Translated Paper**Spectroscopic Performance of Oscopes during Oscopic Examination by LED Headlight**Mitsuhiro MATSUMOTO[†]

Kanagawa University, Department of Industrial Engineering and Management, Faculty of Engineering

Received January 21, 2021, Accepted May 17, 2021

Paper was originally published in Japanese in advance online publication of Journal of the Illuminating Engineering Institute of Japan, <https://doi.org/10.2150/jieij.20000601>.

ABSTRACT

We evaluated the spectroscopic performance of an otoscope during otoscopic examinations using a headlight with an LED source. We used the mechanisms and the specifications of the objects measured with the otoscope and so on to evaluate the spectroscopic performance. Experimental equipment was built using the existing otoscope and headlight, and we demonstrated methods of measuring the spectral irradiance of the otoscope. We demonstrated methods of evaluating the spectroscopic performance using the spectral irradiance ratio and chromaticity by the measured spectral irradiance. We measured the spectral irradiance of the otoscope using the measuring methods. We found that the spectral irradiance distribution in the otoscope is greatly affected by the spectral distribution in the headlight source. We evaluated the spectroscopic performance of the otoscope using the evaluation methods. The spectroscopic performances of the reflected light onto the surface of, and the direct and reflected lights in, the otoscope differ and are affected by differences in shape, surface condition, length, and the diameter of the wide mouth. The spectroscopic performance of the direct and reflected lights in the otoscope is affected by differences in the diameter of a narrow mouth and the distance and angle between the otoscope and the headlight.

KEYWORDS: otoscope, headlight, otoscopic examination, LED, spectrum

1. Introduction

Otoscopic examinations investigate changes in color and morphology of the eardrum and ear canal inside the ear¹⁾. With regards to changes in the color tone of the eardrum, a normal eardrum has a pearl-like grayish-white translucent luster¹⁾. Pathological eardrums have reddening and hyperemia that appears reddish, appears opaque, and loses its luster, yellowish changes are transparent and have a starch syrup-like or pale-yellow color, and blue-blackish changes appear blue or black¹⁾. In otoscopic examinations, these changes in color are required to be accurately determined. Otoscopic examinations involve the use of a light source, head mirror, and otoscope²⁾. The light from the light source is reflected by the head mirror and illuminates the inside of the ear through the otoscope¹⁾. An incandescent light bulb is used as the light source³⁾. The head mirror is inconvenient because there are restrictions on the positional relationship between the light source, head mirror, and otoscope⁴⁾. Therefore, headlights with a built-in light source are present instead of light

sources and head mirror⁵⁾. A light-emitting diode (LED) is used as the built-in light source⁶⁾. The incandescent light bulb, which is the light source, has different color tone and spectrum compared to the LED^{6, 7)}. The light that illuminates the inside of the ear includes direct light from the light source and light reflected on the surface of the otoscope⁸⁾. The fraction of direct light and reflected light in the light that illuminates the inside of the ear depends on the shape, surface conditions, length, and wide-mouth/narrow-mouth diameters in the otoscope specifications as well as on the distance and angle between the otoscope and headlight⁸⁾. Otoscope surfaces include black, chromed matte, chromed gloss, and aluminized gloss, which have different spectral reflectances. The light that illuminates the inside of the ear is considered to have spectral irradiance that differs from the color tone and spectrum of the light source owing to differences in the specifications of the otoscope and positional relationship between the otoscope and headlight. The color tone inside the ear changes when the spectral irradiance is different. It has also been

[†] Corresponding Author: Mitsuhiro Matsumoto m-matsumoto@kanagawa-u.ac.jp

Figure 1 Mechanism of otoscope and relationship between otoscope and headlight.

indicated that doctors need to become accustomed to changes in color tone during examinations because they may be confused by the difference in color tone or feel uncomfortable^{6,7}. Therefore, showing how the spectral irradiance and chromaticity change depending on the specifications of the otoscope or positional relationship between the otoscope and headlight can help doctors determine the correct color tone.

In this study, the spectroscopic performance of an otoscope in an otoscopic examination using headlights was evaluated. The mechanism and specifications of the otoscope and other measuring objects for which the performance is evaluated are presented. A method of measuring spectral irradiance of an otoscope by constructing a measuring device using an existing otoscope and headlights as well as a method for evaluation of spectroscopic performance by the spectral irradiance ratio and chromaticity using the measured spectral irradiance are proposed. The evaluation method was used to evaluate the spectroscopic performance of the otoscope.

