Paper

Effect of the Highest Lightness on the Brightness Size of the Recognized Visual Space of Illumination

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ABSTRACT

We have proposed a new estimation method for a perceived brightness of a room based on the concept of the recognized visual space of illumination, or RVSI. We use the term 'brightness size' of the RVSI to express an observer's perception of the intensity of illumination. We define the border luminance between the surface color and the unnatural surface color modes as the brightness size of the RVSI. Our previous work¹⁾ showed that the border luminance was proportional to the illuminance of a room and that was equal to the luminance of the brightest object in the room. We measured the border luminance in two differently decorated rooms to test the effect of the highest lightness of the object. One room was furnished with white walls and various lightness objects from black to white (environment N). The other was furnished with black walls and objects whose Munsell Values were 5 or less (environment L). Although the illuminances of the two rooms were the same, the border luminance in environment L was a half of that in environment N. Contrary to our previous result, the border luminance in environment L was higher than the luminance of the brightest object. We also compared the border luminance among between three different positions where the local contrast and the local illuminance were different. The border luminance was almost constant regardless of the measuring position, suggesting that the local environments have little effect on the perceived brightness of a room.

KEYWORDS: space brightness, color appearance mode, lightness, recognized visual space of illumination (RVSI)

1. Introduction

When we observe an object in our environment in our daily life, we recognize the color and brightness of the object unconsciously. Even if the color and brightness levels in the surrounding environment are varied significantly, the appearance of the surface of the object remains almost unchanged. Although this phenomenon is called brightness and color constancy, it was pointed out in the past study²⁾ that the degree of this constancy varies with the conditions under which the objects are observed. We consider that it is necessary to understand, at least, the illumination conditions of the space where an object exists, because, for the constant perception of the object surface, it is necessary to deduct components attributable to the illumination contained in the light reflected from the surface of the object. In concrete terms, recognition of the intensity and color of the illuminating light projected into the space is indispensable for recognition of the object surface. We call recognizing the illumination environment the formation of the recognized visual space of illumination (RVSI) in the cerebrum, and we call the intensity of the illuminating light, which is

the degree of recognizing the space brightness, the brightness size of the recognized visual space of illumination. The brightness size is quantitatively defined by the border luminance of the color appearance mode. The border luminance of the color appearance mode is the luminance at the border where the appearance mode is changed from "an object color" of an object surface under a certain illumination environment to "an unnatural color" for an object existing in the environment when the luminance of the object is varied by means of local illumination for the specific object alone by a light source different from the main illumination. "An unnatural color" as used here is the appearance mode existing between the "object color mode" and the "light source color mode", both in the color appearance mode, that is not seen so bright as the light source color but appears unnatural for the illuminated object surface.

In various studies^{3,4)}, it has been pointed out that the simple measurement of illuminance and luminance, which are the existing photometric quantities, is insufficient for expressing quantitatively the perception of the brightness of a space in an actual environment in

our daily life. In regard to this problem, Loe et al.⁵⁾ concluded that the perception of brightness of a space can be evaluated by the average luminance in the visual range 20° above and below the horizontal at eye level. Iwai et al.⁶⁾ also described how the average luminance of specific areas, such as walls and corners of a room, which influence the impression of the room illumination, largely contributes to the perception of brightness. Ogiuchi et al.⁷⁾ proposed a calculation method called the virtual luminance distribution method, in which the perceived brightness of a space is represented by assumed the luminance of a virtual illuminating light source. We have proposed to measure the border luminance of the color appearance mode as a practical evaluation method for the perceived brightness of a space, and we have studied its determining factors.

When the border luminance of the color appearance mode was measured on achromatic test patches in a normal living room in our previous report¹⁾, the border luminance varied in parallel with the illuminance of the room, and, as a result, it nearly matched the luminance of an object placed in the room with the highest lightness or, in the former experiment, the luminance of the white flowers and walls. When the illuminance of the room is kept constant and the highest lightness of an object placed in a room is restricted to a lower level, will the border luminance be influenced and lowered? Also, although measuring the border luminance was done at a certain location in the room in the previous experiments, is it constant for any position in a room? Hence, in Experiment 1, an interior environment in which the lightness of the furniture and the walls in a room was limited to below a certain level of lightness as well as a normal interior environment without lightness constraints were prepared in order to clarify the relationship between the highest lightness of the interior environment and the border luminance. In Experiment 2, the border luminance was measured at three different positions in the room in order to evaluate the relationship between the local environment by measuring position and the border luminance. Specifically speaking, what was studied was if the illuminance at the measuring positions and the background luminance influence the determination of the border luminance.

