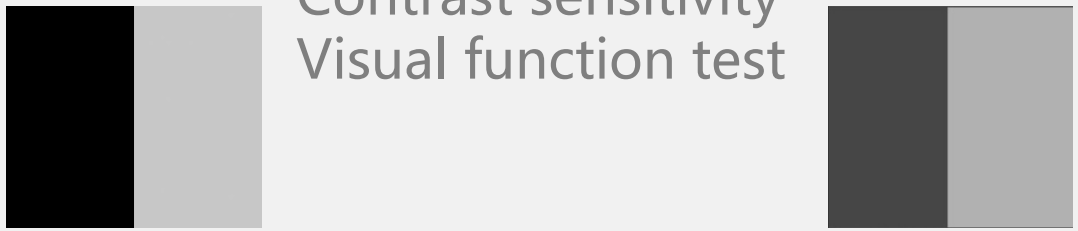
Reading task



Visual resolution

Contrast sensitivity

Visual function test



Review on past research: glare & visibility

Glare and Contrast Threshold

对比度等级	环境情况	
	眩光	背景亮度
1 ∶23	OFF	0.032±0.003cd·m^{-2}
1 ∶5	OFF	0.032±0.003cd·m^{-2}
1 ∶2.7	OFF	0.032±0.003cd·m^{-2}
1 ∶2	OFF	0.032±0.003cd·m^{-2}
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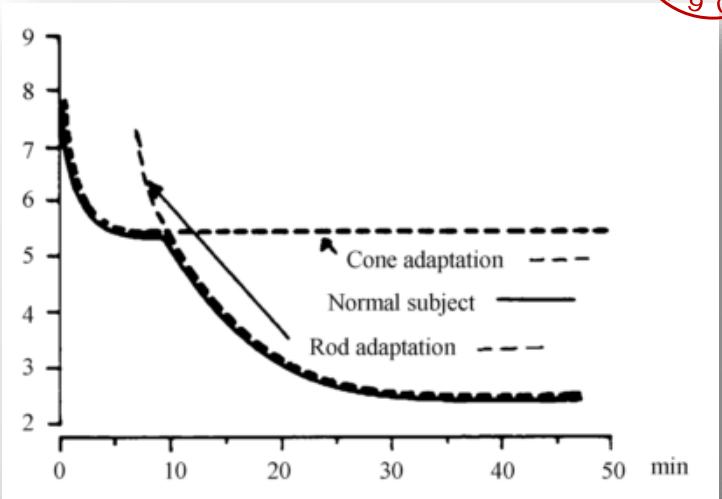
1 ∶1.14	OFF	0.10±0.01cd·m^{-2}

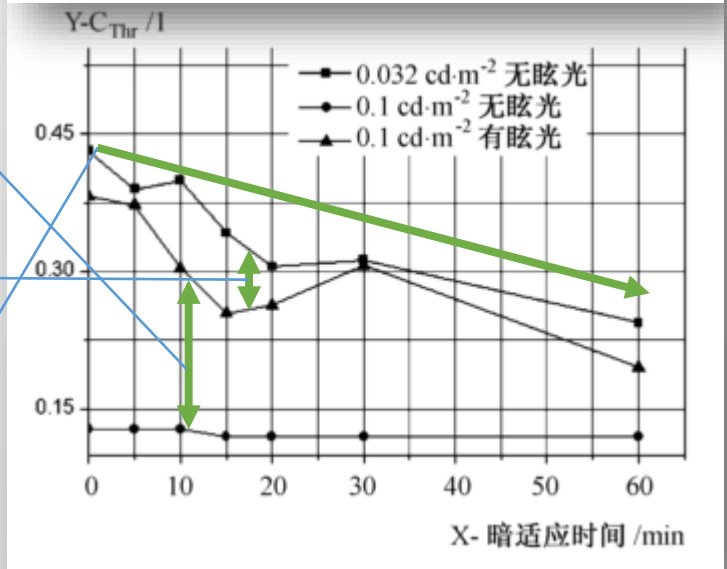
8 contrast levels
2 glare conditions
2 background luminance levels
7 adaptation time levels

Glare will significantly increase the contrast threshold

The increase of luminance will decrease the contrast threshold

A longer adaptation time will decrease the contrast threshold

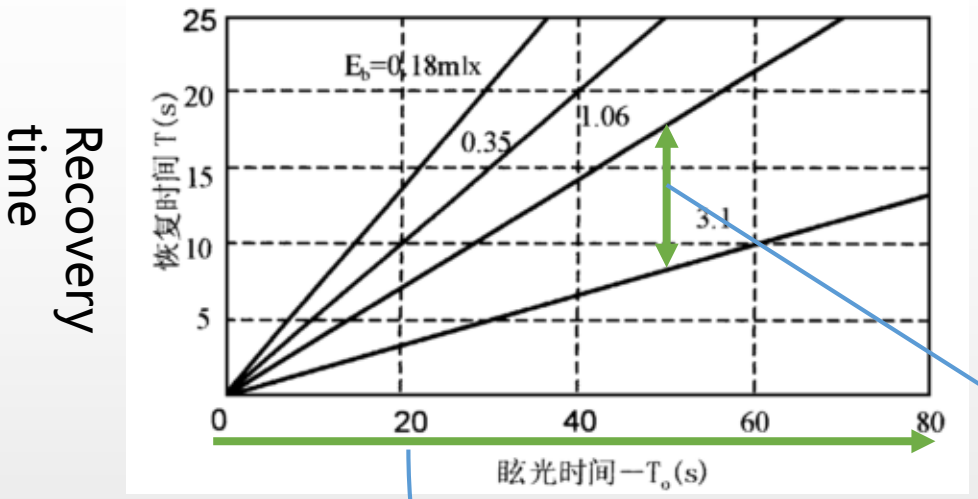




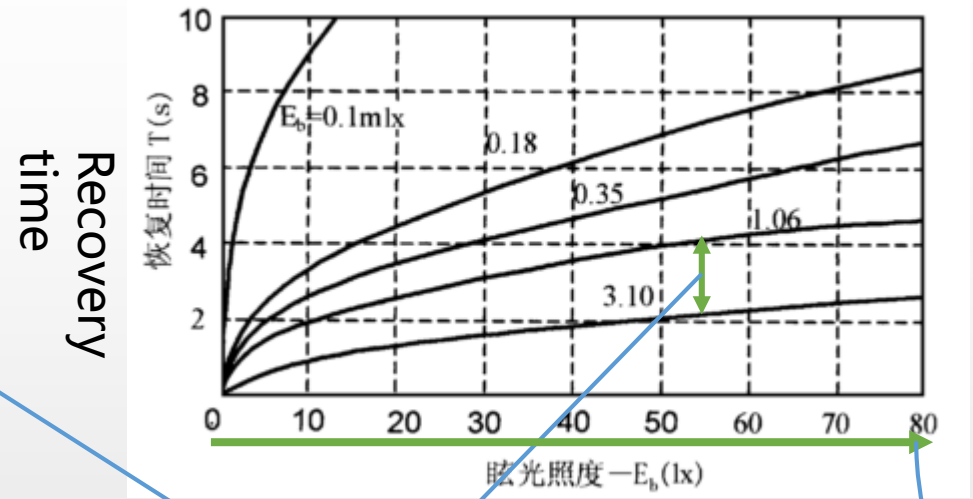
Ji Z, Lin Y. The Effect of Adaptation Time, Adaptation Luminance and Glare on Contrast of Human's Eye[J]. China Illuminating Engineering Journal, 2006

Review on past research: glare & visibility

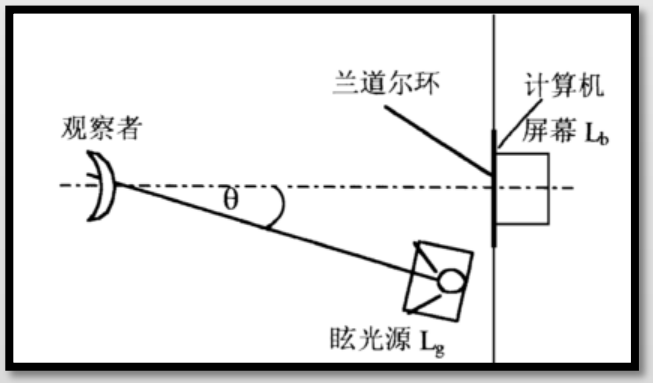
Glare and Recovery Time



Time illuminated by glare source



Illuminance on eye’ s position caused by glare source



layout

The increase of background luminance will decrease the recovery time

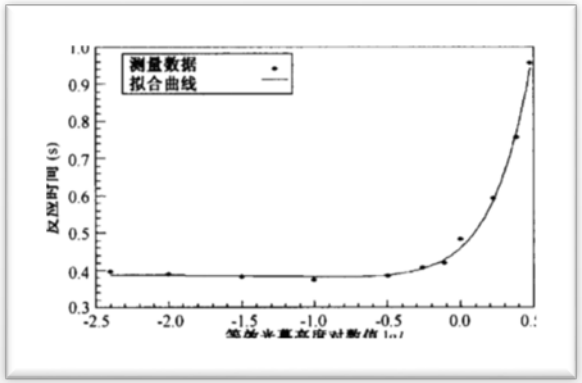
The increase of time illuminated by the glare will increase the recovery time

The increase of glare source intensity will increase the recovery time

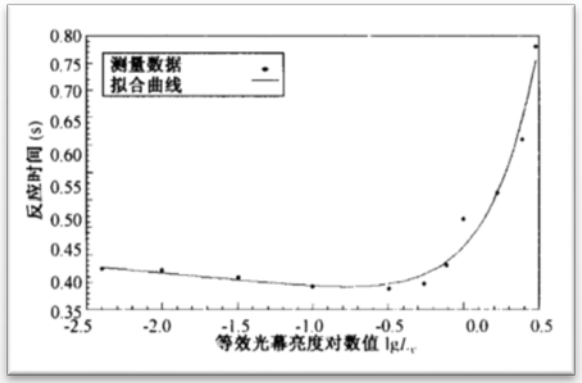
Xiang Z. Glare of Lighting and Recovery Time of Human Vision Over Glare[J]. China Illuminating Engineering Journal, 2002