2. Measured object

The spectroscopic performance of the otoscope was evaluated using a headlight. The mechanism of the otoscope and relationship between the otoscope and headlight are described. Figure 1 shows the mechanism of the otoscope and relationship between the otoscope and headlight. In Figure 1, (a) shows a left-side view, (b) shows a front view, (c) shows a right-side view, and (d) shows a cross-sectional view of the front view. The otoscope has wide and narrow mouths centered on the central axis. The headlight was installed on the wide-

mouth side of the otoscope. The light emitted from the focal point on the central axis of the headlight entered the otoscope through the wide mouth. The light that entered the otoscope was either direct light that reached the narrow mouth without being reflected on the surface or light reflected on the surface reaching the narrow mouth. The narrow mouth was illuminated with either direct or reflected light. l is the length of the otoscope in the central axis direction, r_w is the radius of the wide mouth, and r_N is the radius of the narrow mouth. The radii r_w and r_N were used to determine the diameter of the wide mouth $2r_w$ and diameter of the narrow mouth $2r_N$. d is the distance from the focal point of the headlight to the center of the narrow mouth, while θ is the angle between the central axis of the otoscope and central axis of the headlight.

The hole for the evaluation of the direct light in the otoscope and otoscope were set as the measured objects. Table 1 shows the specifications of the measured object. The measured object was numbered according to the specifications. The measured object number of the hole is set as Hk , where k is a natural number, from 1 to 3. The measured object number of the otoscope is set as Om , where m is a natural number, from 1 to 21. The holes numbered as H1 to H3 were used to evaluate the direct light in the otoscope. The hole did not have a thickness corresponding to the length l of the otoscope. Numbers O1 to O15 were purchased otoscopes. The manufacturer names were Daiichi Medical Co. Ltd. and Matsuyoshi & Co. Ltd. The otoscopes were in the shape of either bell or funnel. The surface conditions were black, chromed matte, or chromed gloss. The length l , diameter $2r_w$, and diameter $2r_N$ were the values mea-

Table 1 Specifications of measured objects.

Hk, Om	Object type	Manufacturer name	Shape	Surface condition	l [mm]	$2r_W$ [mm]	$2r_N$ [mm]
H1	Hole	—	—	—	—	—	3
H2	Hole	—	—	—	—	—	4
H3	Hole	—	—	—	—	—	5
O1	Otoscope	Daiichi medical	Bell	Black	34.1	21.7	3
O2	Otoscope	Daiichi medical	Bell	Black	34.1	21.7	4
O3	Otoscope	Daiichi medical	Bell	Black	34.1	21.7	5
O4	Otoscope	Daiichi medical	Bell	Chromed matte	34.1	21.9	3
O5	Otoscope	Daiichi medical	Bell	Chromed matte	34.1	21.9	4
O6	Otoscope	Daiichi medical	Bell	Chromed matte	34.1	21.9	5
O7	Otoscope	Daiichi medical	Bell	Chromed gloss	34.1	22.1	3
O8	Otoscope	Daiichi medical	Bell	Chromed gloss	34.1	22.1	4
O9	Otoscope	Daiichi medical	Bell	Chromed gloss	34.1	22.1	5
O10	Otoscope	Matsuyoshi	Bell	Chromed gloss	35.1	20.7	3.1
O11	Otoscope	Matsuyoshi	Bell	Chromed gloss	35	20.7	3.9
O12	Otoscope	Matsuyoshi	Bell	Chromed gloss	35	20.7	5
O13	Otoscope	Matsuyoshi	Funnel	Chromed gloss	34.8	12.4	2.9
O14	Otoscope	Matsuyoshi	Funnel	Chromed gloss	34.5	13.2	4.1
O15	Otoscope	Matsuyoshi	Funnel	Chromed gloss	34.8	13.6	5.1
O16	Otoscope	—	Funnel	Aluminized gloss	34.8	12.4	2.9
O17	Otoscope	—	Funnel	Aluminized gloss	34.5	13.2	4.1
O18	Otoscope	—	Funnel	Aluminized gloss	34.8	13.6	5.1
O19	Otoscope	—	Funnel	Aluminized gloss	34.8	12	2.9
O20	Otoscope	—	Funnel	Aluminized gloss	34.5	15.2	4.1
O21	Otoscope	—	Funnel	Aluminized gloss	34.8	17.6	5.1

Figure 2 Comparison of shape in otoscopes.

sured using a caliper in units of 0.1 mm. The diameters $2r_W$ and $2r_N$ were almost identical for numbers O1 to O9, even under different surface conditions. The length l and diameter $2r_W$ were different between manufacturers for numbers O7 to O12, even when they had the same shape. The length l and diameter $2r_W$ were different for different shapes for numbers O10 to O15. Numbers O16 to O18 were otoscopes with an aluminized glossy surface, to evaluate the difference in surface between O13 to O15. The length l , diameter $2r_W$, and diameter $2r_N$ in O16 to O18 were the same as those in O13 to O15, respectively. The Viva mirror film by Takahara Corporation was used for the aluminized gloss. Viva mirror film is a film of an aluminum-deposited 0.1-mm-thick polyethylene terephthalate sheet with a 0.06-mm-thick protective coat. A film was attached to the inner

surface in the shape of an otoscope molded from an aluminum alloy. O19 to O21 indicate otoscopes created by a condensing optimization design by Matsumoto⁸⁾. The length l and diameter $2r_N$ were the same to those for O13 to O15, whereas the diameter $2r_W$ differed. The otoscope creation was the same for O16 to O18.

