

REQUIRED LUMINOUS INTENSITY RATIO OF LED ROAD TRAFFIC SIGNAL LIGHTS

– TEST FOR FINDING THE LUMINOUS INTENSITY RATIO THAT ENSURES THE SAME VISIBILITY PERFORMANCE OF RED, YELLOW, AND GREEN ROUNDEL LIGHTS –

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1. ABSTRACT

The minimum luminous intensity values of traffic signal lights are provided as recommended values in the report of the Commission Internationale de l'Eclairage (International Commission on Illumination) (CIE). Japanese standards are based on these recommended values of CIE. On the other hand, the luminous intensity ratio of the RED, YELLOW, and GREEN roundel lights is not yet made clear by CIE.

Therefore, we carried out a test to determine the luminous intensity ratio that ensures that all of the RED, YELLOW, and GREEN roundel lights of an LED road traffic signal light provide the same visibility performance.

2. INTRODUCTION

In Japan, LED road traffic signal lights began to be introduced in 1994 on a limited basis. As LEDs acquired high luminance later on, LED signal lights began to replace incandescent signal lights in earnest in fiscal 2002. As of the end of March 2005, there were about 1,110,000 road traffic signal lights (except traffic lights using “arrow symbol”) in operation in Japan, of which about 100,000 were of the LED signal lights. LED signal lights are characterized by their energy saving effects, long lives, and lack of false lighting phenomena.

The Japanese standard for the luminous intensity characteristics of 300-mm roundel road traffic signal lights was established under the following circumstances. Incandescent signal lights use either 250-mm or 300-mm roundels. In the future however, 250-mm roundels will likely be replaced by 300-mm roundels, because the latter utilize light more efficiently. Meanwhile, LED signal lights use 300-mm roundels only.

As part of its efforts to protect the global environment, Japan has been endeavoring to save electricity consumed in road traffic signal lights. Electricity consumption in incandescent lamps used in signal lights was improved from 100W to 70W in 1975. In 1986, a 60W incandescent lamp was developed and introduced into signal light systems. In 2000, the specifications for incandescent signal lights were revised and at the same time new specifications were set up for the LED signal lights. LED traffic signal lights offer far better energy efficiency than conventional incandescent signal lights and can reduce the power consumption to about one-fifth from 70W to 15W in the case of signal lights for vehicles and to less than one-fourth from 60W to 15W in the case of signal lights for pedestrians. Therefore, replacing the conventional traffic signal lights throughout Japan to LED signal lights is equivalent to annual power saving of 830 million kWh, consequently achieving a CO₂ reduction effect equivalent to planting of about 83 million trees.

Japan has made efforts to save electricity in signal lights and improve their visibility for drivers. Specifically, a series of demonstration tests have been carried out under the guidance of the National Police Agency to enhance the visibility of signal lights.

The Japanese standards for luminous intensity distribution, color, uniformity of luminance and sun phantom are based on these demonstration tests and Japan’s conventional standards and experience in operation of the signal light systems, as well as on the CIE and other international standards, including those practiced in some countries. Luminous intensity distribution is defined in terms of absolute values.

The specifications for luminous intensity distribution of LED signal lights are as follows:

The RED and the GREEN roundel lights shall have a minimum operational luminous intensity of 288 cd along the reference axis for the light. The luminous intensity within 10° to the right and left of the reference axis and 5° below the reference axis shall be at least 96 cd. The intensity shall be at least 20.4 cd within 20° to the right and left and within 10° below, and at least 7.2 cd within 30° to the right and left and 20° below. The intensity shall be at least 3.6 cd within 33° to the right and left and within 33° below. The intensity shall be at least 2.4 cd at 0° to the right and left and within 45° below.

For the YELLOW roundel, the luminous intensity along the reference axis shall be 1.5-fold or more than that of the RED roundel, for the sake of consistency with incandescent signal lights.

