A Study on Visibility with Night Driving

K. Yamanaka, S. Yamamoto, and M. Kawakami

***Abstract*—A new method is proposed to measure the visibility when one is driving a automobile at night. Since the size of visual object is strength of visual stimuli, a procedure to measure the visibility is discussed in this paper where the psychometric curve is obtained by the statistical estimation using staircase methods. The proposed method enables one to estimate the threshold of recognition with probability that means the recognition-probability-based visibility. Furthermore, the proposed method illustrates the effect that color temperature of automobile headlights and color difference between the illuminated object and background have on visibility. For color difference between the illuminated object and background, colors were represented as points in three-dimensional space using the LCH color system, and color difference was quantified with respect to luminance, chroma and hue.**

I. Introduction

The expansion of motorization in recent years has been accompanied by an explosive increase in the proportion of automobile traffic together with a sharp increase in number of traffic accidents, with a notable increase in the proportion of accidents involving an elderly person as the main party [1]. In addition, although nighttime accidents account for only about 30% of total accidents, the number of fatal accidents is similar to daytime rates [2]. This indicates that major accidents are more likely to occur at night [3-5].

In this study we conducted experiments to assess visibility during nighttime driving. A clearer understanding of visibility properties during nighttime driving may make it possible to develop guidelines for designing a safer and more comfortable road environment for all drivers, not only the elderly. To assess visibility, we propose a method in which stimulus intensity is defined as size of the visual target to be recognized by the subject, and the psychometric function is a recognition probability curve. According to this method, the probability point is defined by the physical response threshold to sensory stimuli, and this threshold value can then be used for quantitative and normative estimation of visibility with respect to each individual. Furthermore, the proposed visibility assessment method illustrates the effect that color temperature of an automobile headlight and color difference between the illuminated object and background have on visibility. For color difference between the illuminated object and background, colors were represented as points in three-dimensional space using the LCH color system [6-8], and color difference was quantified with respect to luminance, chroma and hue.

K. Yamanaka is with Faculty of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino, Tokyo 191-0065, Japan (corresponding author to provide phone: +81-42-585-8696; fax: +81-42-585-8696; e-mail: kiyamana@ cc.tmit.ac.jp).

S. Yamamoto is with Graduate School of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino, Tokyo 191-0065, Japan (e-mail: 06892524@sd.tmu.ac.jp).

M. Kawakami is with Faculty of System Design, Tokyo Metropolitan University, Asahigaoka 6-6, Hino, Tokyo 191-0065, Japan (e-mail: kawakami@tmit.ac.jp).

II. Experiment

A. Experimental Layout and Procedure

In this experiment, 10 university students aged 21 to 23 years were selected as subjects who fulfilled the candidate criteria of having a regular class automobile license and normal vision or corrected normal vision. Following the instructions of the experimenter, subjects tried to recognize a visual object in a university gym, and the response category was measured. The experimental layout is shown in Fig.1. A Landolt ring as visual object, of size from 0.5' to 2.0', was displayed at 22 m distance from the eye of the subject and was located 0.5 m above the ground. Based on inspection of automobiles, the headlight was located 0.9 m above the ground.

This study examines the visibility due to variation in the

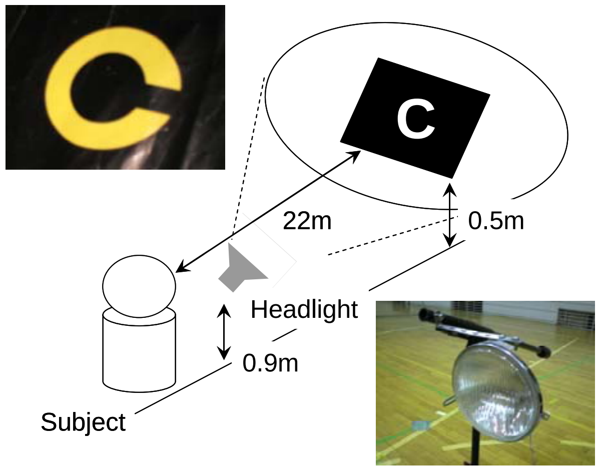


Figure 1 Experimental layout

Table 1 Color difference between Landolt rings and black background

Colors	ΔL*	Δc*	Δh	ΔL*c*h
Blue	5.40	17.30	37.40	18.45
Brown	15.30	36.30	44.20	39.38
Red	57.00	8.90	93.00	58.04
Mars yellow	42.70	69.70	14.10	81.77
Yellow	54.10	81.50	2.50	97.82

color temperature of automobile headlights and the color difference between the visual object and the background. Accordingly there were two different experimental factors: the color temperature of an automobile headlight and the color difference between the visual object and background. The color temperature of the halogen headlight was set to two different levels: 3100 K and 4700 K. The mean illuminance at the Landolt ring presentation position in each color temperature condition was 40.56 lx in 3100 K condition, and 23.95 lx in 4700 K condition. The colors of the visual objects were set to five different levels. Luminance, chroma and hue of the five chosen foreground colors were measured by a color meter. Table 1 shows the color differences between the black background and the values of these five colors.

