A New Energy Saving Method for Street Lamp under the Equivalent Brightness Perception

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Abstract. In the process of vehicle driving, the driver's brightness perception to the ground is not equal to the luminance of road surface due to different degree of stimulation caused by glare of street lamp. Based on brightness perception, this pupil size aims to explore the specific influence of different glare on the brightness perception, and further understand how to reduce the glare of street lamp and the luminance of road surface while maintaining the same brightness perception. However, the existing road lighting standards are still based on luminance, and the current research on brightness perception is also just limited to the division of different brightness perception levels as the measurement is very complex. In this study, the pupil size is used as a new research medium in the study of brightness perception. A linear relationship between pupil size and brightness perception can be discovered through experimental studies. Since pupil size can be measured in real time, the influence of glare on pupil can be further studied to obtain the relationship between glare and the brightness perception of the road surface, which provides a possibility for the study of maintaining the same brightness perception and reducing street lamp energy consumption.

Introduction

Brightness perception refers to the photochemical effect caused by the light flux projected on the retina by the imaging beam on photoreceptor cells distributed on the retina in the imaging area, and the special stimulation caused by it is perceived by the observer to produce vision. The observer relies on the strength of the sensation to determine the brightness of the object being observed. This kind of active judgement determines the complexity and unreliability of brightness perception measurement. The existing brightness perception measurement within the range of road lighting is just divided into 7 different levels, such as bright, brighter, dark, darker, and so on [1]. There is no relatively clear measurement method, so the existing lighting standards [2] are still measured on the basis of luminance.

Existing studies only show that different degrees of street lamp glare can affect brightness perception, but no specific degree of influence has been explored. Therefore, in order to further study how to maintain the same brightness perception, we need to find a more suitable medium for equivalent measurement. Quantify the relationship between subjective brightness and several objective physical quantities, and provide a certain theoretical and data basis for the study of Brightness perception.

Methods

Because brightness perception is closely related to human vision, existing studies have shown that glare from street lamps can also cause pupil irritation[3,4], this pupil size attempts to take the pupil of human eye as a new research medium from the perspective of human vision to seek the internal relationship between brightness perception and the pupil of human eye. Thanks to the pupil of human eyes can be measured in real time. By exploring the change of pupil size in different environments, we can correspondingly express the change of brightness perception, so as to know how to change the objective environment to maintain the same brightness perception.
According to Weber-Fechner Law, the external stimulus is proportional to the logarithm of the subjective experience.

The luminance of the road surface is set as $L$ (Luminance) and the driver’s brightness perception is set as $B_P$ (Perception brightness), and the relationship between brightness perception and luminance is

$$B_P = C + D \cdot \ln L_U \quad (C > 0, D > 0)$$

(1)

In the researches of visual experimental psychology, based on the relevant theories and experimental results of Leonard Thompson Troland[5], the changes of luminance have an influence on the pupils and cause varying degrees of stimuli. There is a functional relationship between pupil size and luminance (see Fig. 1).

![Figure 1. Relationship between the luminance and the pupil size.](image)

The pupil size is set as $S_P$, so the expression of the pupil size and the luminance of the human eyes is

$$L_U = (S_P - E) / F \quad (E > 0, F > 0)$$

(2)

From equation (1) and equation (2), we have

$$(B_P - C) / D = (B_P - E) / F$$

(3)

So if we compare two sets of different brightness perception, we will get

$$B_{P_1} - B_{P_2} = D \cdot (S_{P_1} - S_{P_2}) / F$$

(4)

$B_P$: Brightness perception; $L_U$: The luminance of the road surface; $S_P$: pupil size;

Due to the constants of C, D, E and F, from equation (4), there is a linear relationship with a higher level of compliance between the brightness perception and the pupil size under the conditions of moderate stimuli. To convert the conditions of equivalent brightness perception to the conditions of equivalent pupil size. Consequently, on the basis of relationship between the measured glare and the pupil size data, the brightness perception and the changes after the decrease of the glare can be obtained.

**Experiment**

**Experimental Conditions**

Experimental site: a full darkroom which is 3.0m in height, 6.5m in width and 23.0m in length. The interior of the space is coated with ultra-low reflective paint.