The shapes of the bell- and funnel-type otoscopes shown in Table 1 were compared. Figure 2 compares the otoscope shapes, where (a) shows a left-side view, (b) shows a front view, and (c) shows a right-side view. The image shows the otoscopes O8, O11, and O14. The installation was on a transparent plate so that the surface condition, wide mouth, and narrow mouth of the otoscope could be easily understood. In the figure, (a) shows the wide mouth and surface of the otoscope, (b) shows the outer shape, and (c) shows the narrow

Figure 3 Images of created otoscope.

mouth. Comparisons of O8 and O11 show that the outer shape was slightly different when the manufacturer was different, even if the shape was the same bell type. Comparisons of O11 and O14 show that different shapes resulted in large differences in the wide mouth and outer shape.

The otoscopes O16 to O21 in Table 1 were created. Figure 3 shows an image of the created otoscope, where (a) shows a left-side view, (b) shows a front view, and (c) shows a right-side view. The image shows an otoscope O17. It was installed on a transparent plate so that the surface condition, wide mouth, and narrow mouth of the otoscope could be easily understood. In the figure, (a) shows the wide mouth and surface of the otoscope, while (c) shows the narrow mouth. A glossy surface could be observed owing to the aluminized gloss.

3. Measurement method

A measuring device using the existing measured object and headlight for the relationship between the otoscope and headlight shown in Figure 1 was built to evaluate the spectroscopic performance of the otoscope. The spectral irradiance of light in the narrow mouth of the measured object was measured using the constructed measuring device. Figure 4 shows an image of the measuring device. The measuring device consisted of a headlight, neutral density filter, measured object, illuminance spectrophotometer, personal computer, and data management software. The Navis LED headlight by AS ONE Corporation was used as the headlight. Navis LED headlights use white-LEDs as a light source and emit light from the focal point of the light source. Navis LED headlights can change the brightness of the LED. However, for the measuring device, they were fixed to the darkest state and used. An ND-0.7 by Fujifilm Corporation was used as the neutral density filter. The ND-0.7 has a transmittance in the range of 15–35% for wavelengths λ in the range of 360 to 760 nm. The ND-0.7 was used to reduce the brightness of the light emitted from the Navis LED headlight and adjust it to the measurement range of the illuminance spectrophotometer. The hole and otoscope shown in Table 1 were used

Figure 4 Image of measuring equipment.

Table 2 Measuring conditions.

Mn	d [mm]	θ [°]
M1	132.3	0
M2	198.3	0
M3	264.4	0
M4	132.3	5
M5	132.3	10.1

as the measured objects. A CL-500A manufactured by Konica Minolta Inc. was used as the illuminance spectrophotometer. The CL-500A can measure the spectral irradiance in increments of 1 nm for the wavelength λ in the range of 360 to 780 nm. A CF-RZ5 by Panasonic Corporation was used as the personal computer. A CL-S10w by Konica Minolta Inc. was used for the data management software. The CL-S10w was installed on the CF-RZ5. The CL-500A could be connected to the CF-RZ5 and the measured values could be obtained using the CL-S10w. Navis LED headlights were installed on the wide-mouth side of the otoscope. The distance d and angle θ were set in the Navis LED headlight by changing the setting position of the focal point. The CL-500A was installed in the narrow mouth of the measured object. The measuring device was installed in a dark room to block light other than that from the Navis LED headlight. The spectral irradiance was measured

by turning the headlight on and off to remove stray light other than that from the Navis LED headlight and using the difference between those values.

Table 2 shows the measurement conditions. Measurement numbers were assigned for each measurement condition regarding measurements with a measuring device. The measurement numbers were set as Mn , where n is a natural number, from 1 to 5. The distance d and angle θ were set and measured using the measured objects with numbers Hk and Om . The distance d of 132.3mm was set as the distance where the light spreading at 12.8° from the focal point of the Navis LED headlight corresponds to the diameter $2r_w$. The value of 132.3mm was the distance corresponding to O7 to O9, which has the largest diameter of $2r_w$. The values of 198.3 and 264.4mm were determined according to the focal length of the head mirror, 170–200 mm (Hinoki) and 200–250 mm (Kaga)^{1, 2)}. The angle θ was determined according to the inclination of the surface from the wide mouth to the narrow mouth in O21. The angle for the surface inclination was 10.1° . Each measuring device was configured based on the measurement conditions shown in Table 2.