2. Experiment 1

2.1 Experimental equipment

The interior environment used in this experiment was a living room 2.7 m wide, 3.6 m deep, and 2.2 m high. This room was illuminated by four day-light-type fluorescent lamps installed on the ceiling, the light from which came through white acrylic plates and could be dimmed by a light controller set on a wall in the room. There was a table 50 cm tall in the center of the room,

and the illuminance of the room I_R was measured by a MINOLTA T-1 illuminance meter, which was set on the table. In the experiment, the border luminance of the color appearance mode was measured on a test patch of N5 grey, 6 cm square. This test patch was locally illuminated from the low side by a slide projector with a halogen lamp. A rotating neutral-density wedge filter was inserted in the light path, and the luminance of the test patch could be changed by its rotation angle. The room and the measuring equipment for the border luminance of the color appearance mode used in this experiment were the same as those that were used in the previous report¹⁾.

2.2 Experimental conditions

In order to study the influence on the brightness size by limiting the highest lightness of the materials composing a room, an experiment was made using two kinds of interior environments. The appearance of each interior environment as seen by the subjects is shown in Figure 1. The upper figure in Figure 1 is a normal interior environment composed of furniture with various lightnesses and hues, and this environment is

Figure 1 Front view of the experiment room

A small square noted as T is the test patch. The labels attached to objects are shown in Table 1. The upper panel shows the environment N, the lower panel shows environment L.

Table 1 Munsell notation and luminance of objects at the room illuminance of 300lx

Label	Items	Environment N		Environment L	
		HVC	Y (cd/m ²)	HVC	Y (cd/m ²)
W	Wall	5Y9/1	41.0	N2	1.76
Fl	Floor	2.5Y4/4	6.15	2.5Y4/4	4.38
Tb	Table	10YR4/3	13.7	10YR4/3	12.0
LB	Low board	10YR5/4	11.3	10YR5/4	6.33
Cu	Curtain	5PB7/4	25.7	7.5PB2/6	2.16
Co	Coat	N2	0.98	N2	0.68
CH	Coat hanger	7.5YR4/6	5.68	7.5YR4/6	3.63
PB	Projector box	N2.5	3.59	N2.5	2.87
M ₁	Magazine1	5R4/14	5.06	5R4/14	3.33
M ₂	Magazine2	N9.5	21.0		
MR	Magazine rack	5PB3/8	1.91	5PB3/8	1.97
L ₁	Leaf1	7.5GY3/3	7.54	7.5GY3/3	6.57
L ₂	Leaf2	7.5GY4/6	9.52	7.5GY4/6	7.06
Tr	Trunk	2.5Y7/4	13.4	10YR3/2	4.03
Pt	Pot	2.5YR3/2	1.57	2.5YR3/2	1.14
FV	Flower vase	5YR2/1	1.07	5YR2/1	0.47
Fw	Flowers	10Y9/2	43.3	5R3/10	2.07
	Flowers	5R4/14	10.4	2.5P5/4	6.91
	Flowers	5Y9/6	31.3		
	Flowers (stem)	5GY5/4	5.86	5GY5/4	2.64

called environment N (normal). Here, T is a test patch of N5 as described before, and it was set at the height of the eyes of the subjects sitting on a sofa and two meters in front of them. The lower figure in Figure 1 shows an interior environment where the lightness of the furniture with various hues was limited to below 5 in the Munsell notation, and this is called environment L (limited). For this environment, the walls W were replaced by black ones with N2, and the curtain Cu, the magazines Mg, the trunk of foliage plant Tr, and the flowers Fw were replaced with those with Munsell notations below 5, while all other objects were the same as those in environment N. Table 1 shows the Munsell notation and luminance for each item in each environment. By the way, the Munsell notation was obtained through visual matching by the authors and the luminance was the measured with a MINOLTA CS-100 at a room illuminance I_R of 300 lx. As shown in Table 1, the object with the highest lightness in the environment N was the magazine M₂, for which the Munsell value was 9.5. Also, the items with the highest luminance were the white flowers Fw, for which the luminance was 43.3 cd/m². In environment L, the item with the highest lightness was the low board LB, for which the Munsell value was 5. The item with the highest luminance was the table Tb, for which the luminance was 12.0 cd/m². The border luminance was measured in both environments with the illuminance I_R set at five levels: 3, 10, 30, 100, and 300 lx.

