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PRELIMINARY RESEARCH ON MATHEMATIC MODEL OF EYE'S ADAPTATION LUMINANCE

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Abstract

CIE recognizes the need for a comprehensive research program to develop a fundamental model of discomfort glare as its Top Priority Topics of research strategy. One drawback for current glare evaluation models is their faults to take average environment luminance as an indicator for visual adaptation, which means that luminance distribution and glare sources are not taken into account. There is no doubt that the measurement or estimation of adaptation level in natural environments is practically important.

IpRGCs act as a photon counter in the same way than a light meter in a camera, which project to the olivary pretectal nucleus (OPN) to control pupil light responses. In this research we will establish a facility to simulate different luminance distribution with a diameter 2.4m LED semi-sphere screen, and monitor the pupil diameter with eye tracker. A preliminary model will be developed on the basis of collected data.

Keywords: Discomfort Glare, Adaptation luminance, Pupil diameter, ipRGC

1 Introduction

According to CIE DIS 017-2017, glare is the condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme luminance contrasts[1]. Glare is the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility [2].

As a very important parameter for visual environment evaluation, glare is a hotspot and difficult topic of this field. CIE recognizes the need for a comprehensive research program to develop a fundamental model of discomfort glare as its Top Priority Topics of research strategy. Most glare assessments method can be expressed as the following formula:

$$G = \sum_{i=1}^{n} \left(\frac{L_s^e \omega_s^f}{L_a^g f(\psi)} \right) \quad (1)$$

where

G is the glare index expressing the subjective judgement;

e, f, g are weighting exponents;

$f(\psi)$ is the function of the displacement angle;

ψ is the angular displacement of the glare source from the observer's line of sight;

L_s is the luminance of the glare source;

ω_s is the solid angle of the glare source;

L_a is the adaptation luminance of the observer;

n is the number of the glare sources.

So the key factors influencing the glare perception can be:

_ Luminance of glare source
_ Apparent size of the glare source (solid angle)
_ Location of glare source in the visual field
_ Number of glare sources
_ Adaptation luminance

One of the most useful operations in our visual system is "adaptation" or "automatic gain control", to adjust the sensitivity of the system to a certain level of luminance so that all the responses are made to lie in the same limited dynamic range[3]. According to <Code for lighting> of CIBSE, visual adaptation is governed by the luminance of the various elements within the field of view, the sizes of the areas involved, and their location with respect to the lines of sight of observers. The adaptation luminance of the eye will play important role on glare evaluation[4].

The adaptation luminance is conventionally determined by the average background luminance of the visual field. For instance, the adaptation luminance of UGR is defined as the uniform luminance of the whole surrounding, which produces the same illuminance on a vertical plane at the observer's eye, as the visual field under consideration, excluding the glare sources [5]. The adaptation luminance of VCP is defined as the average luminance of the entire field of view [2]. The adaptation luminance of GR or TI is defined as the average luminance of a specified surface being observed (road surface and ect.)[6].

In everyday lives, however, we see an object or a light in complex surrounds consisting of objects and lights of various luminance and chromaticity. We should know the adaptation level of the visual system to a complex field in order to make an accurate evaluation of glare. Hopkinson [3] pointed out that the large glare source influences the adaptation level. Wonwoo demonstrate the influence of local background luminance on glare perception[7].Therefore, the conventional method, that uses the average luminance of the field of view as the background luminance is not suitable for the evaluation of discomfort glare. When the background contains areas of different luminance, the adapting luminance is mainly affected by the luminance of each area. But there is no research concerning the level of visual adaptation not only in experimental conditions but also in natural and complex environments.

So it is really an urging task to carry out research on visual adaptation mechanism, which make us better understand the formation mechanism, and provide us technical supporting measures to glare evaluation.