4. Evaluation method

The spectral irradiances of the measured objects in Table 1 were measured using the measuring device shown in Figure 4 and measuring conditions in Table 2. The distribution of spectral irradiance for each wavelength λ could be obtained by the measurements. Additionally, the spectral irradiance of only the reflected light on the surface of the otoscope could be obtained by the measured spectral irradiance. The distribution of the reflected light in the spectral irradiance for each wavelength λ could be obtained. The spectral irradiance ratio was used to clearly show the change in spectral irradiance due to the use of the otoscope in the evaluation of the spectroscopic performance. The chromaticity that indicates the color tone was also used.

The spectral irradiance of the reflected light was obtained by subtracting the spectral irradiance in the hole from the spectral irradiance in the otoscope. The spectral irradiance of $i_{Hk, Mn}$ was set for numbers Hk and Mn shown in Tables 1 and 2. The spectral irradiance of $i_{Om, Mn}$ was set for numbers Om and Mn shown in Tables 1 and 2. The spectral irradiance of only the reflected light, $i_{Om, Mn} - i_{Hk, Mn}$, was determined by subtracting the spectral irradiance $i_{Hk, Mn}$ from the spectral irradiance $i_{Om, Mn}$. The measurement conditions were fixed to M1 and the measured object number of the hole was fixed to H3 to compare the spectral irradiance $i_{Om, Mn} - i_{Hk, Mn}$ of the reflected light only for the surface conditions. The spectral irradiance of the reflected light was $i_{Om, M1} - i_{H3, M1}$.

The spectral irradiance ratio is the ratio of the spec-

tral irradiance in the otoscope to the spectral irradiance in the hole. For example, the spectral irradiance ratio is 1 if there is no change in the spectral irradiance of the otoscope with respect to the spectral irradiance of the hole. The change in the spectral irradiance can be determined regardless of the magnitude of the spectral irradiance. f_s is the spectral irradiance ratio of only the reflected light on the surface of the otoscope. f_o is the spectral irradiance of the entire otoscope that combines direct light and reflected light.

The spectral irradiance ratio f_s was determined. The effect of only reflected light on the surface of the otoscope was evaluated by the spectral irradiance ratio f_o . The spectral irradiance ratio f_o was obtained by dividing the spectral irradiance $i_{Om, Mn} - i_{Hk, Mn}$ of only the reflected light by the spectral irradiance $i_{Hk, Mn}$. The spectral irradiance ratio f_s can be expressed as

$$f_s = (i_{Om, Mn} - i_{Hk, Mn}) / i_{Hk, Mn} \quad (1)$$

For the spectral irradiance ratio f_s , the measurement conditions were set as those of M1, while the otoscopes for O3, O6, O9, O12, O15, O18, and O21 were used for the hole of H3. The effects of the differences in the shape, surface, length l , and diameter $2r_w$ on the surface of the otoscope were evaluated for a diameter $2r_N$ of 5 or 5.1 mm.

The spectral irradiance ratio f_o was obtained. The entire otoscope that combines the reflected light and direct light was evaluated by the spectral irradiance ratio f_o . The combined spectral irradiance of the reflected light and direct light is the spectral irradiance $i_{Om, Mn}$. Furthermore, by dividing it by the spectral irradiance $i_{Hk, Mn}$, we obtain the spectral irradiance ratio f_o .

$$f_o = i_{Om, Mn} / i_{Hk, Mn} \quad (2)$$

For the spectral irradiance ratio f_o , the effects of differences in the shape, surface, length l , and diameter $2r_w$ on the overall otoscope combining the reflected light and direct light were evaluated for a diameter $2r_N$ of 5 or 5.1 mm. The effects of differences in the diameter $2r_N$, distance d , and angle θ on the overall otoscope combining the reflected light and direct light were evaluated. Table 3 shows the correspondence between the numbers Hk , Om , and Mn in Eq. (2).

The chromaticity was obtained by the spectral irradiance of the reflected light as well as by the spectral irradiance of the otoscope using a color matching func-

Table 3 Correspondences of numbers Hk , Om and Mn in Eq. (2).

Hk	Om	Mn
H1	O1, O4, O7, O10, O13, O16, O19	M1
H2	O2, O5, O8, O11, O14, O17, O20	M1
H3	O3, O6, O9, O12, O15, O18, O21	M1, M2, M3, M4, M5

tion. The chromaticity values x and y of the direct light and reflected light were obtained for the spectral irradiance $i_{Om, M1}-i_{H3, M1}$ of the reflected light and spectral irradiance $i_{Om, Mn}$. A color matching function for each nm of the wavelength λ in the range of 380 to 780 nm was obtained.

5. Performance evaluation

5.1 Measured spectral irradiance

The spectroscopic performance of the otoscope

Figure 5 Measured spectral irradiances.