Review on past research: glare & visibility

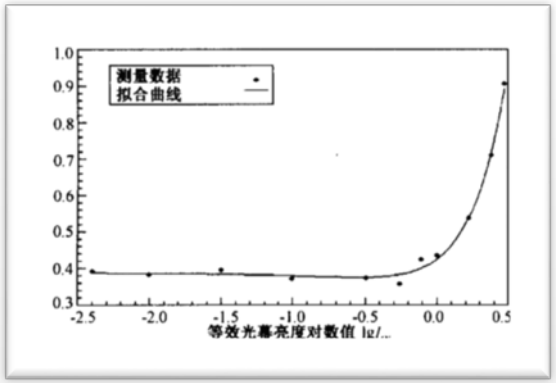
Glare and Reaction Time



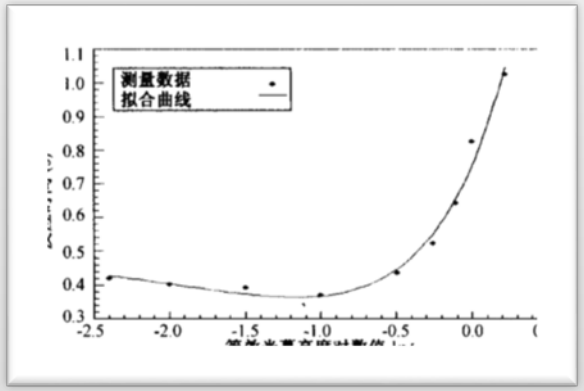
$L_b = 0.3cd/m^2, C = 0.3, \theta = 0$



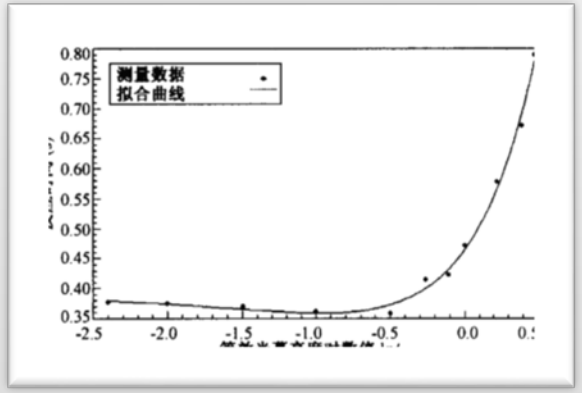
$L_b = 1.5cd/m^2, C = 0.3, \theta = 0$



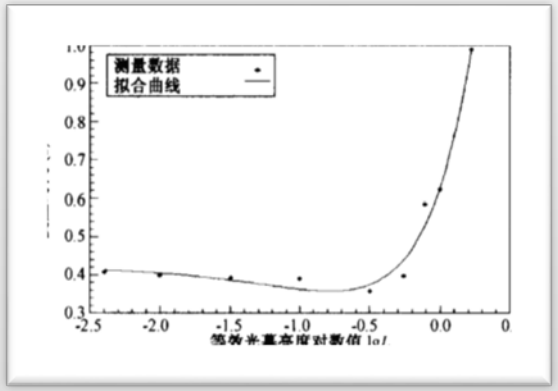
$L_b = 0.5cd/m^2, C = 0.3, \theta = 0$



$L_b = 0.3cd/m^2, C = 0.3, \theta = 10$



$L_b = 1.0cd/m^2, C = 0.3, \theta = 0$



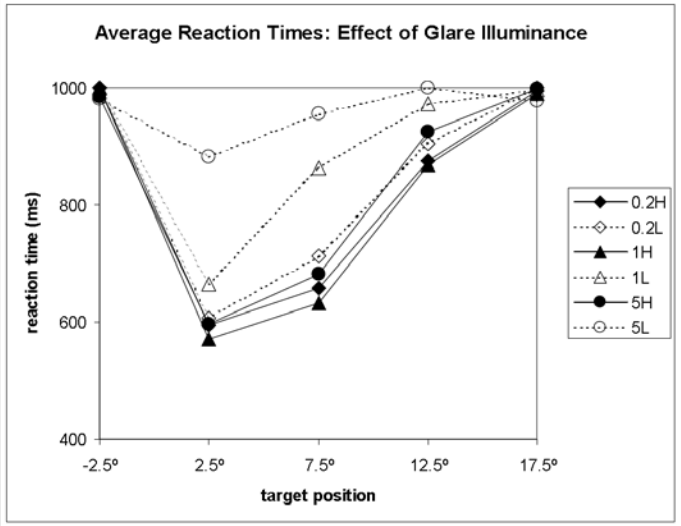
$L_b = 0.5cd/m^2, C = 0.3, \theta = 10$

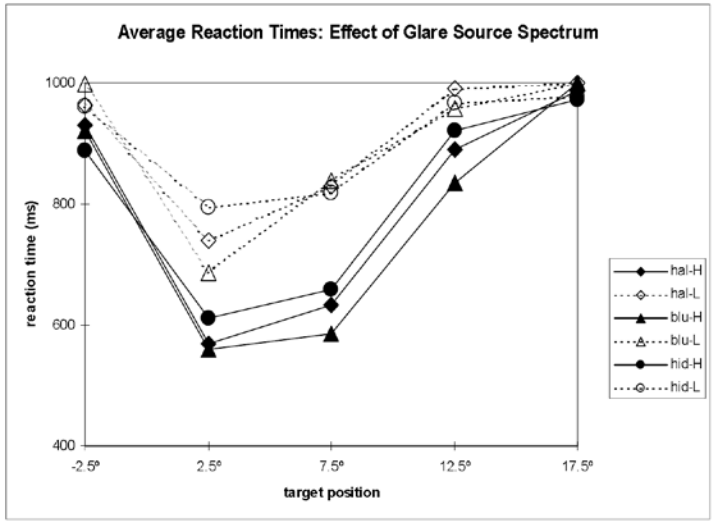
The increase of glare source intensity will make the reaction time decrease first and then increase

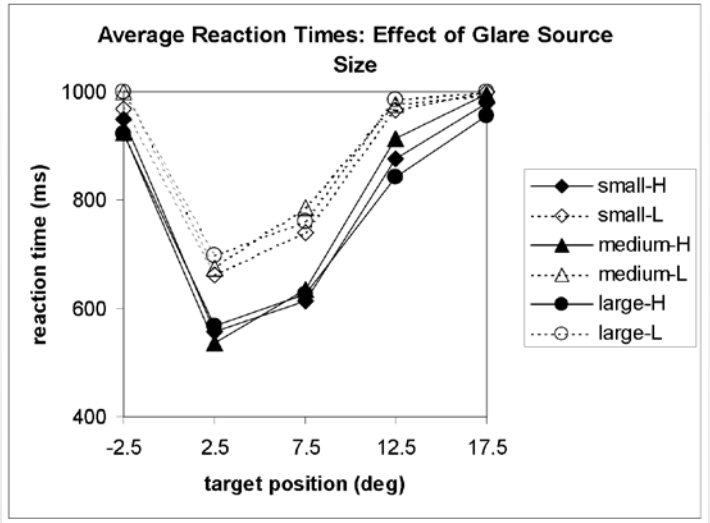
Yang C. Research of the Influence of Disability Glare on Road Lighting Safety[J]. China Illuminating Engineering Journal, 2007.

Review on past research: glare & visibility

Glare and Reaction Time







Angle is the most important factor. The glare source intensity will increase the reaction time, while the reflectance of target will decrease the reaction time.

Bullough J D, Van Derlofske J, Dee P, et al. An investigation of headlamp glare: intensity, spectrum and size[R]. 2004.

Review on past research: glare & visibility

Model for headlamp glare

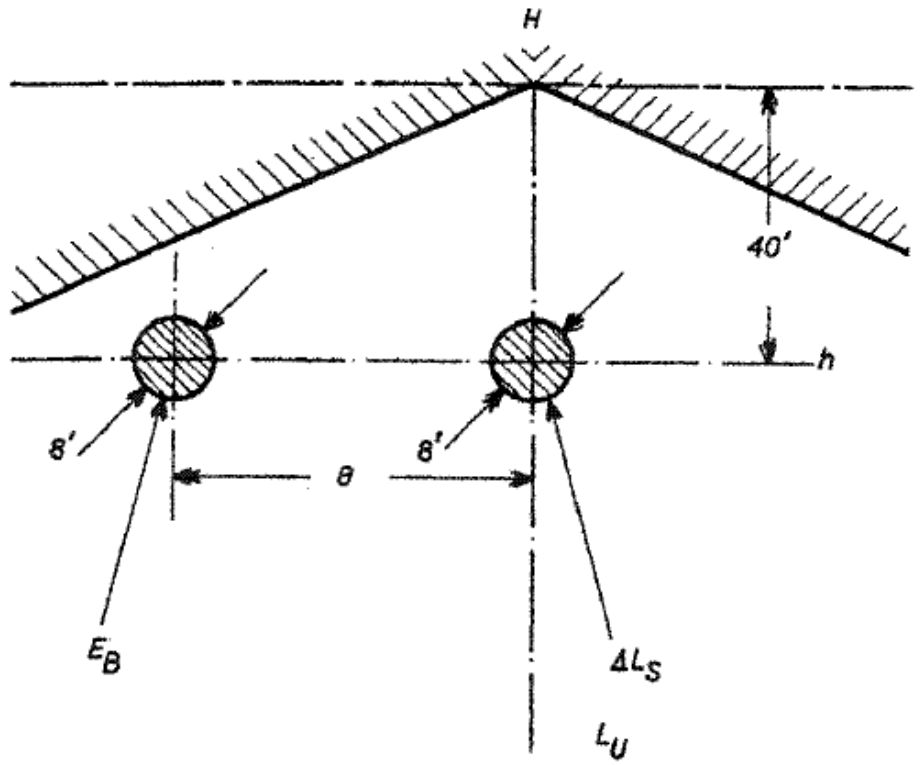


Fig. 1. Schematic diagram of experimental set-up.

E_B = glare illuminance, θ = angle of glare, L_U = adaptation luminance, and ΔL_S = luminance of test object.

Comparison of the assessment of disability and discomfort glare

Disability glare	Discomfort glare
$f_B = \Delta L_{SOO}\left[1 + \frac{L_U}{C_L}\right]$	$f_B = 5.0 + 2\log\left[1 + \sqrt{\frac{L_U}{C_{pL}}}\right]$
$f_D = \frac{E_B}{C_{EOO}\,\theta^{2.2}}$	$f_D = 2\log\frac{E_B}{C_{POO}\,\theta^{0.46}}$

Disability glare	Discomfort glare
$\Delta L_{SOO} = 1.3\times10^{-2}$ cd m^{-2}	
$C_L = 3.5\times10^{-1}$ cd m^{-2}	$C_{pL} = 4.0\times10^{-2}$ cd m^{-2}
$C_{EOO} = 3.8\times10^{-6}$ lux min$^{-2.2}$	$C_{POO} = 3.0\times10^{-3}$ lux min$^{-0.46}$

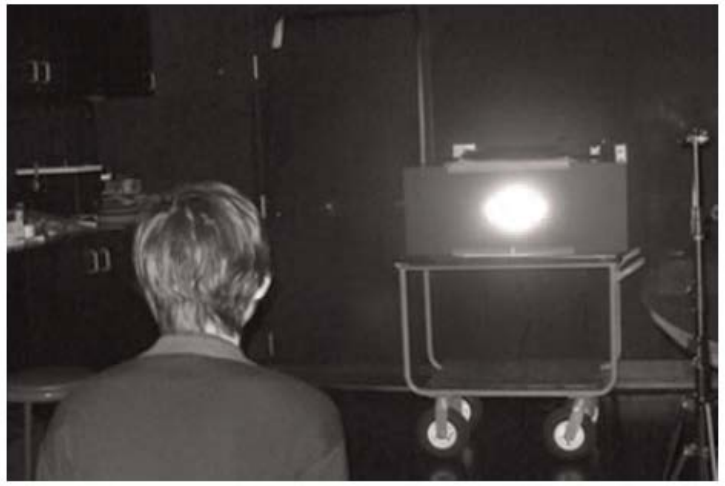
H. J. Schmidt-Clausen and J. T. H. Bindels, “Assessment of discomfort glare in motor vehicle lighting,” Lighting Res. Tech. 6(2), 79-88 (1974).