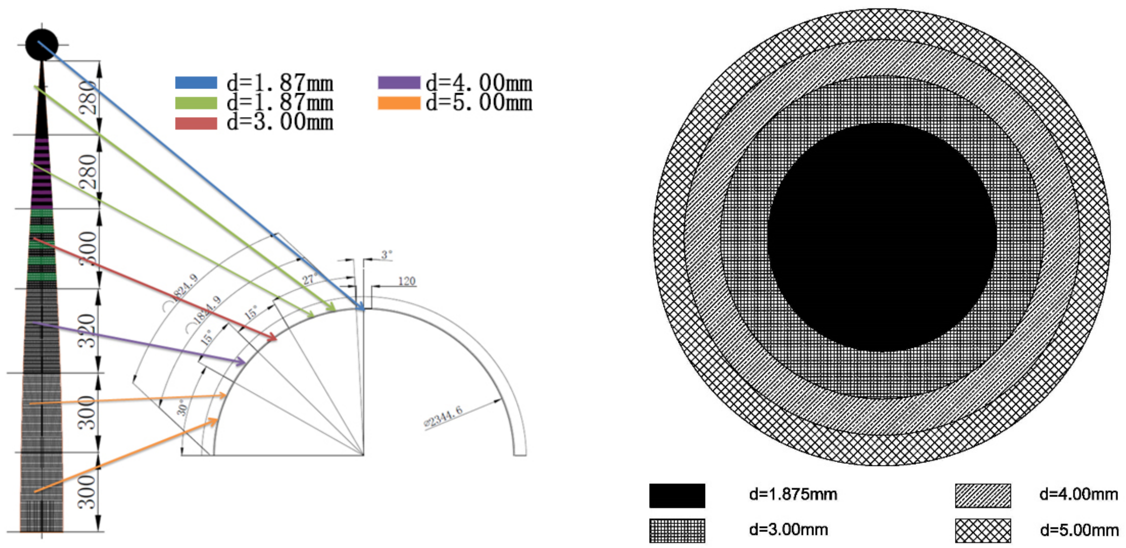
2 Research Methodology

2.1 Research Apparatus

Many authors have previously used a sphere/hemisphere with diffuse painting, like Goldmann perimeter, in the studies of discomfort glare, because it provides a uniform adaptation luminance[8,9,10,11]. In this research a hemisphere LED screen for producing a complex luminance distribution for subjects is established, with the following characters:

Table 1 – Characters of the hemisphere LED screen

Diameter(m)	2.4	Quantity of pixel	723360
Colour	R/G/B	Maximum luminance (cd/m2)	1000
AD conversion	12bit	Pixel distance(mm)*	1.875/3/4/5
* The distribution of different pixel arrangement is shown in figure 1			



d: pixel distance

Figure 1 – The distribution of different pixel arrangement

The subject positioning station by the chinrest used to fix the subject's head position (Figure 2). The observer's eyes were located at the center of the hemisphere LED screen, so that the distance between the observer's eyes and the surface of the sphere was 1.2m. During the experiment the subjects had to adjust, if necessary, the height of the chair to match their eye level and the mark on the chinrest (this was checked by the experimenter). A Tobii Pro Glasses 2 eye tracker to monitor and record the pupil diameter data.