B. Measurement of Visibility

The aim of this study was to measure visibility. In the experiment, the two response categories of “possible to recognize” or “impossible to recognize” for the size of visual object were measured. As shown in Fig.2, the strength of stimuli is defined as size of visual object, which constitutes the psychophysical quantity. The visual object is possible to recognize when large, but impossible to recognize when small. In other words, the larger the visual object, the greater the strength of stimuli. This experiment was designed to measure the threshold of recognition when the response category changed from “possible to recognize” to “impossible to recognize” or vice versa. It is well known that the function relating probability of recognition and the strength of stimuli can be obtained by a psychometric curve that is equivalent to the cumulative distribution function of normal distribution. Since the threshold between “possible to recognize” and “impossible to recognize” constitutes the threshold of recognition, this threshold of recognition can be estimated by psychometric curve as the point of subjective equality (PSE) [9-11]. It is also known that the stimulus threshold can be obtained as a percentile of this psychometric curve. A stimulus threshold of 50% probability corresponds to the PSE, which is equivalent to threshold of recognition.

III. PSYCHOMETRIC CURVE AND STAIRCASE METHOD

The psychometric curve is defined by the strength of stimuli

$$P = f(x) \tag{1}$$

Eqation (1) can be derived easily from the relationship [12].

$$P = \Phi(y) = \int_{-\infty}^{y_i} \phi(y)dy, \quad y = \frac{x - \mu_x}{\sigma_x} \tag{2}$$

In Eq. (2), $\Phi(\bullet)$ and $\phi(\bullet)$ are cumulative distribution function and probability density function of the standardized normal distribution

$$\phi(y) = \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} \tag{3}$$

where μ_x and σ_x are mean and standard deviation of the strength of stimuli x.

The probability obtained by psychometric curve by Eq. (1) means the probability that one can perceive the visual object in Fig.2 at that strength of stimuli. Therefore, this probability is also calculated by Eq. (2) as a probability that a visual object with a particular stimuli strength can be recognized with 50% of the probability of Fig. 2. From this discussion, suppose that this probability is defined by

$$P_i = P(E_i) \tag{4}$$

where $P(\bullet)$ is an occurrence probability of probability event $\bullet$. E_i denotes the probability event of being unable to recognize the visual object. Thus the relationship

$$P(E_i) + P(F_i) = 1 \tag{5}$$

consists of E_i and F_i that are the probabilistic events of being able and unable to recognize the visual object at strength of stimuli x_i.

In this paper, the staircase method [13,14] is used to estimate the parameters of the psychometric curve as a recognition probability distribution. Figure 3 shows the

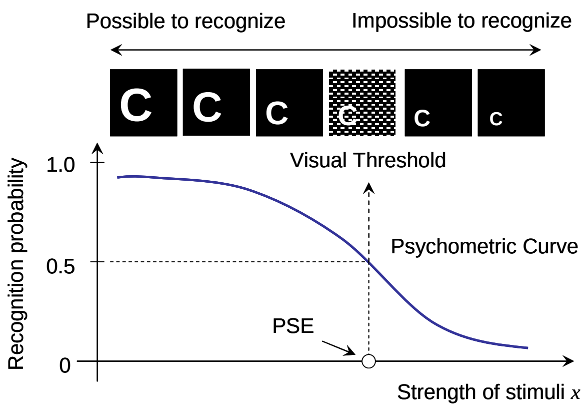


Figure 2 Strength of stimuli and psychometric curve

	$r^{(0)}$	$r^{(1)}$	$r^{(2)}$	$r^{(3)}$	$r^{(4)}$	$r^{(5)}$			$r^{(26)}$	$r^{(27)}$	$r^{(28)}$	$r^{(29)}$	$r^{(30)}$
$i = 4$													
$i = 3$				+		-			+		+		+
$i = 2$			-		-					-		-	
$i = 1$		-											
$i = 0$	-												

Figure 3 Example of result by staircase method

Table 2 Table of stair case method

i	x_i	+	- (f_i)
4	x_4	3	0
3	x_3	8	3
2	x_2	3	8
1	x_1	0	4
0	x_0	0	1
	Total	14	16

example of results of the staircase method, where "+" means a successful result for recognition and "-" means a failure of recognition. $x^{(i)}$ is the size of visual object at the i-th trial $(= x_i)$. Symbol d means step value of strength of stimuli. In this experiment, step value of strength of stimuli is 0.1'. From the frequencies of the results f_i as shown in Table 2, the estimates of mean value and standard deviation of the threshold of recognition $\bar{x}$ and s_r are obtained by Eq. (7).