2.3 Experimental procedure

The subjects sat on a sofa located at a corner of the

room and set the luminance of the test patch to the border luminance of the color appearance mode after observing the whole interior of the room. The following instructions were given to the subjects: "Please set the luminance of the test patch at the border when you start to feel that the appearance of the test patch in front of you is unnatural as an object in this room. When you make a judgment, please do not gaze at the test patch alone but observe the whole interior of the room." Nine subjects participated in the experiments. Three subjects, HH, HS, and HY, measured the border luminance at the all five levels of illuminance of the room I_R , while the remaining six subjects measured the border luminance at three levels of illuminance of the room I_R , or 3, 30, and 300 lx. In the sessions of Experiment 1, the border luminance was measured by changing the illumination level at random in either one of the interior environments. Subjects set the border luminance for each illuminance level three or four times consecutively. By repeating this session four times, fifteen values in total were obtained for each environment, as well as for all the illuminance levels.

2.4 Results and consideration

Figure 2 shows the results at the five levels of illuminance for the subjects HH, HS, and HY, as well as the results at the three illuminance levels for all nine subjects. The horizontal axis in the figure shows the value of the illuminance of the room I_R and the vertical axis shows the border luminance set by the subjects. ○ show the averages of the fifteen judgments in the normal interior environment N where there was no limit on the lightness. ● show the averaged border luminance judgments for the interior environment L where the lightness was limited so that the Munsell value was below 5. The standard deviations are also shown on the results for subjects HH, HS, and HY. In the graph of the results for all subjects, the symbols show the averages by subject, and the results for the three subjects HH, HS, and HY are included. Also, the solid lines show the average of the results for the nine subjects in each environment.

The results for subject HH will be taken up as an example in the following explanation. In either interior environment, the border luminance varied in parallel with the room illuminance I_R . When these changes are approximated by straight lines, the slope of the line in the case of environment N with no limit on the lightness was 0.90 and it was 0.84 in environment L in which the Munsell value was limited to below 5. It was clarified by the results of the previous report¹⁾ that the changes in illuminance of the room and the border luminance were linear changes with an approximate slope of 0.9 in logarithmic value. The slope obtained in

Figure 2 Border luminance as a function of room illuminance
 ○ show the averaged border luminance in environment N, and ● show the same in environment L. Error bars show the standard deviations. In the right below panel, the solid lines indicate the averaged border luminance across all nine subjects.

this experiment is consistent with the previous results despite the differences in the interior environments. However, there is a notable difference in the absolute values between the border luminance in environment N and the same in environment L. Despite the same illuminance of the room, the border luminance in environment L constantly showed lower values at each illuminance level.

Also, with the other subjects, the illuminance of the room and the border luminance are in a proportional relationship in logarithmic value. The slope of the border luminance in subject HS was 0.91 in environment N and also 0.91 in environment L, and the same for subject HY was 0.88 in environment N and 0.86 in environment L. The slope of the straight line in the average for the nine subjects was 0.90 in environment N and 0.86 in environment L. Also, similar to the case of subject HH, the border luminance in environment L showed a consistently lower value than that in environment N for all the subjects. Thus, it can be said that the border luminance and the illuminance level in the room are in proportional relationship in logarithmic value and that the proportional coefficient is almost equal irrespective of the highest lightness in the interior environment. However, the border luminance is apparently lowered even when the illuminance level is the same by limiting the Munsell value to below 5. It

Figure 3 Conversion of the border luminance to the corresponding lightness

○ show the corresponding lightness calculated from the border luminance for each subject in environment N, and ● show the same in environment L. The upper horizontal dashed line indicates the highest lightness in environment N, and the lower dashed line shows the same for environment L.

was reported that the subjects felt that environment L was darker in their opinion, and this is consistent with the measured results of the border luminance.

Then, to what extent will the border luminance be reduced by limiting the highest lightness to a lower level? In the previous report, it was found that the border luminance became almost equal to the luminance of the object with the highest lightness. Now, since the upper limit luminance that allows the recognition of the object color is the border luminance, the lightness is more suitable for expressing the brightness of the object color than the luminance. Hence, the border luminance was converted to the lightness L^* using the CIE1976 conversion equation, as shown in equation (1), and a comparison with the highest lightness of the interior environment was made.