Review on past research: glare & visibility

Model for headlamp glare

Bullough mode

- **Subjective judgements of discomfort glare**
- Light source illuminance (El)
- Light source luminance (Ll)
- Surround illuminance (Es)
- Ambient illuminance (Ea)



Discomfort glare

$$DG = a\ \log(E_\ell + E_s) + b\ \log(E_\ell / E_s) - c\ \log(E_a)$$

De Boer ratings

$$DB = 6.6 - 6.4\ \log\ DG$$

- Subjects: Six to eighteen
- Ages: 20 to 57 years

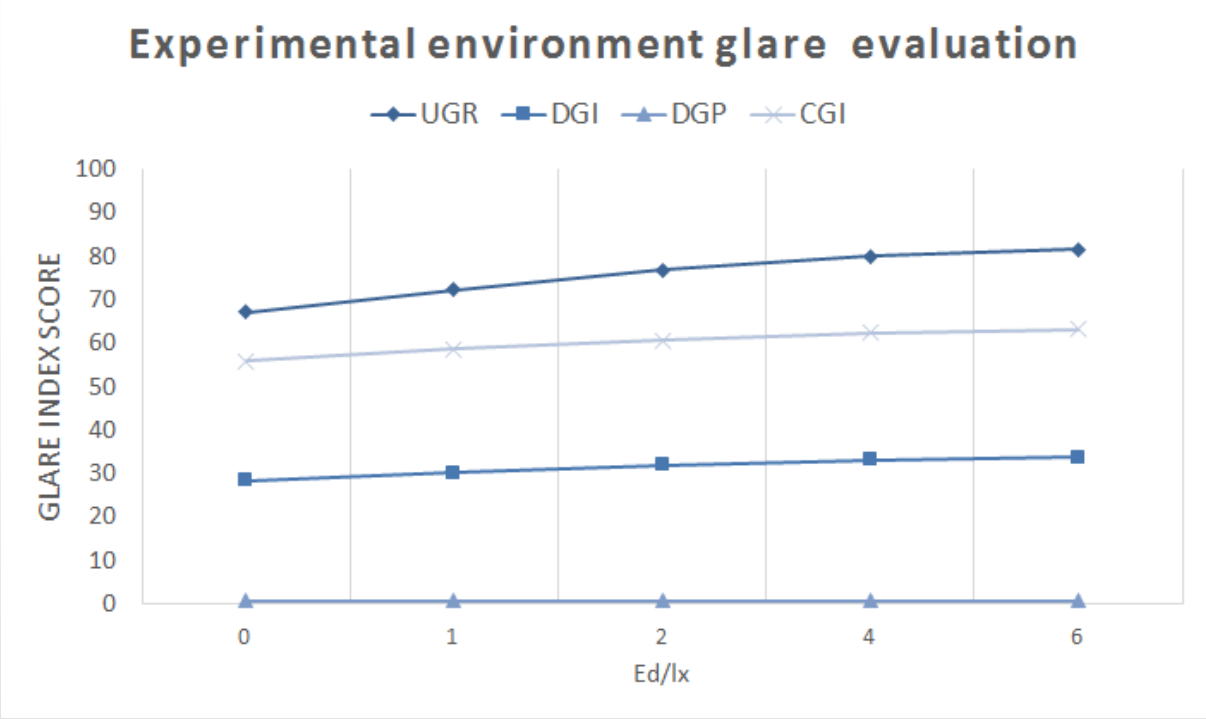
- Applicable ambient wide range of outdoor lighting

Bullough J D, Brons J A, Qi R, et al. Predicting discomfort glare from outdoor lighting installations[J]. Lighting Research & Technology, 2008, 40(3):225-242.

Review on past research: glare & visibility

Model for headlamp glare

The calculated value of different glare model



Degree of glare in different glare indices [9,10,20,21].

Degree of perceived glare	Imperceptible	Perceptible	Disturbing	Intolerable
DGP	Below 0.35	0.35–0.40	0.40–0.45	Above 0.45
DGI	Below 18	18–24	24–31	Above 31
UGR	Below 13	13–22	22–28	Above 28
VCP	80–100	60–80	40–60	0–40
CGI	Below 13	13–22	22–28	Above 28

Review on past research: glare & visibility

Summary

- Glare certainly affect visibility by affecting contrast sensitivity, reaction time, recovery time and so on
- Parameters which certainly affect glare is still being discussed
- Variances among different glare models are big
- Relationship between glare and visibility need to be defined

3

General Strategies of Headlamp

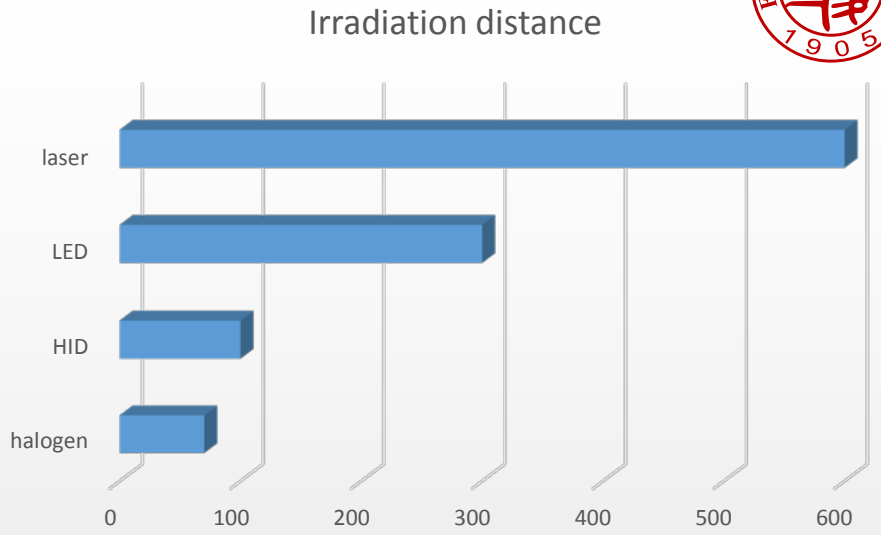
Strategies

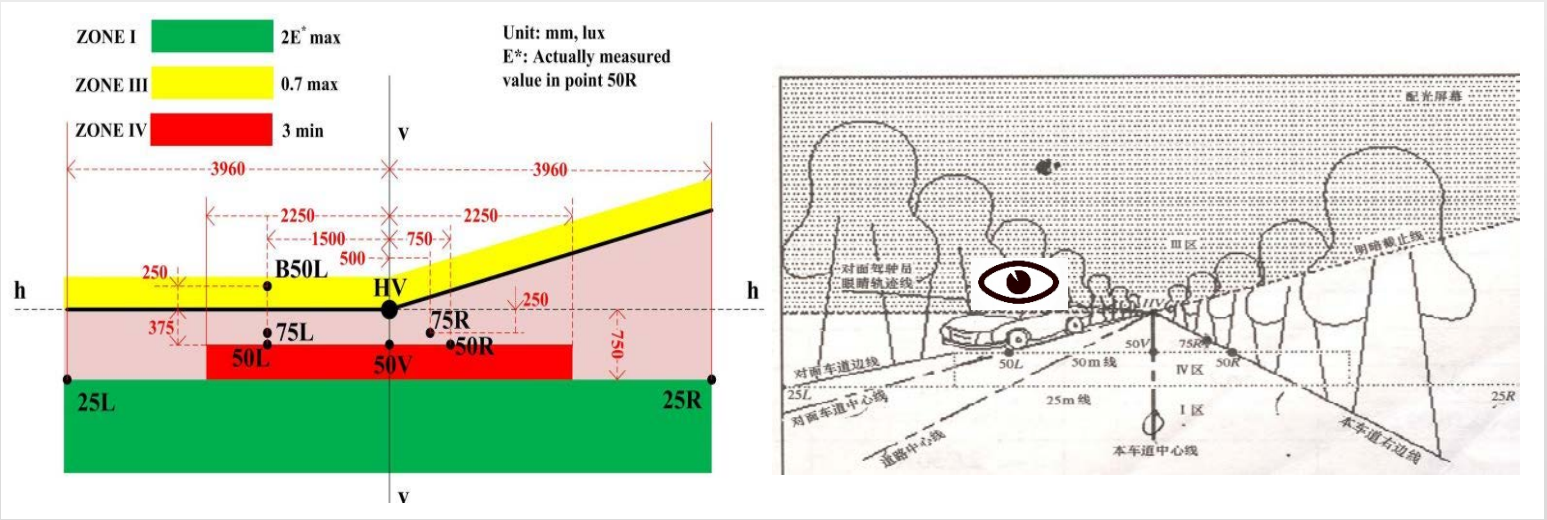
Increasing visibility & decreasing glare

For direct **visibility**, the luminance of headlamp shall be as high as possible

High beam, aiming for longer irradiation distance, suffer from serious glare

For **glare**, headlamp shall avoid direct glare and reduced visibility due to high target/surrounding contrast





ECE R112 low beam standards and corresponding simulated diagram

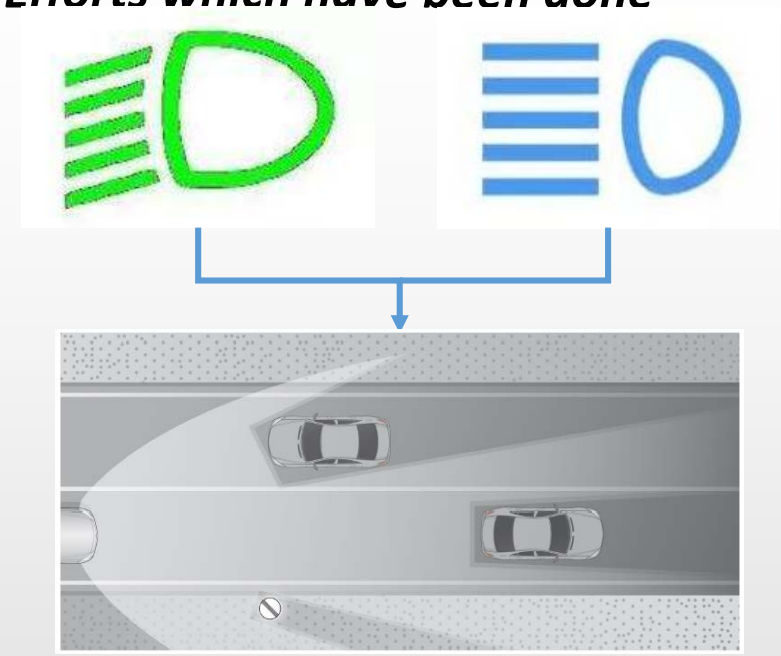
Low beam, avoid directly glare, has short irradiation distance

30-40m

The driver has to switch the condition of headlamp frequently to realize the balance

Strategies

Efforts which have been done



The ADB system can achieve long detection distance and avoid disability glare at the same time.