Figure 6 Spectral irradiances of reflected light.

was evaluated using the evaluation method. Figure 5 shows the measured spectral irradiance, while Figure 6 shows the spectral irradiance of the reflected light. The distributions of the spectral irradiances $i_{Hk, Mn}$, $i_{Om, Mn}$, and $i_{Om, M1}-i_{H3, M1}$ at the wavelength λ are shown. Figure 5 shows that the spectral irradiance $i_{Om, Mn}$ is larger than the spectral irradiance $i_{Hk, Mn}$. Furthermore, the maximum ranges of the wavelength λ where the spectral irradiances $i_{Hk, Mn}$ and $i_{Om, Mn}$ become zero in all distributions were 360–409 nm and 741–780 nm, respectively. Figure 6 shows that the spectral irradiance $i_{Om, M1}-i_{H3, M1}$ increased in the order of black, chromed matte, chromed gloss, and aluminized gloss, regarding the different surface conditions. Figures 5 and 6 show that the spectral irradiances $i_{Hk, Mn}$, $i_{Om, Mn}$, and $i_{Om, M1}-i_{H3, M1}$ had peaks at wavelengths λ of approximately 450 and 540 nm for all distributions, because the light source of the white-LED was used for the headlight in the measuring device, similar to the spectral distribution of the white-LED. Therefore, the spectral distribution of the headlight source had a major effect on the distributions of the spectral irradiances $i_{Hk, Mn}$, $i_{Om, Mn}$, and $i_{Om, M1}-i_{H3, M1}$.

5.2 Spectral irradiance ratio of the reflected light

Figure 7 shows the spectral irradiance ratio of the reflected light. The distribution of the spectral irradiance ratio f_s at the wavelength λ is shown. The spectral irradiance ratio f_s cannot be determined when the spectral irradiance $i_{Hk, Mn}$ is zero. Therefore, according to Figure 5, the range of the wavelength λ was set to 410–740 nm, where the spectral irradiance $i_{Hk, Mn}$ is not zero.

Figure 7 Spectral irradiance ratios of reflected light.

The spectral irradiance ratio f_s became larger for the funnel type, compared to the bell type, regarding the different shapes. Regarding the different surface conditions, the ratio increased in the order of black, chromed matte, chromed gloss, and aluminized gloss. Regarding the comparison by length l and diameter $2r_w$, the value became larger with the bell type when the length l was larger and the diameter $2r_w$ was smaller. The ratio was larger with the funnel type when the diameter $2r_w$ was larger.

The spectral irradiance ratio f_s largely increased over the wavelength λ ranges of 410–420 nm and 690–740 nm for all distributions. The rate of increase was larger for the funnel type than for the bell type, regarding the different shapes. Regarding the different surfaces, the value increased in the order of black, chromed matte, chromed gloss, and aluminized gloss. Regarding the comparison by length l and diameter $2r_w$, the value became larger with the bell type when the diameter $2r_w$ was larger. The spectral irradiance ratio f_s did not considerably change even with the increases in the wavelength λ in the range of 420–690 nm and when the surface was black. This ratio increased when the surface was chromed matte, chromed gloss, and aluminized gloss. In addition, the ratio increased with the wavelength λ in the range of 470–490 nm. The value did not considerably change when the wavelength λ was in the range of 490–690 nm.

Table 4 shows the chromaticity of the reflected light. The chromaticity values x and y were larger for the funnel type than for the bell type, regarding the different shapes. Regarding the different surfaces, the values decreased in the order of black, chromed matte, chromed gloss, and aluminized gloss. Regarding the comparison by length l and diameter $2r_w$, the values became smaller with the bell type when the length l was larger and the diameter $2r_w$ was smaller. For the funnel type, the values became larger when the diameter $2r_w$ became larger.

Figure 5 shows the distribution of the spectral irradiance ratio f_s , while Table 4 compares the chromaticity values x and y . The rate of increase in the spectral irradiance ratio f_s and chromaticity values x and y were compared in the wavelength λ ranges of 410–420 nm

and 690–740 nm. There was a positive correlation with the shape as well as the length l and diameter $2r_w$ in the case of the funnel type. There was a negative correlation with the surface as well as the length l and diameter $2r_w$ in the case of the bell type. The rate of increase in the spectral irradiance ratio f_s and chromaticity values x and y were compared in the wavelength λ range of 420–690 nm. There was a negative correlation with the surfaces of chromed matte, chromed gloss, and aluminized gloss. Therefore, the spectroscopic performance of the reflected light on the surface of the otoscope was affected by the differences in the shape, surface, length l , and diameter $2r_w$ of the otoscope.

5.3 Spectral Irradiance Ratio of Direct Light and Reflected Light

Table 5 shows the correspondence between the numbers Om and Mn (Figures 8 to 15 and Tables 6 to 13). Figures 8 to 15 show the spectral irradiance ratios of direct light and reflected light. The distribution of the spectral irradiance ratio f_0 at the wavelength λ is shown. The spectral irradiance ratio f_0 cannot be determined when the spectral irradiance $i_{Hk, Mn}$ is zero. Therefore, according to the results in Figure 5, the wavelength λ range was set to 410–740 nm, where the spectral irradiance ratio $i_{Hk, Mn}$ is not zero. Tables 6 to 13 show the chromaticity values of the direct light and reflected light.