These luminous intensity values are determined as follows:

- (1) The required minimum luminous intensity along the reference axis is 200 cd as calculated by the following formula (i):

$$I_d = 2 \times 10^{-6} d^2 L_b \quad (i)$$

I_d : Required minimum luminous intensity (cd)

d : Required recognition distance (m)

L_b : Background luminance (cd/m^2)

Required recognition distance can be derived from the equation (12), and figure 3.5 of CIE Publication No.48 (1980). Figure 3.5 suggests that a required recognition distance for ordinary urban roads (speed less than 80 km/h) would be 100 m. Accordingly, in Formula (i), the required luminous intensity I_d is 200 cd at $d=100$ (m) and $L_b=10,000$ (cd/m^2).

- (2) Considering the deterioration of the initial luminance of the incandescent lamp and the influence of dust over the front surface of the roundel, the luminous intensity along the reference axis shall be 288 cd, 44% greater than the required minimum luminous intensity of 200 cd.
- (3) The luminous intensity off the reference axis shall comply with the luminous intensity standard established in 1986.
- (4) For the luminous intensity distribution region of a signal light, the angle of divergence of luminance from the roundel shall be 45° so that the light may be visible not only to drivers but also to pedestrians, considering intersections without pedestrian signal lights.

3. TEST

3.1 Background and Objective of Test

The minimum luminous intensity values of traffic signal lights are provided as recommended values in the report of the CIE. Japanese standards are based on these recommended values of CIE. On the other hand, the luminous intensity ratio of the RED, YELLOW, and GREEN roundels of LED traffic signal lights required to cause the same degree of reaction among drivers is recommended as RED: YELLOW: GREEN = 1: 2.5: 1.3 in recently published CIE and ITE reports. However, the effect of the luminous intensity ratio among the different-color roundels (a condition under which different-color roundels provide the same visibility) is not yet made clear by CIE, either. This test was carried out to determine the luminous intensity ratio that ensures that all of the RED, YELLOW, and GREEN roundels of the LED traffic signal light provide the same visibility performance.

3.2 Outline of Test

The test was planned based on the test conducted by Takeuchi et al. to determine the "Required Luminance and Luminous Intensity of Road Traffic Signal Lights" (a paper read at the 1980 national convention of the Illuminating Engineering Institute). To obtain the absolute value of luminous intensity, it is necessary to know an actual recognition distance, luminous intensity, and light source size. If we need to obtain the luminous intensity ratio among different-color roundel lights, however, only the relative dimensions of these factors are required. Therefore, a simulator was used in this test. As recognition conditions, it was assumed that the driver looks at 300-mm roundels placed at a distance of 100 m or 150 m in the road ahead. The simulator was made as a one-tenth scale model. Specifically, 30-mm roundel signal lights (representing 300-mm ones) were placed at a recognition distance of 10 m or 15 m (representing 100 m or 150 m each). The background luminance was a surface light source of about 7000 cd/m^2 to reproduce an adverse condition under which the signal light is seen against the bright, daytime sky. The visibility performance was assessed by a luminous intensity value at which the driver can positively identify the color of a signal light that went on for a very short time. About 0.1 second is said to be the minimum length of time in which the driver can turn his gaze to perceive and identify a certain object while casting glances at various directions to obtain necessary visual information every moment during driving. Additionally, a signal light must be recognized, at first, in peripheral vision on an actual road. Paying consideration to these elements, while the driver of a vehicle on the road (about 1.2 m high) was gazing at a road surface 50 m ahead in the traveling direction, the observer was allowed to see for 0.1 second a signal light at a geometrical position at which a signal light (5.5 m high) would be at a regular position of 100 m and 150 m ahead on the road.