Experimental light source: a. LED glare source (spot light, cold light, 8W). b. Road light of producing the luminance of road surface (Grille lamp, warm light, 6W).

Luminance and glare measurement: RADIANT VISION SYSTEMS I-PLUS, Brightness Imager, which is able to measure luminance and the intensity of glare. Because in this paper, the object of our study is the field of road lighting. So the average road surface luminance ($L_{av}$) was researched.
in this study, glare (TI value) was researched in this study. In this study, Lav and glare light source were separated to facilitate the control of different Lav and TI values to meet the requirements of the experiment.

Pupil measurement: Dikeablis Pro Eye Tracker, to collect the data of such indicators as the area of the pupils and the frequency of blink [6]. The measurement accuracy is 130 ms. Although the measurement data of the eye tracker will be error due to the wearing angle, we only need to know the relative value.

Collection of Pupil Data
Stimulated by light, the pupil size is constantly changed and adjusted and the pupil will gradually enlarge and recover until it finally adapts to the light environment [7,8]. The pupil size selected by the experiment refers to the pupil area data fluctuation after the glare stimulation for a period of time is relatively stable within 5-10s.

Collection of Luminance Pupil Size
Lav is increased from 1.05cd/m² to 1.85cd/m², increased by 0.20cd/m². The TI is increased from 1% to 10%, increased by 1%. In the experiment, the pupil size $S_p$ is a function of the TI value and the Lav. The changes of TI value and pupil size in the laboratory are as shown in Fig. 2. Take the situation that Lav is 1.45cd/m² and the TI values are 1%, 4% and 10% as an example.

Table 1. Different Lav and relative pupil size under different TI values [Unit: pixel].

|       | 1.05 cd/m² | 1.25 cd/m² | 1.45 cd/m² | 1.65 cd/m² | 1.85 cd/m² |
|-------|------------|------------|------------|------------|------------|
| TI=1% | 900.63     | 923.83     | 1003.47    | 1008.56    | 1116.86    |
| TI=2% | 820.44     | 853.53     | 900.82     | 968.69     | 1035.88    |
| TI=3% | 791.87     | 837.13     | 791.22     | 905.40     | 938.09     |
| TI=4% | 740.97     | 828.60     | 783.14     | 860.87     | 910.61     |
| TI=5% | 735.07     | 796.96     | 770.20     | 820.83     | 871.66     |
| TI=6% | 679.62     | 756.03     | 760.98     | 796.15     | 836.99     |
| TI=7% | 649.90     | 677.70     | 731.58     | 760.63     | 822.90     |
| TI=8% | 640.55     | 649.11     | 710.26     | 734.80     | 812.02     |
| TI=9% | 637.38     | 645.88     | 695.77     | 717.52     | 800.52     |
| TI=10%| 630.98     | 643.66     | 680.38     | 703.28     | 787.10     |

According to Table 1, the characters are discovered as follows. Firstly, with the same luminance, as the TI value increases, the pupil size gradually decrease; with the same TI value, as the luminance increases, the pupil size increases. Then, within limits, under the same pupil size, the relatively high TI value with the relatively low Lav have the same effect as the relatively low TI value and high Lav, which means that strengthening the Lav and reducing the TI value can improve
the brightness perception of human eyes. What’s more, corresponding to the 5 sets of Lav, the pupil size increase monotonically with the TI value by nearly one third, corresponding to the 10 sets of TI value, while the pupil size increase monotonically with the Lav by nearly on fifth. Since the pupil is a sign of retinal light sensitivity [9], the pupil size is more sensitive to TI value than Lav [10].

**Discussion and Verification**

Scatter diagram is used to perform curve fitting for the table above, and the fitting results are shown in Fig. 3. The linear relationship between the pupil size and the logarithmic unit of light intensity shows a close correlation in all cases.

![Figure 3. Curve of the relationship between different TI value and pupil size.](image)

On the basis of Fig. 3, all curves contain pupil area in the 750-950 pixel range, typical points such as 750, 800, 850, 900 and 950 are drawn to make vertical lines intersecting with the curves in the figure. The intersection points are the relationship between the glare and Lav under the same pixel, as is shown in Fig. 4.