The distribution of the spectral irradiance ratio f_0 in Figure 8 was compared to the distribution of the spectral irradiance ratio f_s shown in Figure 6. The spectral irradiance ratio f_0 was larger than the spectral irradiance ratio f_s , but there were no changes in their respec-

Table 4 Chromaticity of reflected light.

Om	Mn	x	y
O3	M1	0.3053	0.2982
O6	M1	0.3026	0.3002
O9	M1	0.3012	0.299
O12	M1	0.2988	0.2965
O15	M1	0.3008	0.2998
O18	M1	0.2922	0.2901
O21	M1	0.2925	0.2915

Table 5 Correspondences of numbers Om and Mn in Figure 8 through Figure 15 and Table 6 through Table 13.

Figure	Table	Om	Mn
8	6	O3, O6, O9, O12, O15, O18, O2	M1
9	7	O1, O2, O3 O3	M1 M2, M3, M4, M5
10	8	O4, O5, O6 O6	M1 M2, M3, M4, M5
11	9	O7, O8, O9 O9	M1 M2, M3, M4, M5
12	10	O10, O11, O12 O12	M1 M2, M3, M4, M5
13	11	O13, O14, O15 O15	M1 M2, M3, M4, M5
14	12	O16, O17, O18 O18	M1 M2, M3, M4, M5
15	13	O19, O20, O21 O21	M1 M2, M3, M4, M5

Figure 8 Spectral irradiance ratios of direct and reflected lights in cases of numbers O3 and M1, O6 and M1, O9 and M1, O12 and M1, O15 and M1, O18 and M1, and O21 and M1.

Figure 10 Spectral irradiance ratios of direct and reflected lights in cases of numbers O4 and M1, O5 and M1, O6 and M1, O6 and M2, O6 and M3, O6 and M4, and O6 and M5.

Figure 9 Spectral irradiance ratios of direct and reflected lights in cases of numbers O1 and M1, O2 and M1, O3 and M1, O3 and M2, O3 and M3, O3 and M4, and O3 and M5.

Figure 11 Spectral irradiance ratios of direct and reflected lights in cases of numbers O7 and M1, O8 and M1, O9 and M1, O9 and M2, O9 and M3, O9 and M4, and O9 and M5.

tive distributions. According to the results shown in Table 6, the chromaticity values x and y were larger for the funnel type than for the bell type, regarding the comparison by shapes. Regarding the comparison by

surface, the values decreased in the order of chromed matte, chromed gloss, aluminized gloss, and black. Regarding the comparison by length l and diameter $2r_w$, the values did not considerably change for the bell type.

Figure 12 Spectral irradiance ratios of direct and reflected lights in cases of numbers O10 and M1, O11 and M1, O12 and M1, O12 and M2, O12 and M3, O12 and M4, and O12 and M5.

Figure 14 Spectral irradiance ratios of direct and reflected lights in cases of numbers O16 and M1, O17 and M1, O18 and M1, O18 and M2, O18 and M3, O18 and M4, and O18 and M5.

Figure 13 Spectral irradiance ratios of direct and reflected lights in cases of numbers O13 and M1, O14 and M1, O15 and M1, O15 and M2, O15 and M3, O15 and M4, and O15 and M5.

Figure 15 Spectral irradiance ratios of direct and reflected lights in cases of numbers O19 and M1, O20 and M1, O21 and M1, O21 and M2, O21 and M3, O21 and M4, and O21 and M5.

For the funnel type, the values became larger when the diameter $2r_w$ was larger. The chromaticity values x and y of the reflected light shown in Table 4 were compared

to those of the direct light and reflected light shown in Table 6. The chromaticity values x and y were smaller for those of the direct light and reflected light than

Table 6 Chromaticity of direct and reflected lights in cases of numbers O3 and M1, O6 and M1, O9 and M1, O12 and M1, O15 and M1, O18 and M1, and O21 and M1.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O3	M1	0.2912	0.2849
O6	M1	0.2964	0.2924
O9	M1	0.296	0.2923
O12	M1	0.2958	0.2925
O15	M1	0.2984	0.2964
O18	M1	0.2917	0.2893
O21	M1	0.2921	0.2906

Table 7 Chromaticity of direct and reflected lights in cases of numbers O1 and M1, O2 and M1, O3 and M1, O3 and M2, O3 and M3, O3 and M4, and O3 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O1	M1	0.2922	0.2857
O2	M1	0.2913	0.2849
O3	M1	0.2912	0.2849
O3	M2	0.2901	0.2833
O3	M3	0.2896	0.2826
O3	M4	0.2914	0.2858
O3	M5	0.2904	0.2848