The following shows the test conditions (Figure 1):

- (1) The distances between the observer and the simulated signal lights shall be 10 m and 15 m.
- (2) The simulated signal lights shall be 30 mm in diameter.
- (3) The simulated signal lights shall go on for 0.1 second.
- (4) Any of the light colors RED, YELLOW, and GREEN shall be selected for each test.
- (5) The luminous intensity values shall be from 0.2 to 3.2 cd in fifteen 0.2-cd steps (Converted to $\phi 300$, these luminous intensity values are from 20 to 320 cd in fifteen 20-cd steps).
- (6) The background luminance shall be about 7000 cd/m².
- (7) The observer's line of sight shall be about 70 cm downward from the simulated traffic lights.
- (8) There shall be 30 observers or more. The observers shall be in their 20's to 50's and have a driver's license.

3.3 Test method

As described in the following, Pretest 1 and Pretest 2 shall be conducted before the main test so that the observers can get used to the lighting of the simulated signal lights and the test methods using them.

3.3.1 Pretest 1 (Identifying a signal light color in direct vision)

- (1) The observer shall stand at a distance of 15 m from the simulated signal lights and directly looks at them.
- (2) The simulated signal lights GREEN, RED, and YELLOW shall be turned on in this order, starting from the lowest luminous intensity to the highest. The lighting time shall be 0.1 seconds each and the lighting cycle shall be 5 seconds.
- (3) The observer shall put on a record sheet how he/she identified lighting every time a light is turned on.

3.3.2 Pretest 2 (Identifying a signal light color in peripheral vision)

- (1) The observer shall stand at a distance of 15 m from the simulated signal lights and gaze at a position 79 cm below them.
- (2) The simulated signal lights GREEN, RED, and YELLOW shall be turned on in this order, starting from the lowest luminous intensity to the highest. The lighting time shall be 0.1 seconds each and the lighting cycle shall be 5 seconds.
- (3) The observer shall put on a record sheet how he/she identified lighting every time a light

is turned on.

3.3.3 Main test

(1) Main test (15 m)

- (a) To adapt to the field of vision, the observer shall stand at a distance of 15 m from the simulated signal lights and gaze at the center of the background for 5 minutes.
- (b) The observer shall stand at a distance of 15 m from the simulated signal lights and gaze at a position 79 cm below them.
- (c) The simulated signal lights shall be turned on in any order, starting from the lowest luminous intensity to the highest. The three color lights shall be lit in 15 luminous intensity levels, for a total of 45 times. The lighting time shall be 0.1 seconds each and the lighting cycle shall be 5 seconds.
- (d) The observer shall put on a record sheet how he/she identified lighting every time a light is turned on.

(2) Main test (10 m)

- (a) The observer shall stand at a distance of 10 m from the simulated signal lights and gaze at a position 68 cm below them and hereafter performs the same procedure described in the above item (1).
- (b) The observer shall put on a record sheet how he/she identified lighting every time a light is turned on.

3.3.4 Evaluation method

- (1) A graph shall be created, in which the horizontal axis represents the luminous intensity levels of different colors and the vertical axis represents the cumulative sum of people who were able to identify lighting. The result shall be evaluated with the cumulative incidence rates.
- (2) Data correction method
 - (a) Singular points apparently due to mistakes such as errors in writing shall be excluded.
 - (b) If two or more correct answers are given in succession, all the answers given thereafter shall be handled as correct answers.
 - (c) The observers who did not identify signal lights correctly even in the 15th round (the maximum luminous intensity level) in pretests or who did not identify signal lights correctly even at the maximum luminous intensity level of the main test (15 m) or the main test (10 m) shall be excluded from the test data.

4. RESULTS

Figures 2 and 3 show the numbers of people who gave correct answers against the luminous intensity ratios of different colors (Figure 2 is for the main test at 15 m and Figure 3 is for the main test at 10 m).

Figure 4 shows the luminous intensity ratios against the accuracy rates.

Figure 5 shows the average values of luminous intensity ratios classified by the different conditions of test subjects.