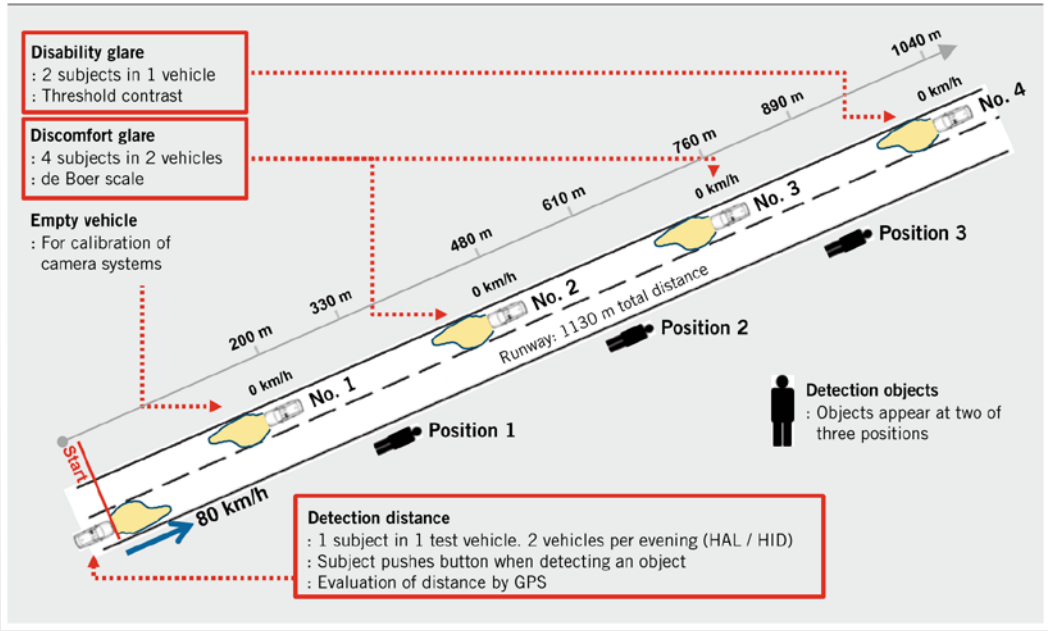


Figure. Experiment to study the performance of ADB compared to high beam and low beam

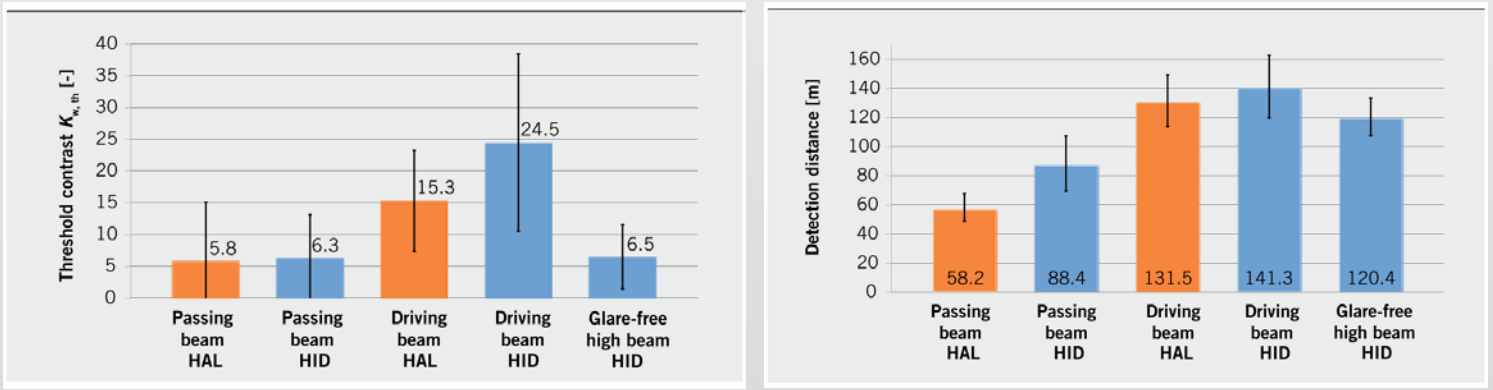


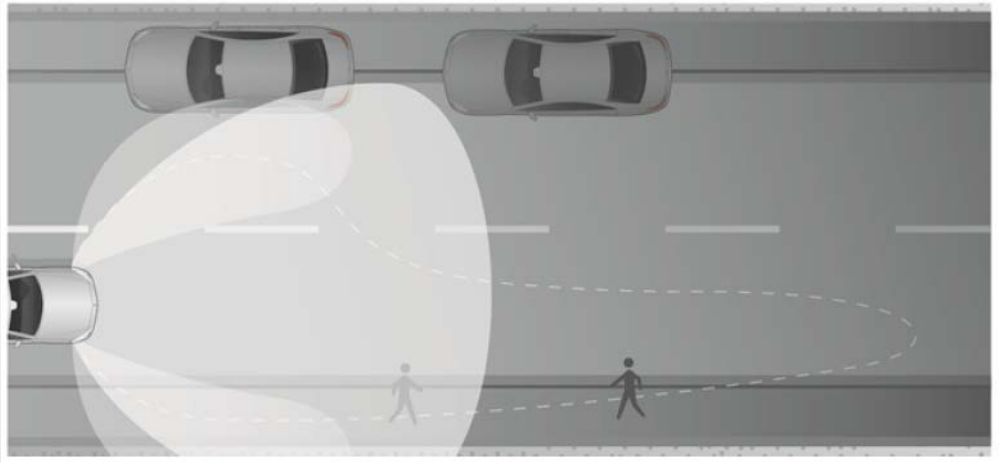
Figure. The threshold contrast and detection distance performance of different headlight

Zydek, D. I. B. and D. I. D. Polin (2014). "Evaluation of Headlamps with a Glare-free High Beam Function." Atz Worldwide 116(6): 46-51

Strategies

Efforts which have been done

Long detection distance is not enough, in some condition, the width is also important.



City light

The detection width is larger to help the driver find pedestrians on the sidewalk.

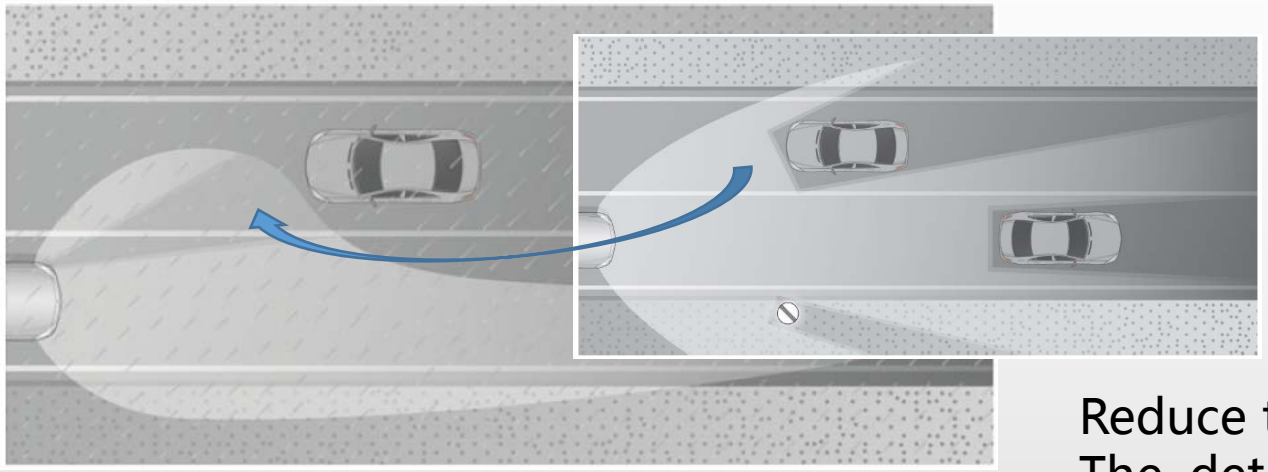
The height is very low to avoid glare.

distance	width	glare
short	wide	N

Strategies

Efforts which have been done

The indirect glare should be payed attention to.



rain light

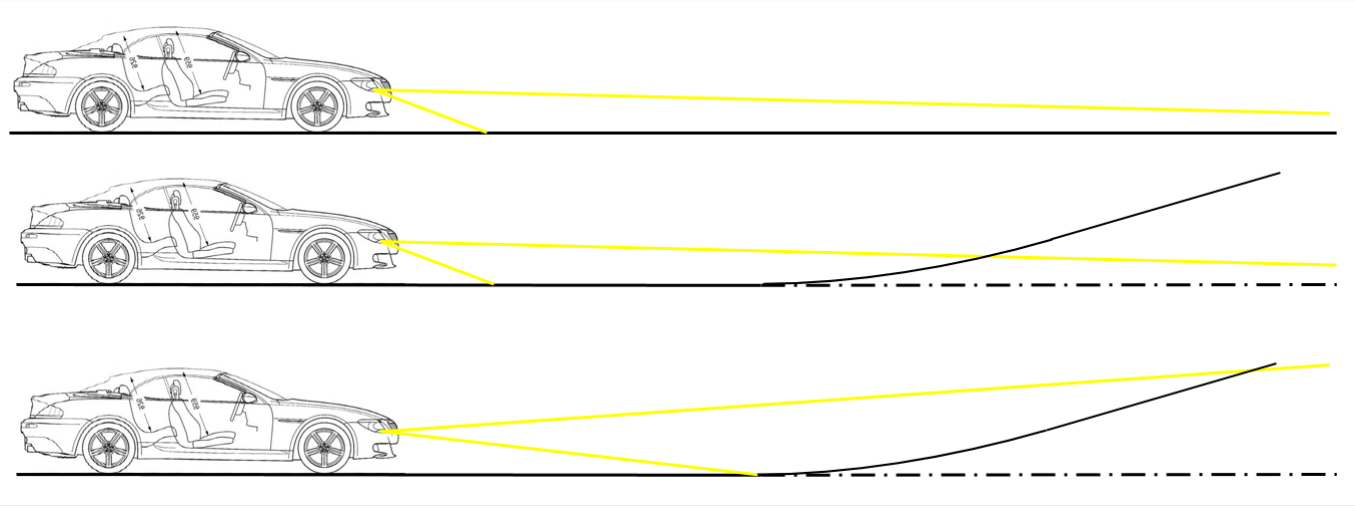
On the basis of ADB, less light will be shot to the surface of road when there is vehicle in front.