Table 8 Chromaticity of direct and reflected lights in cases of numbers O4 and M1, O5 and M1, O6 and M1, O6 and M2, O6 and M3, O6 and M4, and O6 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O4	M1	0.2967	0.2921
O5	M1	0.2956	0.2916
O6	M1	0.2964	0.2924
O6	M2	0.2946	0.2897
O6	M3	0.2935	0.2882
O6	M4	0.2968	0.293
O6	M5	0.2976	0.2943

Table 9 Chromaticity of direct and reflected lights in cases of numbers O7 and M1, O8 and M1, O9 and M1, O9 and M2, O9 and M3, O9 and M4, and O9 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O7	M1	0.2991	0.2956
O8	M1	0.2988	0.2952
O9	M1	0.296	0.2923
O9	M2	0.2934	0.2887
O9	M3	0.2931	0.2879
O9	M4	0.2961	0.2926
O9	M5	0.2972	0.2941

Table 10 Chromaticity of direct and reflected lights in cases of numbers O10 and M1, O11 and M1, O12 and M1, O12 and M2, O12 and M3, O12 and M4, and O12 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O10	M1	0.2971	0.2937
O11	M1	0.2974	0.2942
O12	M1	0.2958	0.2925
O12	M2	0.294	0.2897
O12	M3	0.2933	0.2886
O12	M4	0.2964	0.2933
O12	M5	0.2977	0.295

Table 11 Chromaticity of direct and reflected lights in cases of numbers O13 and M1, O14 and M1, O15 and M1, O15 and M2, O15 and M3, O15 and M4, and O15 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O13	M1	0.2984	0.2956
O14	M1	0.2982	0.2957
O15	M1	0.2984	0.2964
O15	M2	0.2946	0.2909
O15	M3	0.2927	0.2884
O15	M4	0.2998	0.2985
O15	M5	0.305	0.305

Table 12 Chromaticity of direct and reflected lights in cases of numbers O16 and M1, O17 and M1, O18 and M1, O18 and M2, O18 and M3, O18 and M4, and O18 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O16	M1	0.2902	0.2872
O17	M1	0.2911	0.2884
O18	M1	0.2917	0.2893
O18	M2	0.2893	0.2842
O18	M3	0.2882	0.2826
O18	M4	0.2918	0.2896
O18	M5	0.2917	0.2902

Table 13 Chromaticity of direct and reflected lights in cases of numbers O19 and M1, O20 and M1, O21 and M1, O21 and M2, O21 and M3, O21 and M4, and O21 and M5.

<i>Om</i>	<i>Mn</i>	<i>x</i>	<i>y</i>
O19	M1	0.2907	0.288
O20	M1	0.2913	0.2892
O21	M1	0.2921	0.2906
O21	M2	0.2896	0.2855
O21	M3	0.2886	0.2836
O21	M4	0.2915	0.2893
O21	M5	0.291	0.288

those of the reflected light. Furthermore, there was a positive correlation for the shape and surface as well as the length l and diameter $2r_W$ for the funnel type. Therefore, the spectroscopic performance of the overall otoscope, which combined the direct light and reflected light, was affected by differences in the shape, surface, length l , and diameter $2r_W$ of the otoscope. However, this was different from the spectroscopic performance of the reflected light on the surface of the otoscope.

According to the results shown in Figures 9 to 15, there were differences in the spectral irradiance ratio f_0 due to differences in the diameter $2r_N$, distance d , and angle θ . According to the comparison of Figures 9 to 15, the generated difference became larger for the funnel type than for the bell type, regarding the comparison of shapes. Regarding the comparison of surfaces, the value increased in the order of black, chromed matte, chromed gloss, and aluminized gloss. Regarding the comparison by length l and diameter $2r_W$, the value increased for the bell type when the length l was larger and the diameter $2r_W$ was smaller. The value became larger for the bell type when the diameter $2r_W$ was larger.

Regarding the distribution, the spectral irradiance ratio f_0 increased significantly in the wavelength λ ranges of 410–420 nm and 690–740 nm when the diameter $2r_N$ was large. The value largely decreased at smaller diameter $2r_N$ and distance d when the surface was chromed matte or chromed gloss. The value largely fluctuated at smaller diameter $2r_N$ and distance d when the surface was aluminized gloss. The spectral irradiance ratio f_0 did not considerably change even with the increase in the wavelength λ in the range of 420–690 nm when the surface was black. The value increased when the surface was chromed matte or chromed gloss. The rate of increase did not considerably change due to differences in the diameter $2r_N$, distance d , and angle θ . The value increased in the wavelength λ range of 470–490 nm when the surface was aluminized gloss. The rate of increase was higher when the diameter $2r_N$ was larger.