5. DISCUSSION

- (1) The luminous intensity values at which 80% or more of test subjects gave correct answers at a distance of 15 m were 1.4 cd for the Red, 2.6 cd for the Yellow, and 1.5 cd for the Green (Figure 2) and around 0.8 cd for the Red, 1.4 cd for the Yellow, and 0.9 cd for the Green (Figure 3). Through comparison of luminous intensity values with accuracy rates, it was found that a majority of people can identify lighting correctly if the luminous intensity ratio of Red:Yellow:Green is 1:2:1.1 (Figure 4).
- (2) No difference was found in the luminous intensity ratios due to test distances (Figure 4).
- (3) No difference was found due to ages, eyesight, and vision correction methods (Figure 5).

From the above result, it can be concluded that the luminous intensity ratio of Red:Yellow:Green needs to be 1:2:1.1 to ensure the same visibility performance in peripheral vision. The Japanese standard specifies luminous intensity values of 2.88 cd for the Red, 4.32 cd for the Yellow, and 2.88 cd for the Green (values converted to the test conditions) and consequently the luminous intensity ratio of Red:Yellow:Green is 1:1.5:1, somewhat lower than the test results.

There has never been a problem in the traffic signal light operations in Japan. Therefore, the luminous intensity ratios required to ensure the same visibility performance in actual operations are considered to be influenced by other factors such as luminous intensity values and environments used in actual operations.

6. CONCLUSION

The results of the test conducted in this study showed that the luminous intensity ratio required to ensure the same visibility performance in peripheral vision against a background luminance of 7000 cd/m^2 was somewhat higher than the luminous intensity ratio specified in

the Japanese standard.

In view of the past operation in Japan, there is no problem in the current luminous intensity ratio employed at present. For the future, however, factors that give influences to luminous intensity ratios shall be considered and examined.

7.ACKNOWLEDGMENT

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8.REFERENCES

- [1] UTMS Japan(Universal Traffic management Society of Japan),Signal Control Equipment(Traffic Light)WG(UTMS/TC32A).*Japanese Standards for 300-mm Roundel Road Traffic Signal Lights Regarding Photometric Properties.*
- [2] Japan LED Association. *LED Lighting Hand Book 2006* (<http://www.led.or.jp>).

