Research Note

A Study on Peripheral Visibility under Different Headlamp Low-beam Pattern

Wencheng CHEN*, Yandan LIN*, Shinichi KOJIMA** and Dahua CHEN*

*Institute for Electric Light Sources, Fudan University, Shanghai 200433, China (ydlin@fudan.edu.cn)

**Research & Development Center, Stanley Electric Co., Ltd., Japan

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ABSTRACT

In this article peripheral visibility under the condition of three types of headlamps' low-beam pattern was compared with the Two-Alternative Forced-Choice (2AFC) method. The three headlamps used in this night-time field study were headlamp No.1: Parabolic-HID, Headlamp No.2: Projector-HID and Headlamp No.3: Parabolic-Halogen. The results show that HID headlamps are better for the detection of pedestrian in peripheral than halogen headlamps because of the higher light output, higher color temperature, brighter foreground and wider spread of light. Some suggestion about criteria of the automobile headlight distribution for Chinese traffic condition was also discussed.

KEYWORDS: automotive lighting, low-beam pattern, peripheral visibility, nighttime driving

1. Introduction

Headlights are required equipment for all cars. The function of vehicle mounted headlamps was to illuminate the street and surrounding area during night time driving¹⁾. The effectiveness of a variety of driver visual aids depends on the illumination from headlamps. For example, retroreflective traffic signs and lane markings are visible primarily because of the reflected headlamp illumination²⁾. The innovation in front lighting has been concentrated on improving light output and optimizing light distribution. The front lighting systems must meet specific requirements standardized in terms of their distributions of luminous intensity and color³⁾.

The distributions of luminous intensity are specified so that headlamps will illuminate the areas of the roadway important to a driver without causing excessive glare to oncoming drivers or to passers-by along the roadway. The photometric standard of automobile lighting in China is based on European system, which suggests a narrow beam pattern and a sharper cutoff, as shown in Figure 1.

With the development of lighting technology, many new headlamps came into the market in recent years: the halogen tungsten lamps, the high pressure gas discharge lamps, first called Xenon and at present known as the High Intensity Discharge (HID) lamps. Moreover, nowadays manufacturers already equip their concept cars with LED headlamp.

HID headlamps have several advantages over tungsten halogen headlamps, including greater luminous

efficacy (lumens per watt) and longer lifetime. With the benefit of small source size of HID headlamps, some new reflector design technology, for example the projector type of headlamp, was developed. A projector headlight produces a stronger beam compared to most parabolic headlights and illuminates a more focused area, providing fewer of what we called "scatter loss"⁴⁾.

As a preparation of this research, an investigation on traffic condition and driver's behavior in China was done through questionnaires on 90 subjects. The results showed that the urban road was more crowded and wide spread low beam pattern was preferred by drivers for detecting other road users around the vehicles, such as pedestrians and cyclists. In the field study we compared the visual performance of drivers under three different types of headlamps' low beam without road lighting and opposing glare lights. The three headlamps used in this nighttime field study were Headlamp No.1: Parabolic-HID, Headlamp No.2: Projector-HID and Headlamp No.3: Parabolic-Halogen. The field experiment was designed according to 2AFC method⁵⁾. The percent of correct (pc) in this 2AFC detection experiment was recorded and then the value of discriminability index (d_a) was calculated as the criteria to evaluate the visibility of the pedestrian under each headlamp.

2. Methods

2.1 Subjects

Nine subjects, three females and six males, aged from 20 to 25, participated in all the experiments. The sub-

The number of Test point names mean target locations in the field.

Ex... 75R; Pedestrian at 75m ahead-Right shoulder. (Long range visibility)

50L; Brightness on the road at 50m ahead-Left. (Beam spread on the straight road) etc.

Figure 1 Photometric requirement of headlamps for motor vehicles in China (according to National Standard of China)

Figure 2 The rack with headlamp system

jects had normal visual acuity and color vision. No other ocular pathology or monocular vision problems were reported. All the subjects understood the purpose and the procedure of the experiments very well.

2.2 Experimental set-up

Figure 2 shows the configuration of the experimental headlamp racks. The height of rack could be adjusted and the mounting height of each lamp is set to 0.65 m (typical height of standard headlamp systems). The headlamp racks were powered by DC 12 Volts.

Three headlamps (the right one) with different beam patterns were used in the experiments. All headlamps were visually aimed at 1% down, so that optical axes of the three headlamps would be parallel.

Figure 3 shows the schematic layout for the field study. The experiment was conducted on a road without road lighting in the campus of Fudan University. The

Figure 3 The schematic layout for the field study

road was 6.8m in width and 60m in length. The pavement surface was dry concrete.

An experiment table with chin-rest for subjects was placed on the road behind the headlamp rack. A computer was placed 40m faraway on a small chair in front

of subject. A distance of 40m is a typical stopping distance, assuming an initial speed of 50km/h. The screen of computer will show numbers randomly in every one second. The target will appear on the right side of road, in one of the five points showed in Figure 3. Average illuminance on the road surface is 0.1lx when the headlamp was off.