$$\bar{x} = x_0 + d\left(\frac{A}{C} - \frac{1}{2}\right) \quad (6)$$

$$s_r = 1.62d\left(\frac{CB - A^2}{C^2} + 0.029\right) \quad (7)$$

where $x_0 = x^{(0)}$ [15],

$$A = \sum if_i,\ B = \sum i^2 f_i,\ C = \sum f_i \quad (8)$$

IV. Experimental Results and Discussion

Figure 4 shows the relation between the color temperature of the headlight and the visibility. In this figure, the vertical axis shows the size of visual threshold with 50% recognition probability, while the horizontal axis shows the color temperature of the headlight. In this

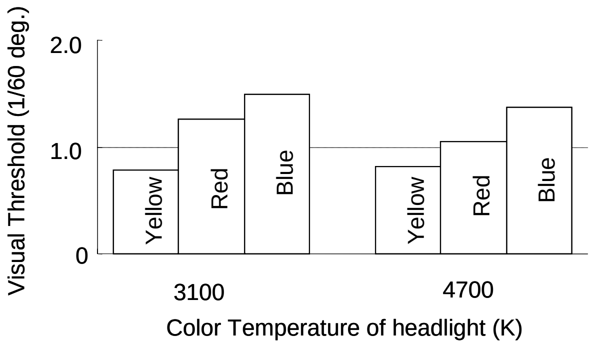


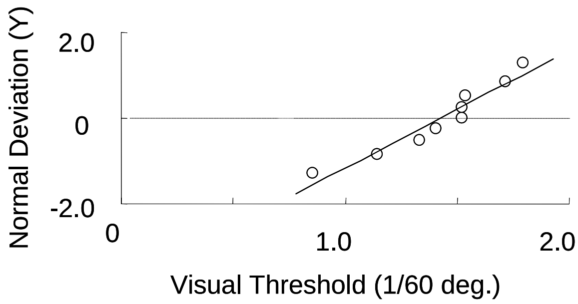
Figure 4 Relation between visual threshold and color temperature of headlight

Table 3 Table of ANOVA

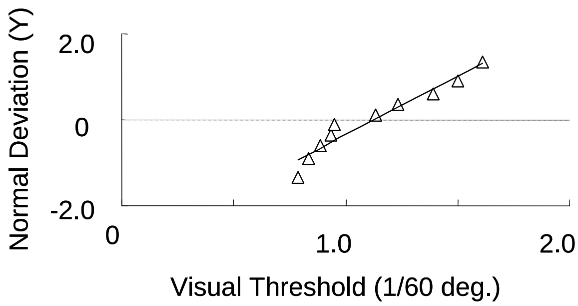
Factors	DOF	Unbiased variance	Variance ratio	Judge
M	1	68.75	—	
A	2	1.81	25.841	**
B	1	0.13	1.795	
e	50	0.07	—	
Total	54			

***: p<0.01*

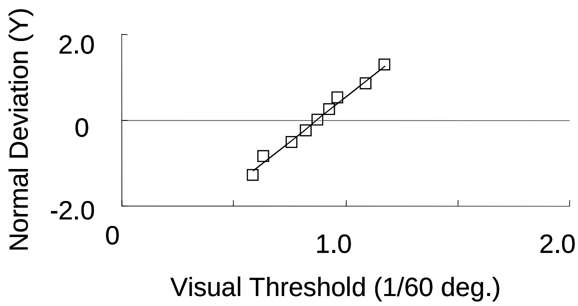
A: Color difference between the visual object and background
B: Color temperature of headlight
DOF: Degree of freedom



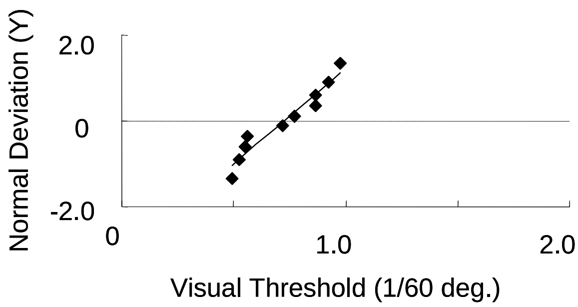
(a) Yellow Landolt ring (ΔL*c*h: 97.82)



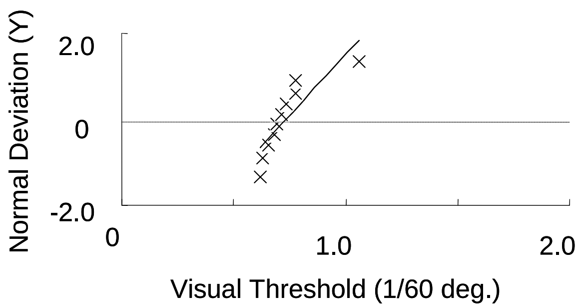
(b) Mars yellowLandolt ring (ΔL*c*h: 81.77)



(c) Red Landolt ring (ΔL*c*h: 58.04)



(d) Brown Landolt ring (ΔL*c*h: 39.83)



(e) Blue Landolt ring (ΔL*c*h: 18.45)

Figure 5 Difference among subjects for color difference experiment, when subjects were able to recognize a small visual object, visibility was good. From this figure, it can be seen that there was no difference between color temperatures of 3100 K and that of 4700 K. However, there was a characteristic tendency for the size of visual threshold stimulus to become smaller as color difference between the visual object and the background became greater.