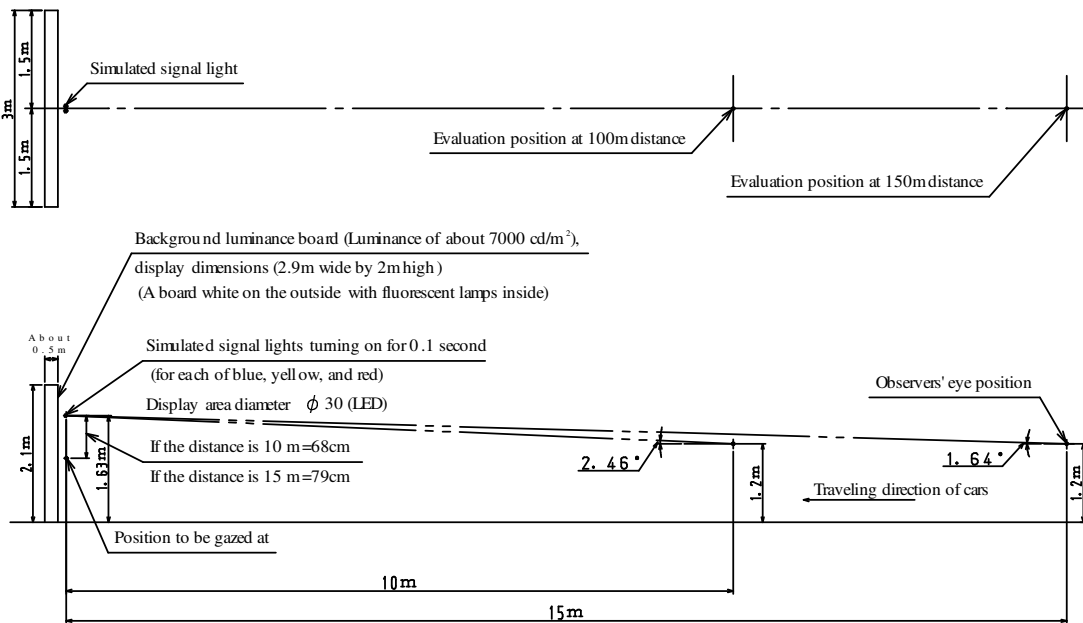


Figure 1-Layout of Test Equipment

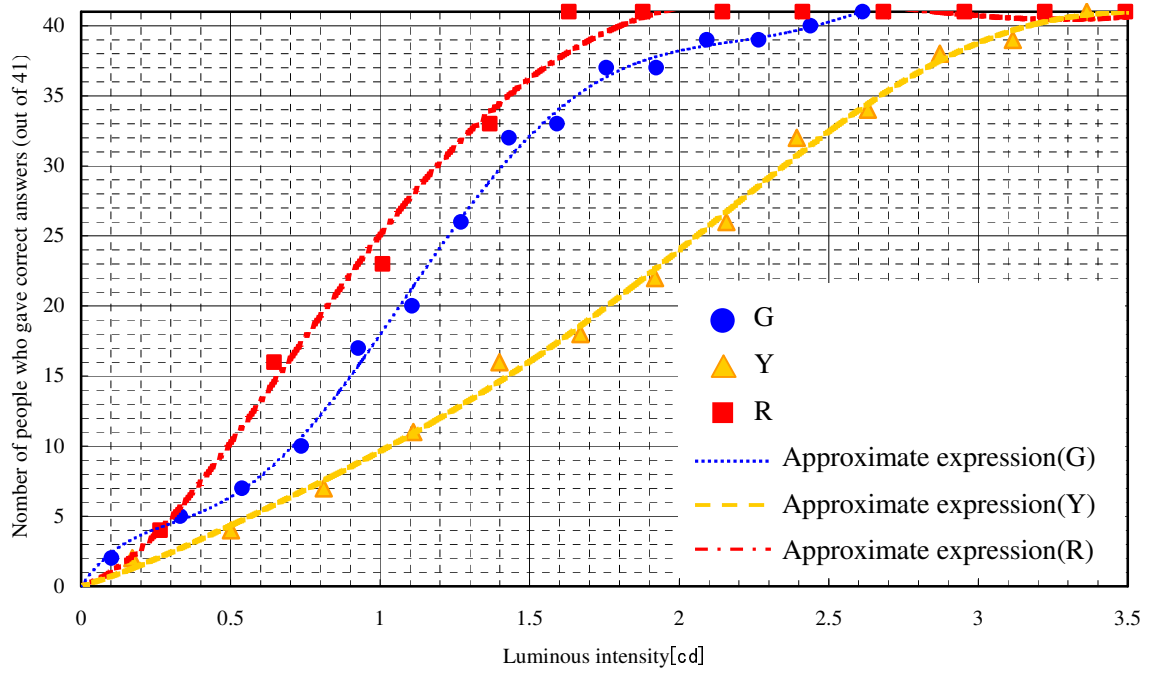


Figure 2-Main test at 15m: Number of people who gave correct answers against luminous intensity ratios