Reduce the glare caused by the reflected light. The detection distance and width won’ t be affected.

Strategies

Efforts which have been done

Taking terrain into consideration.

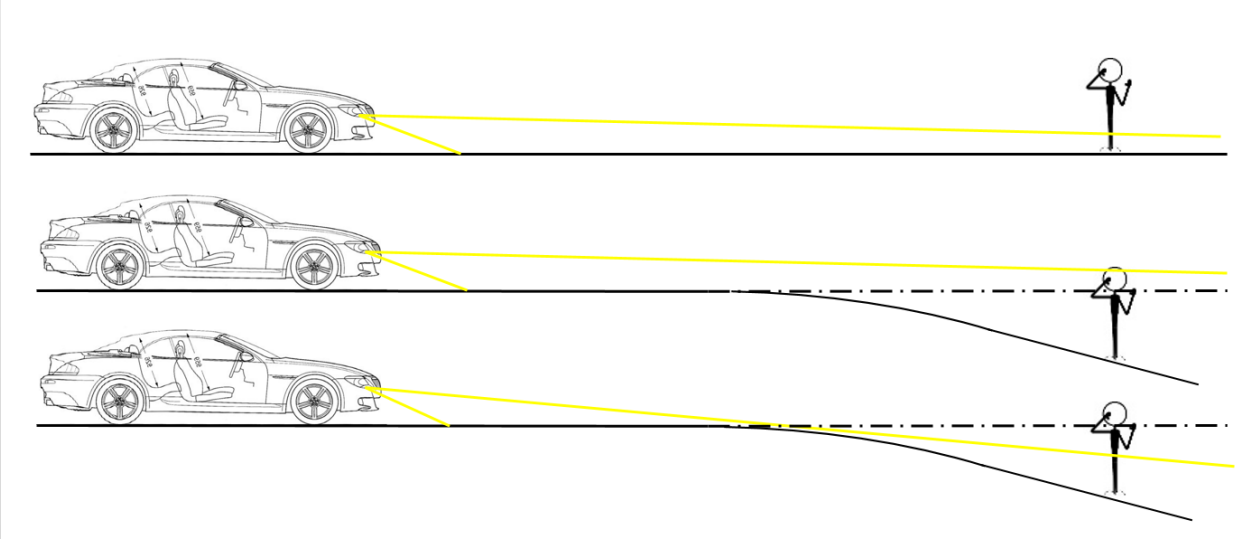


Slope light

Before entering a slope, turn up or turn down the light to offset the decrease of distance or increase of glare.

Increase the detection distance

Keep the detection distance and avoid the glare



Strategies

Efforts which have been done

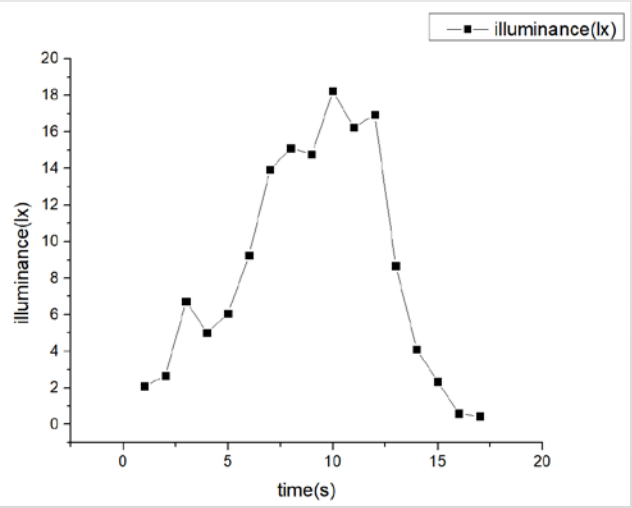
Extra light for the pedestrians.

Spot light

The infrared camera can find the pedestrians that were not illuminated.
The spot light strategy will put extra light to the pedestrians to help the driver find them.

Visibility Vs. Glare, the real data

How much light should be adjusted?
What is the real balance?



Tested by Lin&Li, Fudan Uni.

4

Research on glare and visibility in FDU

FDU research: glare & visibility

Glare and Contrast Threshold

对比度等级	环境情况	
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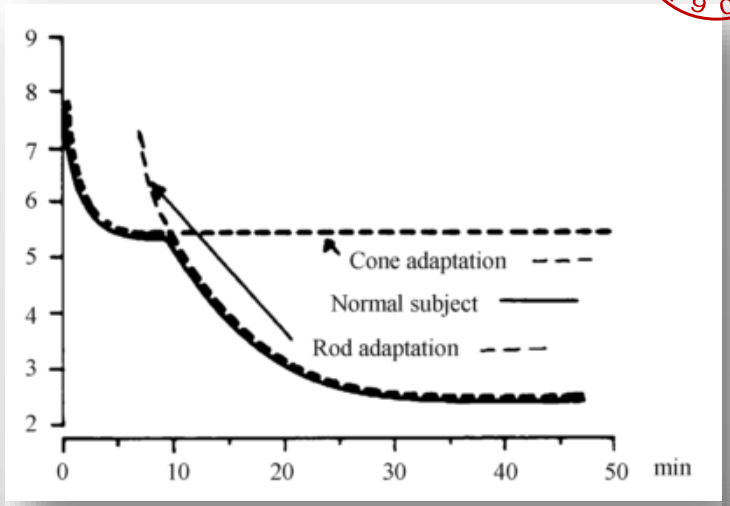
1.1.25	OFF	0.032±0.003cd·m^{-2}
1.1.14	OFF	0.032±0.003cd·m^{-2}
1.23	ON	0.10±0.01cd·m^{-2}
1.5	ON	0.10±0.01cd·m^{-2}
1.2.7	ON	0.10±0.01cd·m^{-2}
1.2	ON	0.10±0.01cd·m^{-2}
1.1.67	ON	0.10±0.01cd·m^{-2}
1.1.47	ON	0.10±0.01cd·m^{-2}
1.1.25	ON	0.10±0.01cd·m^{-2}
1.1.14	ON	0.10±0.01cd·m^{-2}
1.23	OFF	0.10±0.01cd·m^{-2}
1.5	OFF	0.10±0.01cd·m^{-2}
1.2.7	OFF	0.10±0.01cd·m^{-2}
1.2	OFF	0.10±0.01cd·m^{-2}
1.1.67	OFF	0.10±0.01cd·m^{-2}
1.1.47	OFF	0.10±0.01cd·m^{-2}
1.1.25	OFF	0.10±0.01cd·m^{-2}
1.1.14	OFF	0.10±0.01cd·m^{-2}

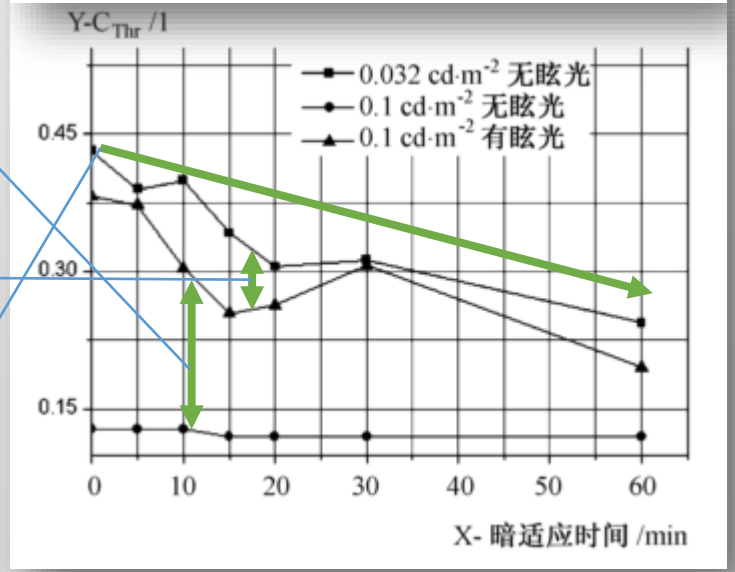
8 contrast levels
2 glare conditions
2 background luminance levels
7 adaptation time levels

Glare will significantly increase the contrast threshold

The increase of luminance will decrease the contrast threshold

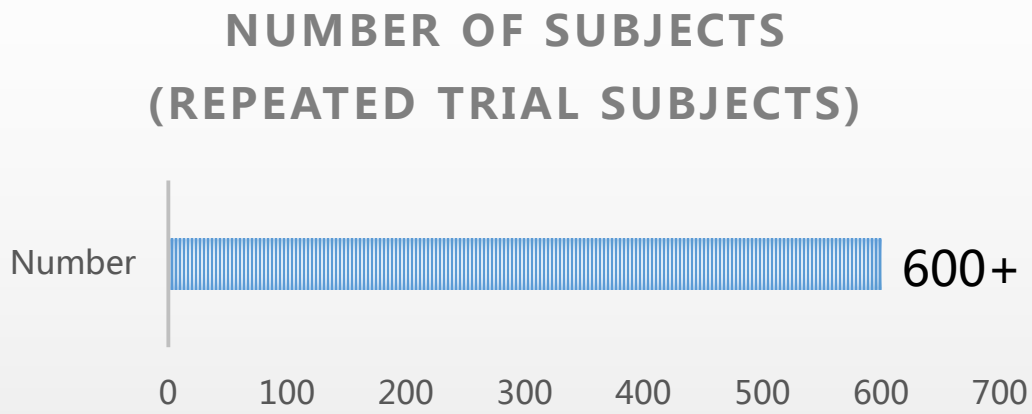
A longer adaptation time will decrease the contrast threshold

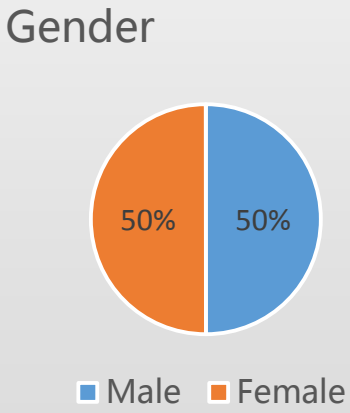


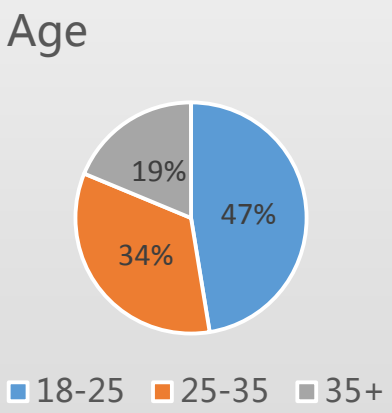


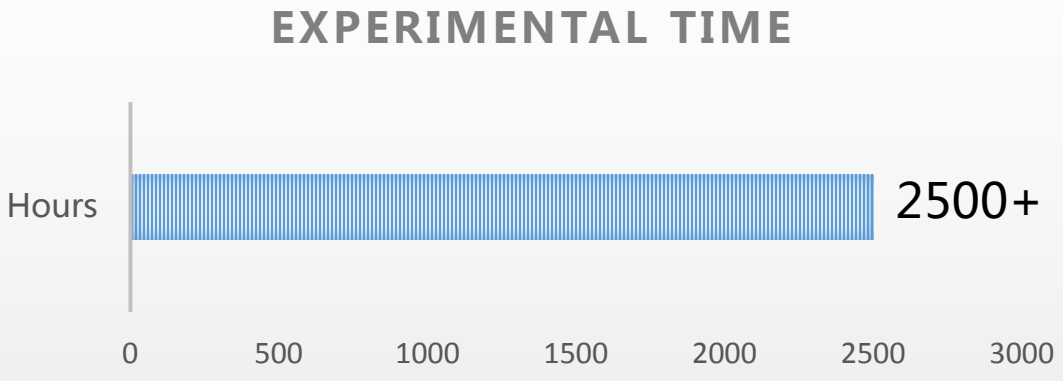
Ji Z, Lin Y. The Effect of Adaptation Time, Adaptation Luminance and Glare on Contrast of Human's Eye[J]. China Illuminating Engineering Journal, 2006