According to the results in Tables 7 to 13, there were differences in the chromaticity values x and y according to the differences in the diameter $2r_N$, distance d , and angle θ . Regarding the comparison with the diameter $2r_N$, the chromaticity values x and y varied more due to differences in $2r_N$ according to the results in Tables 7, 8, 10, and 11. According to the results in Table 9, the values were smaller when the diameter $2r_N$ was larger. According to the results in Tables 12 and 13, the values were larger when the diameter $2r_N$ was larger. Regarding the comparison with the distance d , according to the results in Tables 7 and 13, the values were smaller when the distance d was larger. Regarding the comparison with the angle θ , according to the results in Tables 7, 8, and 12, the values varied according to

the differences in angle θ . According to the results in Table 13, the values were smaller when the angle θ was larger. Therefore, the otoscopes that correlated with the chromaticity values x and y without variations in the diameter $2r_N$, distance d , and angle θ were O7 to O9 and O19 to O21. O7 to O9 were otoscopes with a bell shape, chromed glossy surface, small length l , and large diameter $2r_W$. O19 to O21 were otoscopes with a funnel shape, aluminized glossy surface, and large diameter $2r_W$ designed for focusing optimization. The correlation between the chromaticity values x and y , diameter $2r_N$, distance d , and angle θ could be determined using these otoscopes. These correlations help doctors determine the accurate color tone.

The distributions of the spectral irradiance ratio f_0 in Figures 9 to 13 were compared with the chromaticity values x and y shown in Tables 7 to 13. The fluctuations in the spectral irradiance ratio f_s in the wavelength λ ranges of 410–420 nm and 690–740 nm were compared with the chromaticity values x and y . There was a positive correlation for the diameter $2r_N$. There was a negative correlation for the angle θ when the surface was chromed matte or chromed gloss. The increase in the spectral irradiance ratio f_s in the wavelength λ range of 420–690 nm was compared with the chromaticity values x and y . There was a positive correlation for the angle θ when the surface was chromed matte or chromed gloss. There was a positive correlation for the diameter $2r_N$ when the surface was aluminized gloss. Therefore, the spectroscopic performance of the overall otoscope, which combined reflected light and direct light, was affected by differences in the otoscope diameter $2r_N$, distance d , and angle θ .

6. Conclusion

In this study, the spectroscopic performance of the otoscope was evaluated in the otoscopic examination using a headlight. The obtained results can be summarized as follows.

1. The mechanism and specifications of the measured object such as the otoscope for evaluation of the spectroscopic performance were described. A method for configuring a measuring device that used an existing otoscope and headlight and measuring the spectral irradiance of the otoscope was presented. A method for evaluating the spectroscopic performance by the spectral irradiance ratio and chromaticity using the measured spectral irradiance was proposed.
2. The spectral irradiance of the otoscope was measured using the measurement method. The distribution of the spectral irradiance in the otoscope was largely affected by the spectral distribution in the headlight source.
3. The spectroscopic performance of the otoscope

was evaluated using the evaluation method. The spectroscopic performance of the reflected light in the surface of the otoscope was affected by differences in the shape, surface, length, and wide-mouth diameter of the otoscope. The spectroscopic performance of the overall otoscope combining direct light and reflected light was affected by differences in the surface, length, and wide-mouth diameter. However, this differed from the spectroscopic performance of the reflected light in the surface of the otoscope. Furthermore, differences in the narrow-mouth diameter in the otoscope as well as the distance and angle between the otoscope and headlight were influencing factors.

4. The correlation between the chromaticity, narrow-mouth diameter, and distance and angle between the headlight and otoscope could be determined using an otoscope with a bell shape, chromed glossy surface, small length, and large wide-mouth diameter or otoscope with a funnel shape, aluminized glossy surface, and large wide-mouth diameter for focusing optimization. These correlations help doctors determine the exact color tone.

References

- (1) Hinoki, M.: Modern oto-rhino-laryngology, Kanehara, pp.159–167 (1983).
- (2) Kaga, K.: Modern oto-rhino-laryngology, Nanzando, pp.63–64 (2013).
- (3) Moriyama, H.: Middle ear. outer ear, Medicalview, p.26 (2000).
- (4) Zusho, H.: Headlight using a fiber light source, *Oto-Rhino-Laryngology Tokyo*, 29-5, pp. 583–586 (1986).
- (5) Otsuka, K., Nonaka, M. and Watanabe, S.: Success otolaryngology, Kanehara, p. 23 (2017).
- (6) Goto, F. and Yabe, H.: Customized catoptric head mirror with white LED and battery replacement, *Oto-Rhino-Laryngology Tokyo*, 49-3, pp. 142–144 (2006).
- (7) Syouji, K. and Kojima, T.: Head Mirror replacement, *Practica Oto-Rhino-Laryngologica*, 98-9, pp. 682–683 (2005).
- (8) Matsumoto, M.: Performance evaluation and optimization of design of light focus in otoscope during otoscopic examination by headlight, *Journal of Science and Technology in Lighting*, 44-0, pp. 34–44 (2021).

This paper is translated from the article of the Journal of the Illuminating Engineering Institute of Japan, Vol. 106, 2022 (in Japanese).