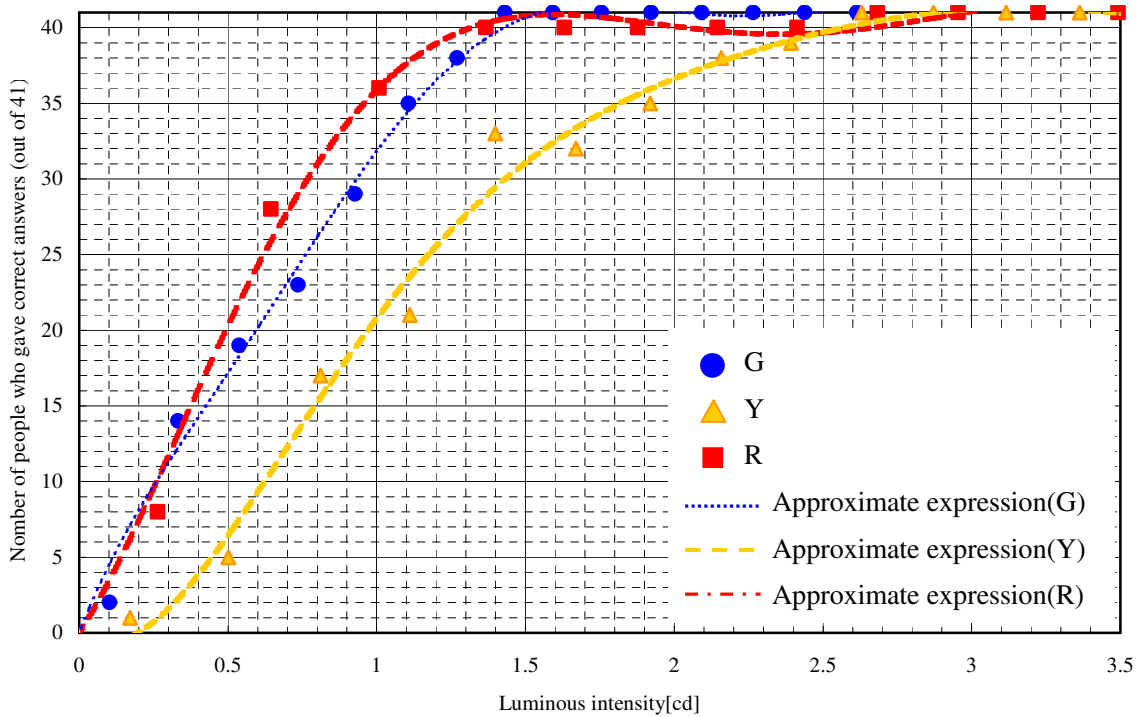


Figure 3-Main test at 10m: Number of people who gave correct answers against luminous intensity ratios