Table 3 shows the result of an ANOVA [16-18] on size of visual threshold with visibility defined as 50% probability of recognition. In this table, the color differences between the visual object and the background are significance factors ($p<0.01$). On the other hand, the color temperature of the headlight is not a significant factor.

Figure 5 shows probability distributions for visual threshold size in five colors of visual object for all subjects. There are two kinds of characteristic tendency apparent from these figures. The first is that the visual threshold became smaller as the color difference between visual object and the background became greater. The second is that individual differences became smaller as the color difference between visual object and the background became greater.

V. CONCLUSION

This study examined visibility due to variation in the color temperature of a headlamp and the color difference between the target object and the background in night driving. The results of this experiment revealed the following.

(1) It is shown that the proposed method using recognition probability to evaluate visibility is effective in terms of both accuracy and efficiency.

(2) There is no relation between visibility and the color temperature of a headlight.

(3) As color difference between the target object and the background increases, not only does visibility improve but individual differences diminish.

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REFERENCES

[1] Y. Nishida, “Driver Education for the Elderly (in Japanese)”, *Journal of Society of Automotive Engineers of Japan*, 2006, Vol.60, No.3, pp.31-36.

[2] National Police Agency, “Crash database”, 2007, http://www.npa.go.jp/english/.

[3] E. Hollnagel, “Effect of a Night Vision Enhancement System on Driving: Results from a Simulator Study”, *Proc. Of the 2nd International Driving Assessment Symposium 2003*, 2003.

[4] A. F. Williams, “Night driving curfews for young drivers”, *Proc. Of the 14th International Conference on Alcohol, drugs and traffic safety, Annecy*, 1997, pp.1043-1048.

[5] H. Ikeda, A. Mihoshi, H. Ikeda and M. Nakaseko, ”Effect of nighttome nap and daytime sleep on heat rate and drowsiness in long-distance highway bus drivers”, *IATSS research*, 2006, Vol.30, No.2, pp.78-82.

[6] A. R. Robertson, “The CIE 1976 color-difference formulae”, *Color Research and Application*, 1977, Vol.2, pp.7-11.

[7] D. L. McAdam, “Visual sensitivities to color differences in daylight”, *Journal of the Optical Society of America*, 1942, Vol.32, pp.247-274.

[8] S. M. Newhall, D. Nickerson and D. B. Judd, “Final report of the O. S. A. Subcommittee on the spacing of Munsell colors”, *Journal of the Optical Society of America*, 1943, Vol.33, pp.385-418.

[9] J. P. Guilford, “Psychometric methods”, *New York: McGraw-Hill*, 1954.

[10] T. Oyama, “A new psychophysical method: Method of transposition or equal-appearing relation”, *Psychological bulletin*, Vol.56, pp.74-79.

[11] F. N. Jones, “History of psychometrics and judgment. In E. C. Carterette & M. P. Morton (Eds.), Handbook of perception, Vol.2. Psychophysical judgment and measurement” *New York: Academic Press*, 1974

[12] W. J. Dixon, A. M. Mood and J. Ameri, “A method for obtaining and analyzing sensitivity data”, *Journal of American Statistical Association*, 1948, Vol.43, pp.109-126.

[13] G. Bekesy, “A new audiometer”, *Acta Oto-laryngology*, 1947, Vol.35, pp.411-422.

[14] T. N. Cornsweet, “The staircase method in psychophysics”, *American journal of Psychology*, 1962, Vol.75, pp.485-491.

[15] The Japan Society of Mechanical Engineers ed., “Method of Statistical Fatigue Test”, *JUSE Press*, 1999, pp.27-37.

[16] S. Hardeo and A. Mohammed, “The Analysis of Variance: Fixed, Random and Mixed Models”, *Birkhauser*, 1999, 2p.125-168.

[17] D. J. Hand and C. C. Taylor, “Multivariate Analysis of Variance and Repeated Measures: A Practical Approach for Behavioural Scientists (Chapman & Hall Statistics Text Series)”, *Chapman & Hall*, 1987, pp.9-44.

[18] R. Maxwell and R. Riccardo, “Student's Guide to Analysis of Variance”, Routledge, 1999, pp. 153-171.