The target used in the field study was two printed models, one is "Go" and another is "Stop", as shown in Figure 4. These two targets are 170cm in height and 60

Figure 4 Target used in the field study

cm in width, comparable with a normal person. When the targets were printed, the value of K for the CMYK color system in the Adobe Photoshop software were set to 75% for inside and 90% for surrounding area. When the value of K is 100%, it means total black. When the value of K is 0%, it means total white. That means the shape of figure is brighter than the surrounding when the headlamp is turned on, namely the target has a positive contrast.

2.3 Procedure

There are two experimenters, experimenter A controls the observing time to be 1s and records the response of the subject. Experimenter B is in charge of placing and changing the target between "Go" and "Stop". Most of the time, the subject's view was shielded by a card 30cm in front of the subject's eyes. The card was moved away for 1 second and then the subject was asked to stare at the number on the central computer screen and meanwhile tell out which target in the peripheral area was detected. In this way, the detection of target depends on the subject's peripheral visibility. The target was put randomly by the experimental B in

(a) The low beam pattern of Headlamp No.1 (Parabolic type) on a test screen. (HID lamp)

(b) The low beam pattern of Headlamp No.2 (projector type) on a test screen. (HID lamp)

(c) The low beam pattern of Headlamp No.3 (Parabolic type) on a test screen. (Halogen lamp)

Figure 5 The right part of isocandela diagrams on the test screen for three headlamps used in the experiment

Figure 6 The right parts of isocandela diagrams on the road for three headlamps used in the experiment
The five blue points were according to five positions in figure 3.

Table 1 Experimental conditions employed in the experiment

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

Figure 7 The experimental scene in the field study

one of the 5 fixed places. The experimental scene is shown as Figure 7. Each subject had to detect the target at each point for 10 times. The percent of correct detection was recorded as a result.

3. Results

Totally 135 measured data of correct percent were recorded in the experiments under three headlamps and five target positions for nine subjects. The results were analyzed by the statistical software SPSS 12.0 with the method of ANOVA.

The mean values and the standard deviation (SD) of

Table 2 The mean values and the standard deviation of percent correct for three headlamps at five positions

Distance(m)	Percent correct (%)					
	Headlamp 1 (Parabolic type, HID)		Headlamp 2 (Projector type, HID)		Headlamp 3 (Parabolic type, Halogen)	
	Mean	SD	Mean	SD	Mean	SD
30	91	10.5	96	7.3	90	12.3
35	92	8.3	93	7.1	89	19.7
40	89	10.5	92	9.7	86	11.3
45	82	10.9	86	18.1	81	16.2
50	89	9.3	82	15.6	74	13.3

Table 3 Illuminance values measured on a vertical surface (1 m and 0.1 m above the ground) at five positions for three headlamps

Distance(m)	Vertical illuminance (lx)					
	Headlamp 1 (Parabolic type, HID)		Headlamp 2 (projector type, HID)		Headlamp3 (Parabolic type, Halogen)	
	Height=1m	Height=0.1m	Height=1m	Height=0.1m	Height=1m	Height=0.1m
30	6.9	5.3	6.4	15.7	1.9	2.4
35	5.7	5.3	5.4	13.1	2.2	2.4
40	4.8	4.9	5.0	10.8	2.1	2.3
45	4.5	4.6	4.6	8.9	2.1	2.2
50	4.2	4.1	4.0	7.4	2.3	2.0

Figure 8 Percent correct plotted at distance for three headlamps

Figure 9 Vertical illuminance plotted at distance for three headlamps

percent correct for three headlamps at five positions were shown in Table 2. The vertical illuminances were measured at the height of 1 m and 0.1 m from the ground at five positions under three headlamps and the values were shown in Table 3.

Figure 8 shows the results of percent correct as a function of distance for three headlamps. Percent correct decreased with increasing distance from 30 m to 50

m except at 50 m for headlamp 1. At distance of 30 m to 45 m, percent correct under the condition of headlamp 2 is the best. At distance of 50 m, percent correct with headlamp 1 is the best. Percent correct with headlamp 3 is the lowest for all distance among the three headlamps. Figure 9 shows the results of the average vertical illuminance at five distances for three headlamps.

In order to get more information from the results,

percent correct was transformed to Z scores by the mean and standard deviation. A Z score describes a score in terms of how much it is above or below the average. If the actual score is above the mean, the Z score is positive. If the actual score is below the mean, the Z score is negative.

Figure 10 Z score of percent correct with the standard deviation plotted at distance for three headlamps

$$Z = (X - M) / SD$$

Where X is the raw score, M is the mean, and SD is the standard deviation.

The mean values and the standard deviation of percent correct for nine subjects and three headlamps at five positions were shown in Table 4. The Z score of percent correct with the standard deviation was shown in Figure 10.

At the distance of 50 m, percent correct for headlamp 1 is 89%, for headlamp 2 is 82% and for headlamp 3 is 74%, which were shown in Figure 11. The corresponding Z score of percent correct at the distance of 50 m which was normalized by headlamp 3 was showed in Figure 12.