![Figure 4. Several typical pupil size.](image)

The corresponding Lav and TI values under the different pupil size can be derived from the values of different intersection points. When the pupil size is constant, the relationship between the TI values and the Lav can be obtained, as is shown in Fig. 5.

According to Fig. 5, it can be discovered that when the pupil size is in the certain range of (750, 950), the TI values have positive correlation with the Lav in the range of (1.05cd/m², 1.85cd/m²) and numerically increase monotonically with Lav. Taking the pupil size of 800 pixels as an example, when the TI value is 8.0%, the corresponding Lav value is 1.85cd/m². When the TI value is reduced to 2.5%, the corresponding Lav is 1.15cd/m², decreased by 0.7cd/m², by more than 37%.

Reverse verification of the experimental results is a procedure that we must go through to conduct an inquiry experiment, so as to further increase the credibility of the experimental results and provide a basis for the improvement of the experiments. As shown in Fig. 5, the curve of the same pupil area is fitted by several data, which may cause certain errors. Therefore, we need to verify the experimental data to some extent.
Figure 5. The relationship between the Lav and TI values under the same pupil size.

According to the fitting formula of the curve, we can get Lav and TI values corresponding to different pupil areas. According to the corresponding objective conditions, we re-measure the corresponding pupil size. The comparison is shown in Table 2.

Within the allowable range of error, the curve fitting data has certain reliability.

The five curves of equal pupil size in Fig. 5 are done the best fitting to obtain an equal pupil size curve with the minimal variance, as is shown in Fig. 6.

Table 2. The comparison between the theoretical pupil value and the actual pupil value [Unit: pixel].

| Objective conditions | Theoretical pupil size | Actual pupil size |
|----------------------|------------------------|-------------------|
| 1.05cd/m², 2.6%      | 750                    | 760.39            |
| 1.25cd/m², 4.0%      | 750                    | 740.20            |
| 1.45cd/m², 6.0%      | 750                    | 751.71            |
| 1.65cd/m², 8.2%      | 750                    | 730.78            |
| 1.05cd/m², 2.0%      | 800                    | 789.64            |
| 1.25cd/m², 3.1%      | 800                    | 803.68            |
| 1.45cd/m², 4.7%      | 800                    | 810.07            |
| 1.65cd/m², 6.6%      | 800                    | 783.19            |
| 1.05cd/m², 1.2%      | 850                    | 840.99            |
| 1.25cd/m², 2.1%      | 850                    | 836.38            |
| 1.45cd/m², 3.3%      | 850                    | 865.56            |
| 1.65cd/m², 4.8%      | 850                    | 866.88            |
| 1.05cd/m², 0.8%      | 900                    | 916.72            |
| 1.25cd/m², 1.5%      | 900                    | 886.31            |
| 1.45cd/m², 2.3%      | 900                    | 880.18            |
| 1.65cd/m², 3.3%      | 900                    | 914.17            |

It is obvious that the comprehensive equal pupil size curve obeys the rule that the TI values increase monotonically with Lav. In Fig. 6, when the TI is 6.0%, the corresponding Lav is 1.80cd/m². When the TI value is reduced to 2.0%, the corresponding Lav is 1.2cd/m², decreased by 0.60cd/m², by 33.33%!
Conclusion

The following conclusions can be drawn from the above experiments. Under the condition of medium stimulation, the pupil size has a linear relationship with the brightness perception, numerically, which enables to reduce the glare of road lights while decreasing Lav and keeping the brightness perception invariable.

To reduce Lav is to reduce energy consumption. Although at present we cannot prove the accurate relationship between Lav and energy consumption, from the existing researches of consumption and luminance, the efficiency of energy saving is apparent by the requirement of lowering Lav. At the same time, reducing the consumption can enable the constant brightness perception of the driver. Compared with the improvement of luminaire and the adjustment of lighting design in transitional road lighting, the experimental results here offer a new method of energy saving for road lighting, from the perspective of reducing Lav and still keep the constant brightness perception. In addition, this study can also provide a new reference for brightness perception measurement.

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