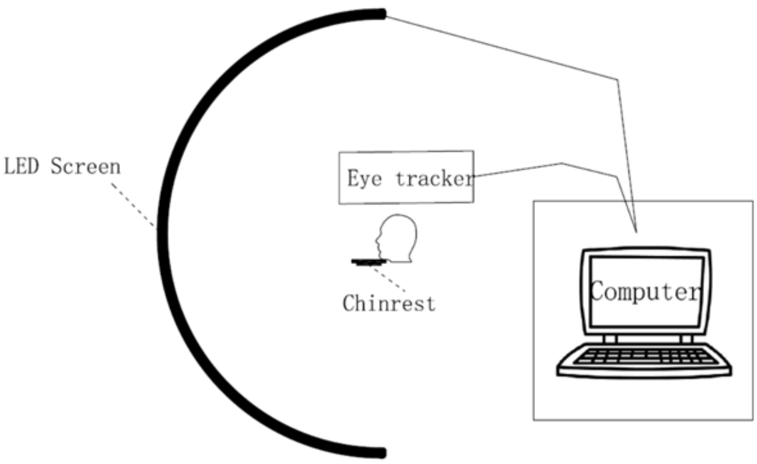


Figure 2 – Schematic of research methodology

2.2 Indicator for eye adaptation

Pupil size depends mainly on the adapting luminance, modulated by other factors, and pupil area decreases with increasing irradiance over a huge intensity range. According to related research, IpRGCs act as a photon counter in the same way than a light meter in a camera [12]. This unique capability, not shared by other photoreceptors, could serve as a reference for the visual system to optimize light adaptation. And IpRGCs project to the olivary pretectal nucleus (OPN) to control pupil light responses [13]. A key feature of the light reflex is its tonic nature in bright light: constriction is held steady under continuous illumination [14]. In this research, the relative pupil constriction is used as indicator for eye adaptation.

2.3 Scenario of research

In the preliminary research stage, we will conduct several experiments to verify the following hypothesis:

1) There is difference on pupil constriction between different CCT scenario;

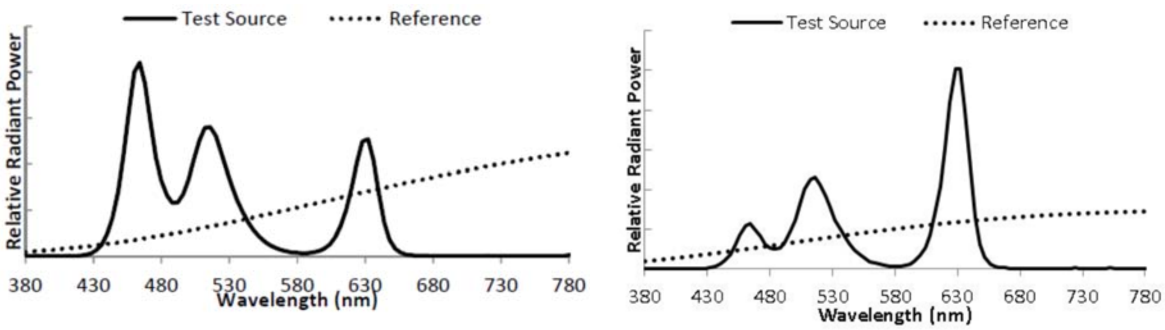
2) Same vertical illuminance on the eye may have different eye adaptation state.

2.3.1 CCT difference verification

The LED screen will be set in the following two CCT scenario with the uniform luminance distribution in full visual field:

Scenario 1: CCT 24200K, the detail information of spectrum is shown in figure 3.a;

Scenario 2: CCT 3460K, the detail information of spectrum is shown in figure 3.b.



Correlated colour temperature (K):24200
Distance to Blackbody Locus(D_{uv}): 0.025

a) Scenario 1

Correlated colour temperature (K):3460
Distance to Blackbody Locus(D_{uv}):-0.0044

b) Scenario 2

Figure 3 – Relative spectrum distribution of two research scenario

2.3.2 Luminance distribution

According to UGR computation method, the vertical illuminance from the environment (excluding the glare sources) is taken as the indicator for the adaptation luminance of the eye, which means the distribution of the environment is not considered. This experiment will make a verification on this assumption, and three scenarios are used:

Scenario 3: CCT 24200K, full screen with a uniform luminance of 1.37cd/m^2, the vertical illuminance on the participant eye is 8.6lx;

Scenario 4: CCT 24200K, only the center part of the Screen (diameter of this part is 120mm,as figure 4 shown) is on with a luminance of 1090cd/m^2, the vertical illuminance on the participant eye is 8.6lx;

Scenario 5: CCT 24200K, only a belt of the screen (as figure 5 shown) is on with a luminance of 4.31cd/ m^2, the vertical illuminance on the participant eye is 8.6lx.