$$L^* = 116 \cdot \left(\sqrt[3]{Y/Y_0} \right) - 16 \quad \text{..... (1)}$$

In equation (1), Y is the border luminance that is to be converted to the lightness, and Y_0 is the luminance of the standard white in the environment. The luminance of the standard white was obtained as follows. Color chips of N5 and N9 were placed perpendicularly at the position where a test patch was demonstrated under each illuminance in the room, and their luminances were measured. The measured luminance values and the lightness corresponding to the color chips were put

into equation (1) to calculate Y_0 . Y_0 under each illuminance was determined by making an average of two Y_0 values calculated as shown above. Figure 3 shows the results of the conversion to L^* by substituting the border luminance measured for all the subjects under each illuminance for Y in equation (1). Usually L^* is not defined above 100, but even the cases of L^* exceeding 100 were converted by the same method in order to make comparison with the same scale. The horizontal axis in the graph shows the room illuminance I_R and the vertical axis shows the lightness L^* , which were converted from the border luminance. ○ in the graph show the L^* values in environment N and ● show the L^* values in environment L. The solid lines show the average for all the subjects in each environment. Also, the horizontal dashed lines show the value of the highest lightness objects in both environments, which are the Munsell values multiplied by 10. The upper dashed line shows the value of the highest lightness L^* 95 in environment N, and the lower dashed line shows the value of the highest lightness L^* 50 in environment L.

The averages of the border luminance L^* in environment N showed values in the range from 78 to 93. A tendency was noted that decreases in the L^* value somehow accompanied an increase in illuminance. This is considered to be a result reflecting the fact that the slope of the straight line for the relationship between the illuminance and the border luminance, as shown in Figure 2, was somehow smaller than 1. Since a similar tendency was noted also in the previous report¹⁾, we have decided to regard this as a characteristic of the border luminance in this range of illuminance. However, further consideration of this will not be made in this paper, since it is necessary to expand the range of illumination in the room in order to examine if this characteristic can be generalized. The L^* values of the border luminance are distributed in positions close to the highest lightness in the environment or 95, although it varies slightly by the illuminance of the room. Thus, it is considered that, in the environment N without the limit on the highest lightness, the border luminance of the test patch is determined to be at the brightness level similar to the brightness of a white object with a lightness close to 100. Since the white object is brightest among the object colors, the definition of the border luminance supports this way of thinking.

If it is assumed that the relationship between the highest lightness (the broken lines) and the L^* value of the border luminance (the solid lines) as seen in the environment N also is valid in environment L, it can be estimated that the average value of L^* in environment L is shown by the dotted lines. However, the average of the border luminance L^* in environment L shows values in the range of 55 to 72, and they are higher than

the estimated level by around 20. Therefore, it is impossible to explain the L^* value of the border luminance in environment L with limited highest lightness using the relationship between the highest lightness and the L^* value of the border luminance in environment N. In other words, the border luminance was not determined based upon the objects of the highest lightness existing in the environment. Also, the highest lightnesses in environments N and L are 95 and 50, respectively, and the highest lightness ratio is limited to 0.53 times. On the contrary, the ratio of the L^* values of the border luminance showed a stable value irrespective of the subjects and the illuminance levels, and the average of the ratios was 0.74. Hence, it is not easy to estimate the L^* value of the border luminance by the changes in the highest lightness alone.

Then, had the subjects determined the border luminance by assuming the brightness of standard white that did not exist in their visual field? However, the L^* values were below 100 for all the subjects, and it is apparent that they did not determine the border luminance to be at a brightness equivalent to the standard white. That is to say, the L^* values of the border luminance determined by the subjects were middle values, which were not equal to the highest lightness in environment L nor to the standard white. Meanwhile, in an environment where there are white objects in the visual fields of the subjects, as was the case in environment N, the L^* values of the border luminance were determined to be in the vicinity of white. It is considered that, since there was no object perceived as white in the visual fields of the subjects in the environment L, the subjects tried to determine the border luminance by extrapolating white, which did not exist in their real visual fields. Thus, it can be said that the L^* values of the border luminance in environment L took the middle value between the highest lightness in the environment and white because the white, as extrapolated by the subjects, was imperfect.

The above results are summarized as follows. In the interior environment N, which was without limits on the lightness of the objects, the border luminance was determined in the vicinity equivalent to white objects such as the flowers Fw and magazine M₂. However, when the lightness of the objects was limited, as was the case in environment L, the border luminance became lower, but it was not consistent with the highest lightness in the environment. In conclusion, although the border luminance does not change so much as the changes in the highest lightness, there is a certain relationship between the changes in the composition of the lightness in the environment and the border luminance. It was verified that the perceived brightness of the environment was reduced to 70% to 80%, in spite of the same horizontal

illuminance of, by limiting the highest lightness to 53% in the experimental environment in this study.