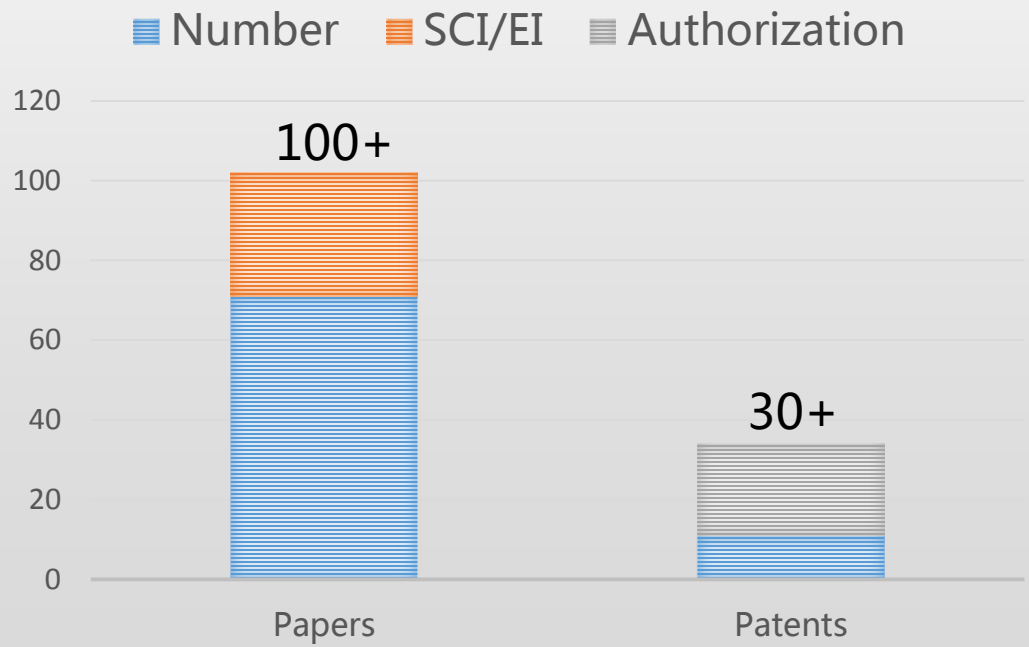
FDU research: glare & visibility









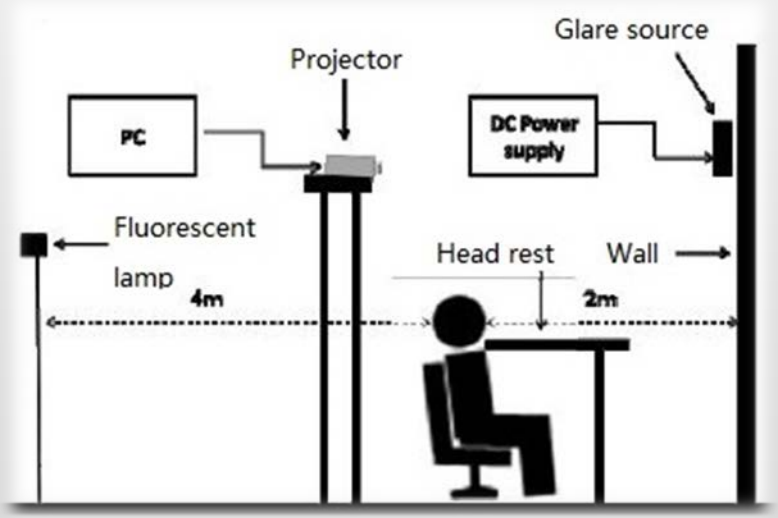


Statistics of research findings

Yongjian Wei, Yandan Lin, etc. The Effect of Stimulus Duration on Discomfort Glare Rating at Mesopic Adaptation. Light & Engineering. Vol.14(3): 80-87, 2006.

FDU research: glare & visibility

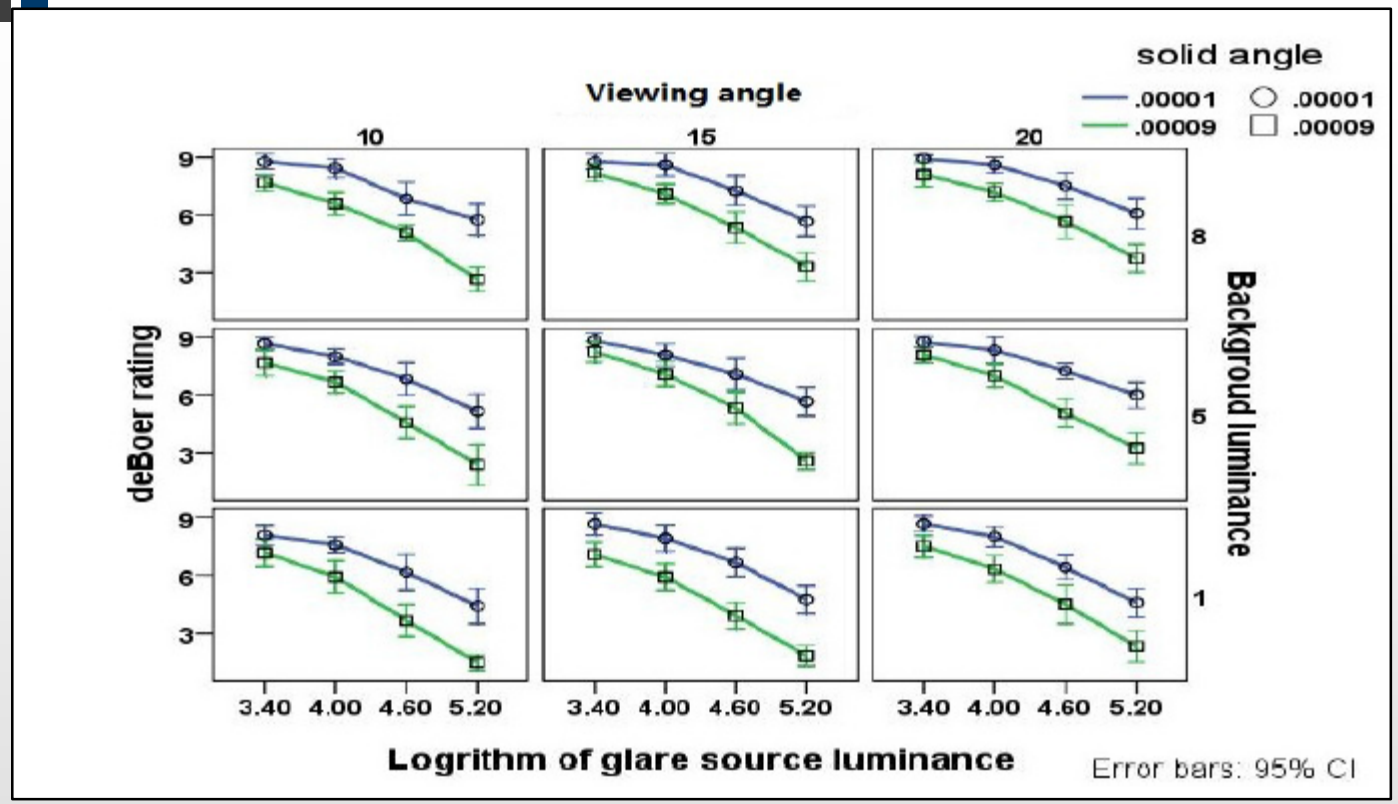
- **Purpose:** To model discomfort glare from LED road lighting by the effect of four key variables.
- **Variables:**
  - The average glare source luminance (Lg)
  - The background luminance (Lb)
  - The solid angle of the glare source from the perspective of the viewer (ω)
  - The angle between the glare source and the line of sight (θ).
- **Number of light conditions: 72**
- **Subjects: Female(7),Male(5)**



The schematic of the experimental set-up

Yandan Lin, Yihong Liu, Yaojie Sun, Xiaoyan Zhu, Jushui Lai, and Ingrid Heynderickx. Model predicting discomfort glare caused by LED road lights. Optics Express, 22: 18056-18071, 2014

Research status of glare and visibility of FDU



Glare source luminance ↓ → The DeBoer rating ↑

Solid angle ↓ → The DeBoer rating ↑

Background luminance ↓ → The DeBoer rating ↓

Viewing angle ↓ → The DeBoer rating ↓

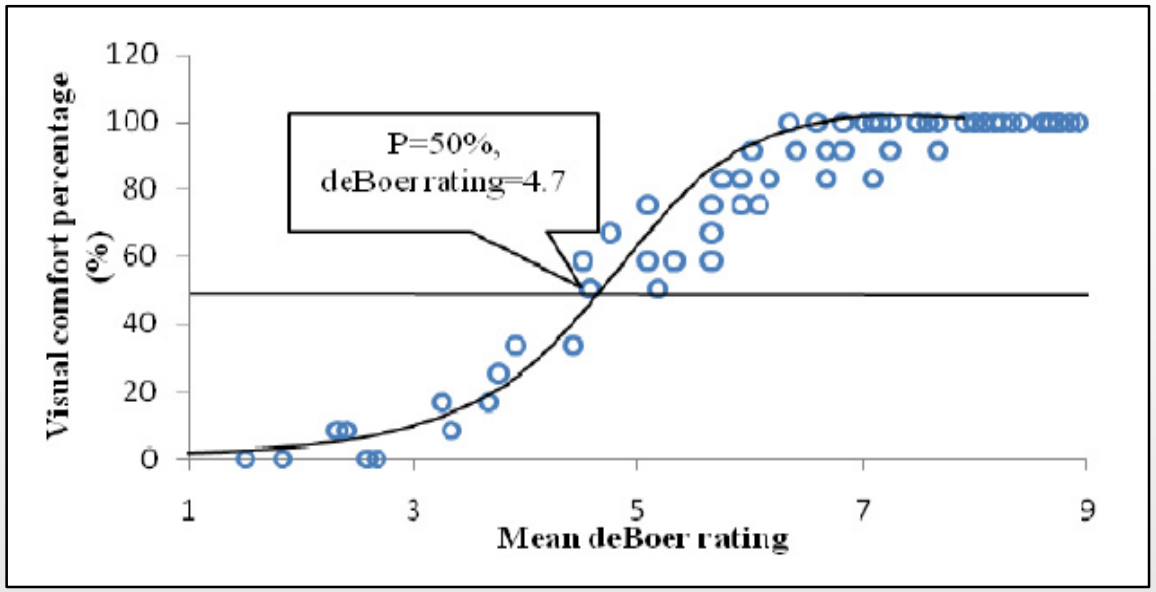
Change in the DeBoer rating for the four independent variables