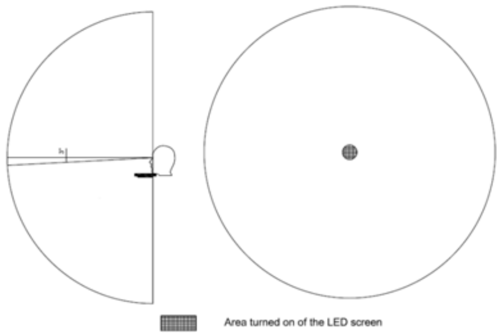


Figure 4 – Schematic of scenario 4

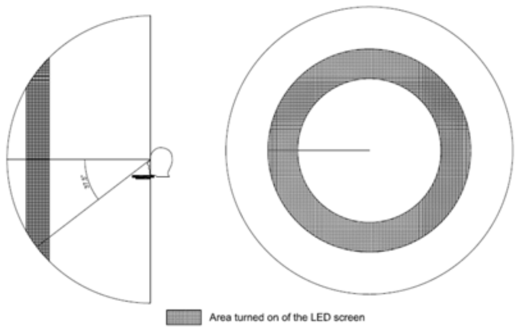


Figure 5 – Schematic of scenario 5

3 Data Analysis

One 37-year male participant undertaking all these experiments in the same morning session (9:00:11:00), and during each experiment scenario, there will be a ten minutes break.

3.1 CCT difference verification

All the experiment data difference between different scenario are statistically significant, and from these data (as figure 6 shown), we can find that:

1) The pupil diameter reduces with the increase of background luminance, but there is threshold that pupil constriction will approach to a limit. In the scenario 1, when the luminance of LED screen is higher than 120cd/m^2, the difference of pupil diameter is not so significant.

2) There is relationship between spectrum of light (here we use CCT as an indicator) and pupil constriction, and higher CCT have higher influence power.