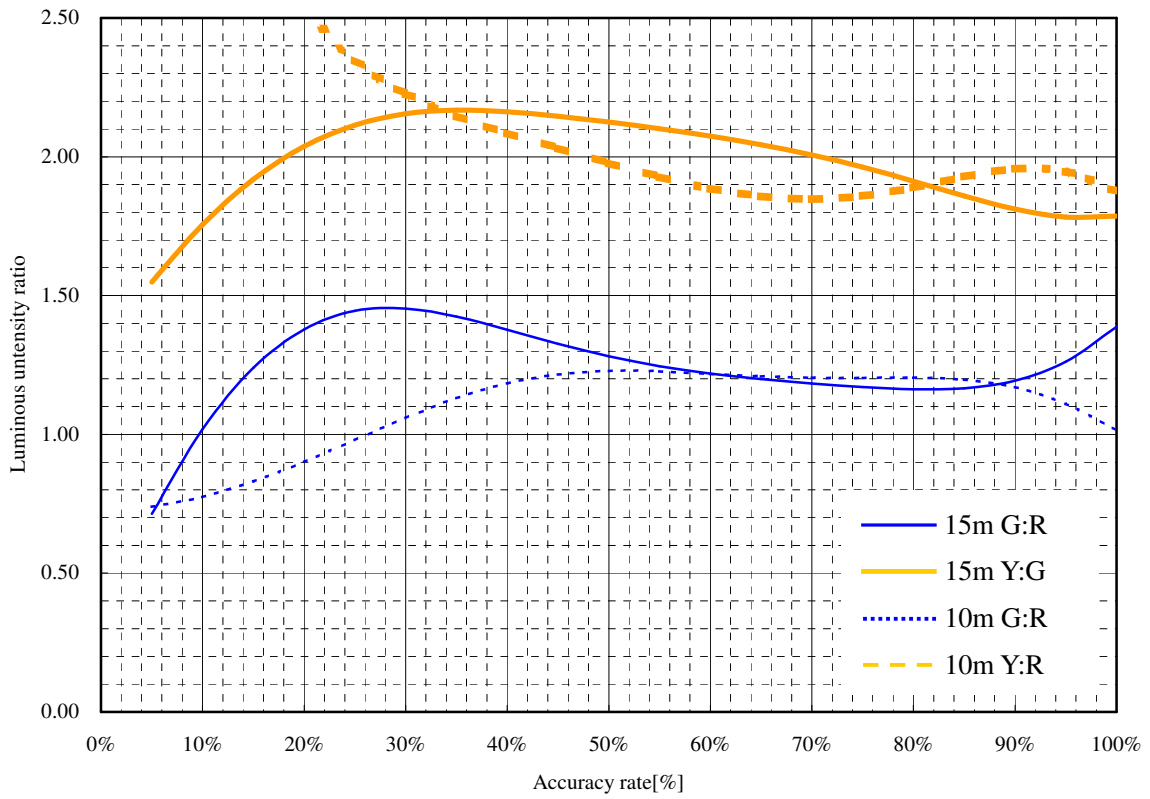


Figure 4-Luminous intensity ratios against accuracy rates

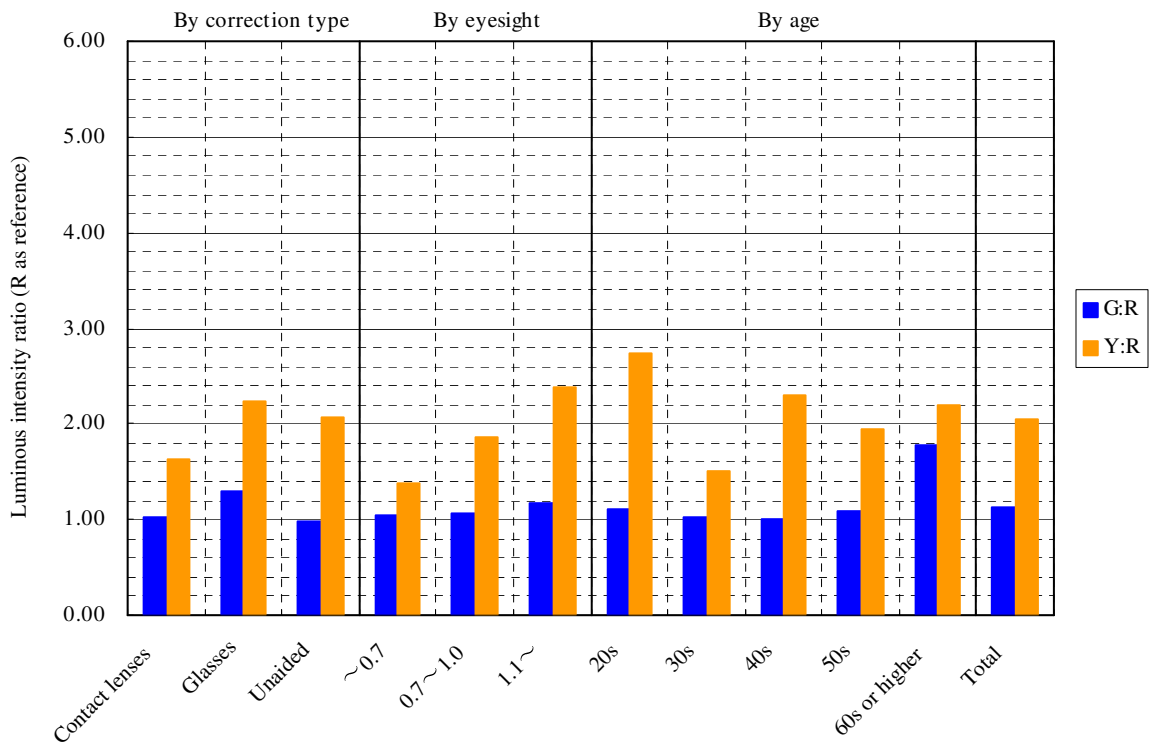


Figure 5-Average values of luminous intensity ratios classified by different conditions