Significant effect on the DeBoer rating by interactions of two variables →

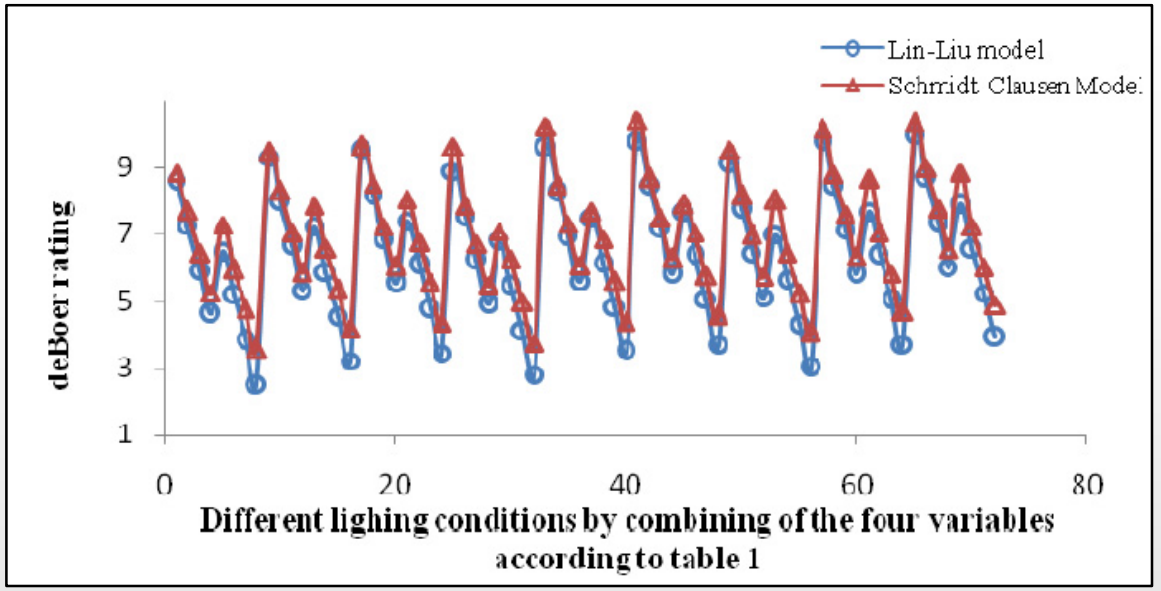
- Glare source luminance with solid angle
- Glare source luminance with background luminance

Yandan Lin, Yihong Liu, Yaojie Sun, Xiaoyan Zhu, Jushui Lai, and Ingrid Heynderickx. Model predicting discomfort glare caused by LED road lights. Optics Express, 22: 18056-18071, 2014

FDU research: glare & visibility



Curve fitting of the mean DeBoer rating vs. the percentage of people indicating that the light setting was comfortable



Comparison between our model for discomfort glare and the one of Schmidt-Clausen for the 72 light conditions used in the main experiment.

$$R_{deBoer} = 3.45 - \log_{10}\left(\frac{(L_g \times \omega)^{2.21}}{L_b^{1.02} \times \theta^{1.62}}\right)$$

$$R_{deBoer} = 5.0 - 2.0 \times \log_{10} \frac{E_i}{0.03 \times \left(1 + \sqrt{\frac{L_a}{0.04}}\right) \times \theta_{max}^{0.46}}$$

Yandan Lin, Yihong Liu, Yaojie Sun, Xiaoyan Zhu, Jushui Lai, and Ingrid Heynderickx. Model predicting discomfort glare caused by LED road lights. Optics Express, 22: 18056–18071, 2014

FDU research: glare & visibility

1995 CIE model

$$V_{UGR} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \frac{L_{s,i}^2 \cdot \omega_i}{p_i^2}\right),$$

2007 Takahashi model

$$V_{UGR_{S1}} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \cdot 200 \frac{I_i^2}{r_i^2 p_i^w}\right),$$

2002 CIE small size light source model

$$V_{UGR_{small}} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \cdot 200 \frac{I_i^2}{r_i^2 p_i^2}\right),$$

2015 Yang model

$$V_{UGR_{S2}} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \cdot 200 \frac{I_i^2}{r_i^2 p_i^{w+c}}\right),$$

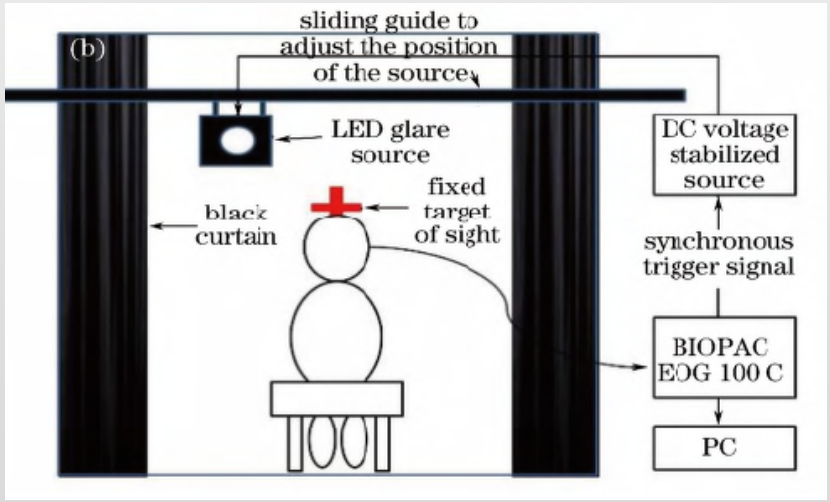


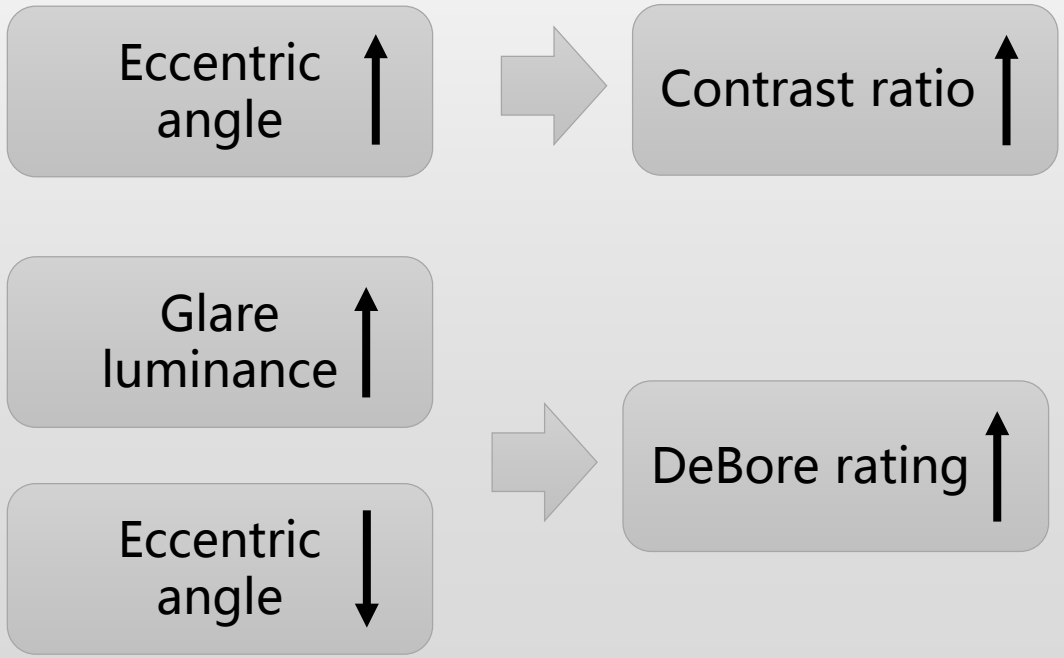
Table 1 Parameter settings of control variables

Control variable	Value
Glare source vertical eye position illumination E_g/lx	20/50/125/300
Glare source orientation angle θ /(°)	2/4/8/16
Glare source color temperature T /K	3300/5700

Feng A, Li L, Zhou L, Lin Y et al. Validation and Optimization of Discomfort Glare Model for White LED[J]. Acta Optica Sinica, 2017, 37(7):0733001.

FDU research: glare & visibility

- **Method:** deboer rating.
- **Number of light conditions: 32**
- **Subjects:** Female(2),Male(8)
- **Average age: 24.5**
- **Results:**



- **Optimized model**

$$V_{UGR_{Sa}} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \cdot 200\frac{I_i^2}{r_i^2 p_i^{\beta-\alpha\cdot c}}\right),$$

$$V_{UGR_{Sk}} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} \cdot \sum_{i=1}^{n} \cdot 200\frac{I_i^2}{r_i^2 p_i^{\beta/k}}\right),$$

- **Revelation**

Feng A, Li L, Zhou L, Lin Y et al. Validation and Optimization of Discomfort Glare Model for White LED[J]. Acta Optica Sinica, 2017, 37(7):0733001.

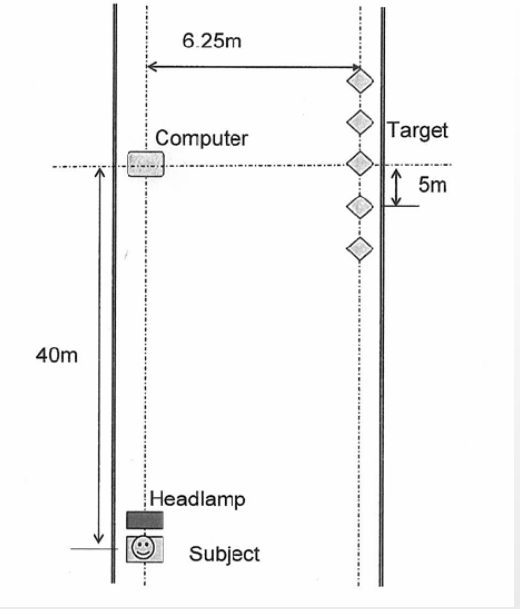
FDU research: glare & visibility

- **Purpose:** Comparing visual performance under 3 types headlamps' low beam without road lighting and opposing glare light.