According to the theory of 2AFC, calculation of discriminability index (d_a) from the 2AFC percent correct is straightforward:

$$d_a = \sqrt{2} \cdot z(pc)$$

Where $z(pc)$ is the z-score transform of the 2AFC percent correct⁵⁾. The value of d_a for the average percent correct of five distances, which was normalized by headlamps 3, was selected as criteria to evaluate the visibility of the pedestrian with headlamps. As Figure 13

Table 4 The mean values and the standard deviation of the Z scores

	Mean of Z scores						Std. Deviation					
	30 m	35 m	40 m	45 m	50 m	average	30 m	35 m	40 m	45 m	50 m	average
Headlamp 1	0.31	0.42	0.04	-0.42	0.16	0.10	0.54	0.33	1.11	1.17	0.80	0.86
Headlamp 2	0.63	0.47	0.34	-0.09	-0.49	0.18	0.51	0.83	0.50	1.17	1.11	0.93
Headlamp 3	0.21	0.26	-0.18	-0.53	-1.15	-0.28	0.57	1.35	0.64	0.94	1.13	1.07

Figure 11 Percent correct at distance of 50m

Figure 12 Z score at distance of 50m and normalized by headlamp 3

Figure 13 The value of d_a for the average of five distances and normalized by headlamp 3

showed, HID headlamps (both parabolic type and projector type) are better for the visibility of pedestrian in peripheral area.

4. Conclusion and Discussions

Figure 14 showed three experimental conditions with three different headlamps. The results of this study showed that HID headlamps are better for the detection of pedestrian in peripheral than halogen headlamps because of the higher light output, higher color temperature, brighter foreground and wider spread of light. The higher light output of HID headlamps provide much more brighter foreground for drivers and higher vertical illuminance of pedestrian on roadside than halogen headlamps, which will be benefited for peripheral visibility. Also the color temperature of headlamps will also affect the peripheral visibility in mesopic light level⁶. Color temperature of HID headlamps (about 5000K) is higher than halogen headlamps (about 3000 K). Wider spread of light should lead to easier road tracking performance and better detection of objects in peripheral, which should be helpful for pedestrian safety^{6,7}. Since the urban road in China was more crowded, wide spread low beam pattern was preferred by drivers for detection other road users around the vehicle such as pedestrians and cyclists under night driving condition.

This experiment was designed according to the Two-Alternative Forced-Choice method (2AFC) which is a widely-used method and an alternative to Signal Detection Theory in psychophysical. The classical psychophysical methods are not able to properly separate the independent factors of sensitivity and decision criterion. Detection performance in the 2AFC paradigm is equivalent to an observer using an unbiased decision criterion,

Figure 14 Three experimental conditions with three different headlamps

and the percent correct performance can be predicted from signal detection theory. This method forces all observers to adopt the same decision criterion and can measure an observer's detection sensitivity relatively uninfluenced by changes in decision criteria⁵. So it can predict actual performance in a detection task under a wide variety of different decision criteria. The variability in measured sensitivity is also reduced.

Since controlling glare is as important as enhance of visibility for headlamps⁸, some further research will be conducted in next stage.

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References

- (1) Sivak, M., Schoettle, B., Minoda, T. and Flannagan, M. J.: Potential visibility gains on straight and curved roads from proportional increases in low-beam headlamp intensities, *Lighting Res. Technol.*, Vol.38, No.3, pp.259-266 (2006).
- (2) Sullivan, J. M., Adachi, G., Mefford, M. L. and Flannagan, M. J.: High-beam headlamp usage on

- unlighted rural roadways, *Lighting Res. Technol.*, Vol.36, No.1, pp.59-67 (2004).
- (3) Flannagan, M. J. and Sivak, M.: Headlighting ratings in the context of comprehensive vehicle safety: Proceedings of the 6th International Symposium on Automotive Lighting, Darmstadt, Germany: Darmstadt University of Technology (2005).
- (4) Zwahlen, H. T. and Schnell, T.: Visual target detection models for civil twilight and night driving conditions, *Transportation Research Record*, 1692, pp.49-61 (1999).
- (5) Egan, J. P.: *Signal Detection Theory and ROC Analysis*, New York, Academic Press (1975).
- (6) Akashi, Y. and Rea, M.: Peripheral detection while driving under a mesopic light level, *J. Illum. Eng. Soc.*, Vol.31, No.1, pp.85-94 (2002).
- (7) Schoettle, B., Sivak, M., Flannagan, M. J. and Adachi, G.: The illuminated surface areas of high-intensity discharge and tungsten halogen headlamps in the USA, *Lighting Res. Technol.*, Vol.36, No.3, pp.243-250 (2004).
- (8) Flannagan, M. J., Sivak, M., Traube, E. C. and Kojima, S.: Effects of overall low-beam intensity on seeing distance in the presence of glare, *Transportation Human Factors*, Vol.2, pp.313-330 (2000).