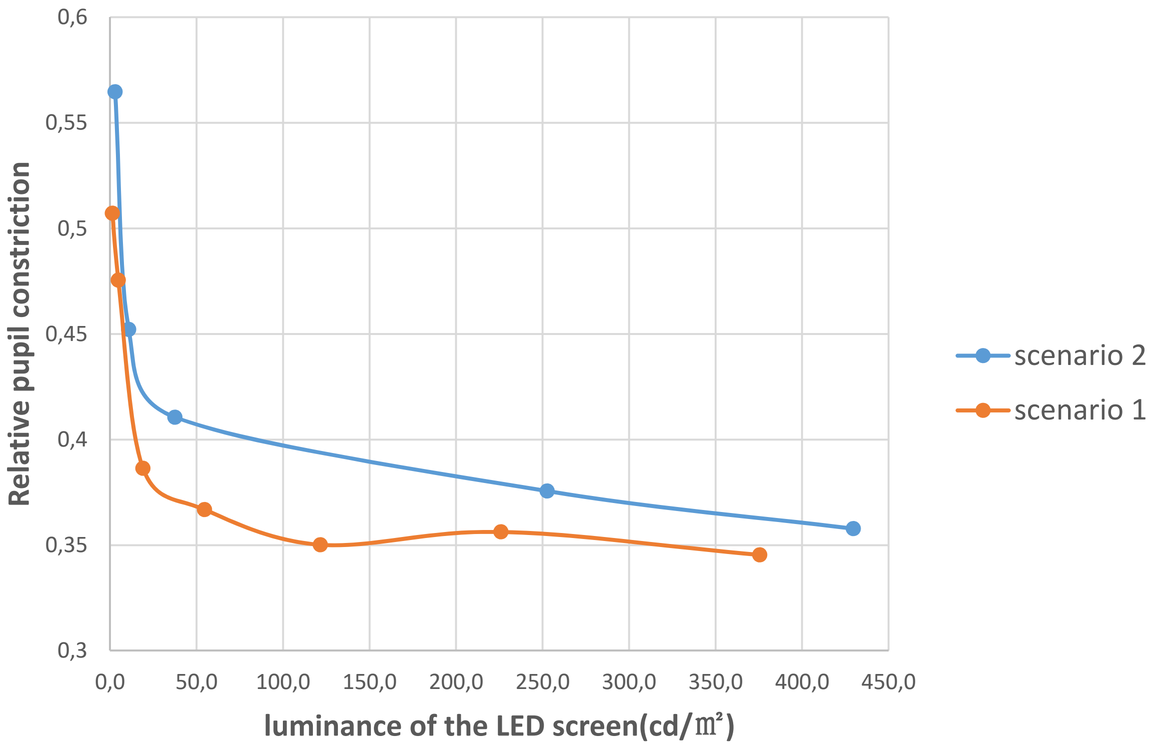


Figure 6 – Relative Pupil constriction comparison under different background luminance in the two scenarios

3.2 Luminance distribution

As table 2 and figure 7 shown, the pupil constriction difference among the three scenarios statistically significant, and from these data (as figure 6 shown), we can find that:

1) The same vertical illuminance on the eye do not always mean the same adaptation luminance;

2) The smaller the angle between the luminous surface and the line of sight, the higher influence power on the pupil constriction;

3) Higher uniformity of the luminance distribution can reduce the influence power on the pupil constriction.

Table 2 – Relative Pupil constriction comparison under different luminance pattern in the three scenarios

(I) Research scenario	(J) Research scenario	Mean difference (I-J)	Standard error	significance	95% confidence interval	
					Upper limit	Lower limit
sc3	sc4	.0623*	.00122	.000	.0594	.0652
	sc5	-.1186*	.00182	.000	-.1229	-.1143
sc4	sc3	-.0623*	.00122	.000	-.0652	-.0594
	sc5	-.1809*	.00186	.000	-.1852	-.1765
sc5	sc3	.1186*	.00182	.000	.1143	.1229
	sc4	.1809*	.00186	.000	.1765	.1852

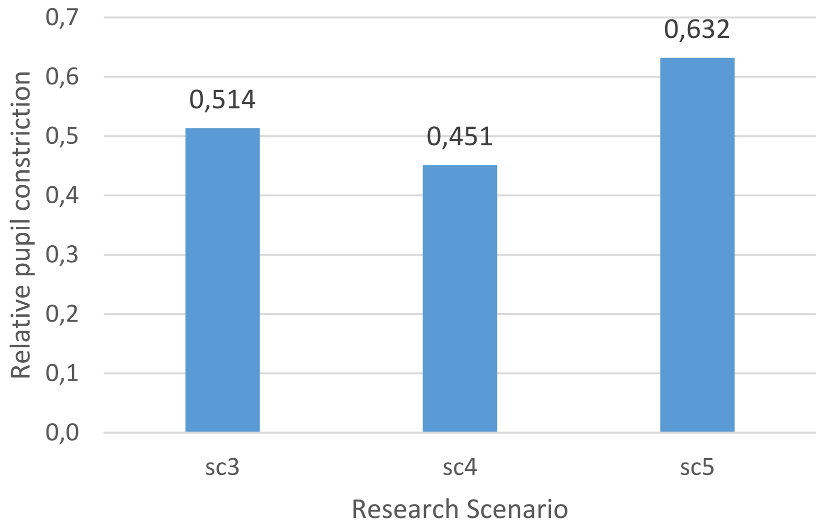


Figure 7 – Relative Pupil constriction comparison under different luminance pattern in the three scenarios

4 Conclusion

A preliminary research on the mathematic model of eye's adaptation luminance was conducted, from which we can found that there is some risk on evaluation the eye's adaptation by using the average luminance of the environment without considering luminance distribution. And light spectrum and luminance pattern in the environment has significant meaning on our adaptation of eyes. A further and deeper research on this topic to develop an adaptation model is needed for better understanding the mechanism of glare.

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