Experimental conditions

Parameter		Values
Fixed parameters	Viewing	Binocular
	Fixed lighting	Without fixed lighting
	Opposing glare	Without opposing glare from other car
	Duration of the viewing time	1s
	Size of target	60 cm in width, 170 cm in height
	Contrast of target	0.6
Variable parameters	Headlamp	Headlamp1: HID, parabolic
		Headlamp2: HID, projector
		Headlamp3: Halogen , parabolic
	Viewing distance	30m, 35m, 40m, 45m, 50m

- **Experimenter A:** Controlling observing time to be 1s and recording response of subject.
- **Experimenter B:** In charge of placing and changing target.
- Totally 135 measured data.



The schematic layout for field study

- Discriminability index (**d_a**) is calculated by Two-Alternative Forced-Choice (**2AFC**) theory.
- **Conclusion:**
  - HID headlamps is better for pedestrian detection in peripheral.
  - HID headlamps provide brighter foreground and higher vertical illuminance on roadside.

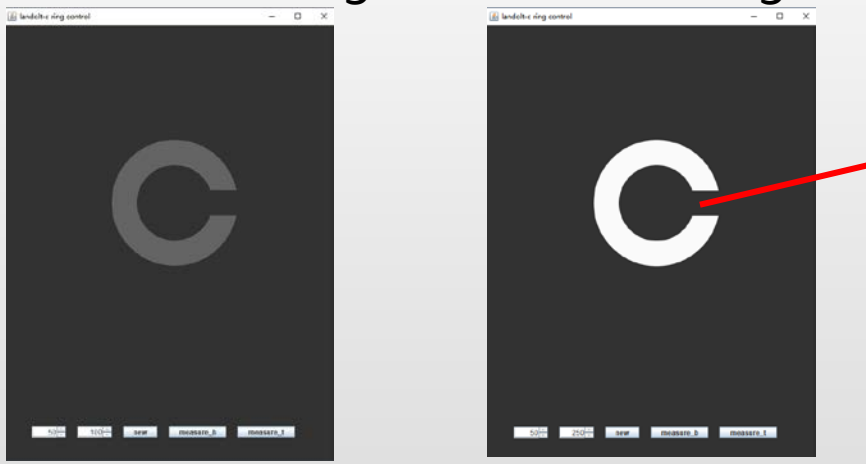
Wencheng Chen, Yandan Lin, Shinichi Kojima, Dahua Chen. A study on peripheral visibility under different headlamp low-beam pattern. Journal of Light & Visual Environment. 12: 1-7, 2008

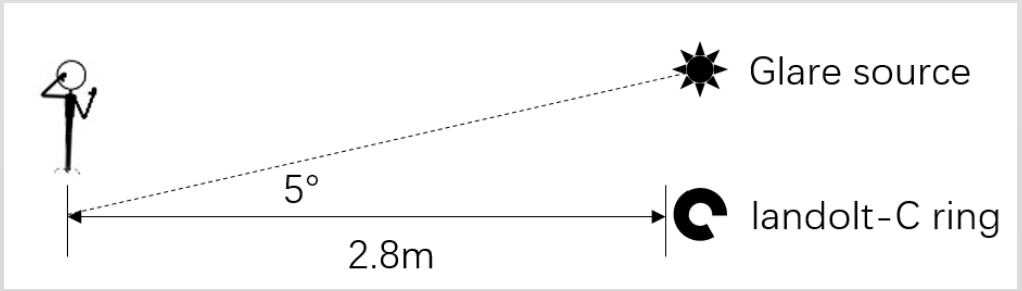
FDU research: glare & visibility

At a certain distance, a proper illumination shall satisfy the demand for recognizing the target without cause serious glare.

Two parts

1. The contrast threshold that the target can be recognized.
2. The effects of glare on different glare levels.



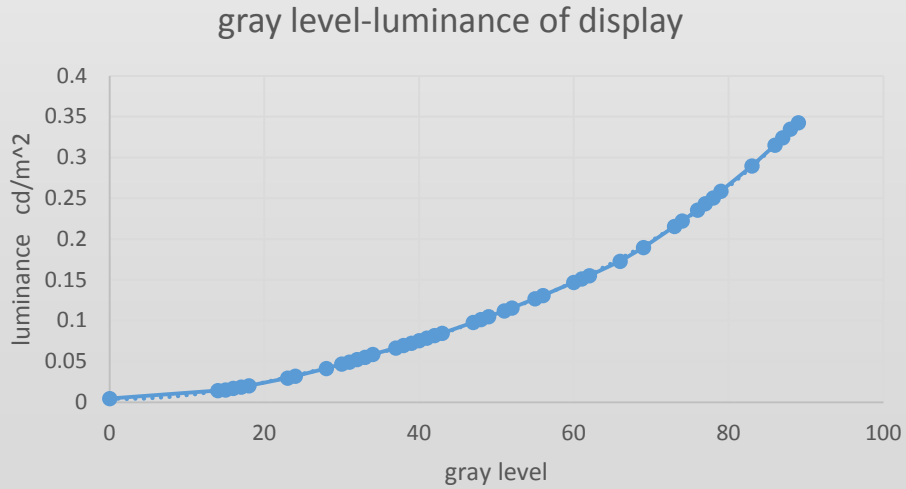


layout

Software to produce different contrast by adjusting the background luminance and target luminance separately

5.6cm, which is equal the field angle that observing a 1.2m child from 60m away

The safe distance driving at 60km/h speed



Tested by Lin&Li, Fudan Uni.

FDU research: glare & visibility

Experiment 1: contrast threshold

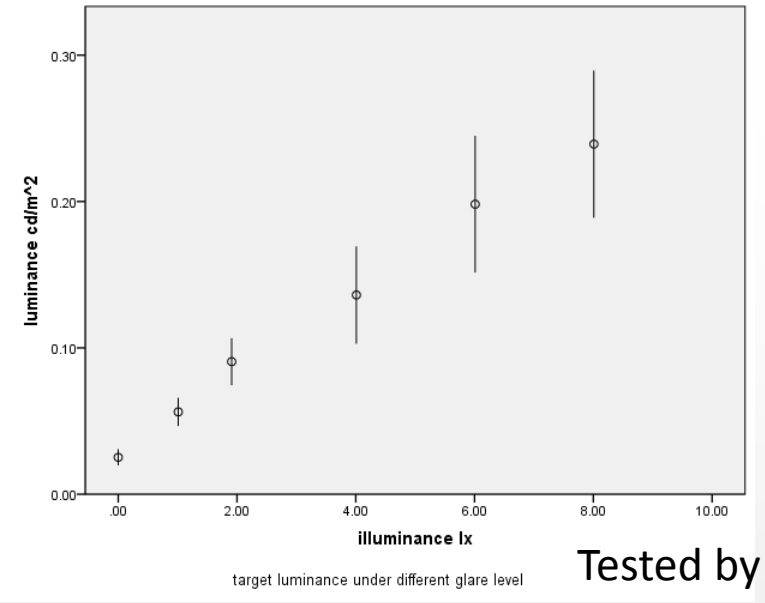
Background : 0.0048 cd/m²

Target luminance: 0.02521 Std: 0.008355

Contrast threshold: 4.25

The average reflectance of black clothes: 0.03

Background luminance cd/m²	Target luminance cd/m²	illuminance lx
0.001009	0.005297	0.554727
0.002	0.0105	1.099557
0.0048	0.0252	2.638938
0.00839	0.044	4.612643
0.021	0.11025	11.54535



Tested by Lin&Li, Fudan Uni.

Taking Background luminance 0.0048 cd/m² as example:The illuminance at 60m away shall be at least 2.63lx

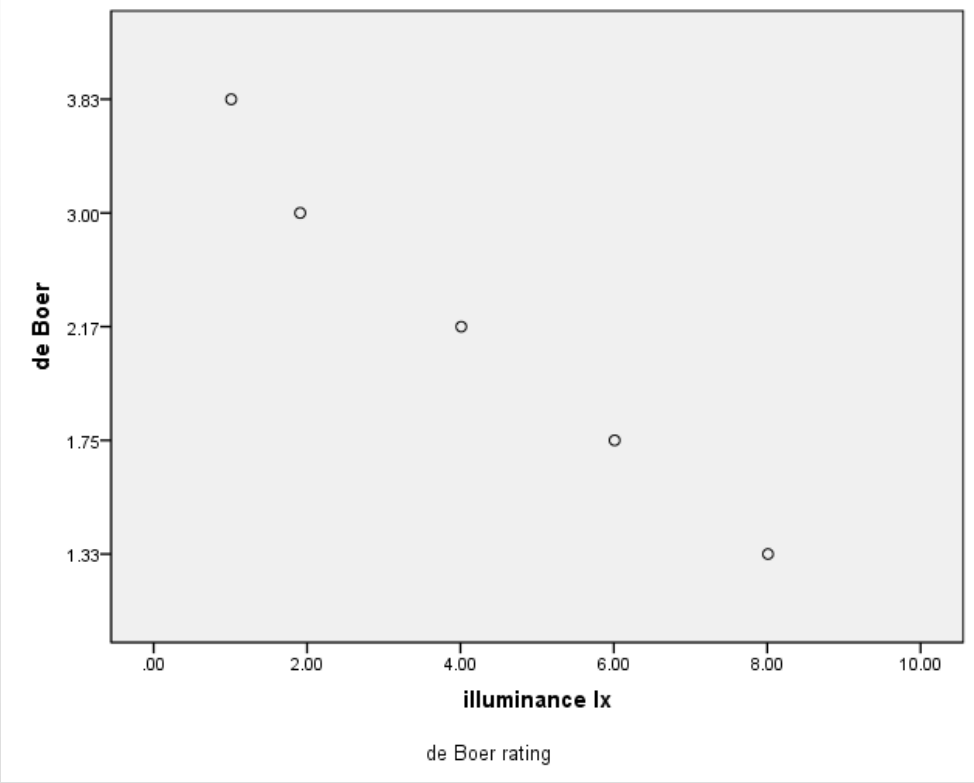
Only in the very dark environment can we suppose that the luminance of the driving target exceeds the background brightness, all of which comes from the illumination of the headlamp.

In other environment, the light is also produced by other light source

Backgound luminance is defined base on reference: Tan M Q, Hao Y X. Study on night-sky brightness in Beijing[J]. China Illuminating Engineering Journal, 1994.

FDU research: glare & visibility

Experiment 2: Evaluation



Illuminance on the eye's position	Target luminance	Threshold increment	De Boer rating
0	0.0252	\	\
1.01	0.0562	6.46	3.833
1.91	0.0906	13.62	3
4.01	0.1361	23.10	2.167
6.01	0.1981	36.02	1.75
8.01	0.2392	44.58	1.33

3-4lx is an just appropriate value

Tested by Lin&Li, Fudan Uni.

Summary

Summary

1 Research method to optimize ADB

- Through the scientific research method to optimize the ADB light distribution, luminance and other parameters.

2 Glare-visibility model to avoid glare for ADB

- Predicting the glare-visibility relationship during different light by the model.

3 Parameters for accessing ADB

- Accessing ADB through the parameters from the parallel field experiments.

Thank You for Your Viewing

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