Since there is a difference in the wall or the background of the test patch between the environments N and L, it can be pointed out as a possibility that the differences of the border luminances in the two environments is determined by the luminance contrast between the test patch and the background. Also, although the border luminance changed in proportion to the illuminance I_R at the center of the room, the local illuminance of the horizontal plane at the position of the test patch varies by position where the test patch is placed in a certain I_R . Hence, the influence of these two factors of the local environment in the vicinity of the test patch, which are the background luminance and the horizontal illuminance on the border luminance, will be studied in both room interiors in Experiment 2.

3. Experiment 2

3.1 Experimental equipment

The experiment was done in the same rooms as were used for Experiment 1.

3.2 Experimental conditions

In Experiment 2, three points with different local environments were set in two interior environments, as were used in Experiment 1, to study the difference in the border luminance. Figure 4 shows the top views of the experiment room. The upper diagram shows environment N and the bottom diagram shows environment L. The contours in the diagrams show the distribution of the horizontal illuminance I_T at the height of the test patch with a room illuminance of $I_R = 300$. The interval of the contour is 50 lx. Table 2 shows the horizontal illuminance I_T and the luminance L_B of the background behind the test patch as seen by the subjects with a room illuminance of 300 lx at each measuring point of three positions, P1, P2, and P3 in the case of environment N, and three positions, P1, P2, and P4 in the case of environment L, where the border luminance is to be measured. By the way, the background luminance L_B is the value of the background area near the upper side of the test patch as seen by the subject measured with a MINOLTA CS-100. The luminance measuring range of the MINOLTA CS-100 is a 1° visual angle, while the size of the test patch as seen by a subject is around 1.7° . The material composing the background of the test patch was a single constituent, and the luminance of the background areas adjacent to the sides of the test patch other than the upper side were within several percent of error from the upper side luminance. Taking the above into consideration, the luminance of the background area surrounding of the test patch within 1° was regarded as being nearly constant, and we de-

cided to have the luminance of the background adjacent to the upper side of the test patch represent the luminance of the surrounding background. Position P1 was the measuring point in both environments, and the other three points (P2, P3, and P4) were set taking the horizontal illuminance and the adjacent background luminance of this point (P1) as a standard as follows. Position P2 was the place where the horizontal illuminance was half of P1, or 200 lx, in either environment, and its adjacent background luminance was the same as P1. P3 in environment N and P4 in environment L were set so that the horizontal illuminance I_T was the same as P1, or 400 lx, but the adjacent background luminance was different from P1. In concrete terms, the adjacent background area of P3 in the environment N was a black coat for which the luminance was 1.80 cd/m^2 , which was almost the same level as the 1.76

Figure 4 Top view of the two environments
These contour lines show the illuminance distribution at the room illuminance of 300 lx. P1, P2, P3 and P4 indicate the position where we measured the border luminance.

Table 2 The local illuminance and the luminance of the immediate background at the measuring positions

Room Type	Environment N			Environment L		
	P1	P2	P3	P1	P2	P4
I_T (lx)	400	200	400	400	200	400
L_B (cd/m^2)	36.1	36.1	1.80	1.76	1.76	3.20

cd/m² of the black wall or the adjacent background of P1 in the environment L. P4 in the environment L was set in front of a curtain so that its adjacent background luminance become higher than that of P1, or 1.76cd/m², and its luminance was 3.20cd/m².

3.3 Experimental procedure

The subjects and tasks were the same as in Experiment 1. Similarly, the three subjects, HH, HS, and HY, measured the border luminance in five stages of room illuminance I_R , which were 3, 10, 30, 100, and 300 lx, and the remaining six subjects measured the border luminance in three stages of the room illuminance I_R , 3, 30, and 300 lx. Actually, Experiments 1 and 2 were implemented simultaneously. That is to say, either one of the two experimental environments was set and the border luminance was measured by changing the illuminance level and measuring point at random. Fifteen measured values of the border luminance were obtained at each measuring point of P1 through P4 under all illuminance levels for the room in the two interior environments.

3.4 Results and consideration

Figure 5 shows the results for subjects HH, HS, and HY as well as the results of the average for all the subjects. The left graph shows the results in environment N and the right graph shows the results in environment L. The horizontal axis in the figure shows the value of illuminance of the room I_R , and the vertical axis shows the border luminance set by the subjects. In regard to the symbols in the graph, a circle shows the border luminance at the measuring position of P1 in both environments, while a square shows the same at P2, and a triangle shows the same at P3 in environment N and at P4 in environment L. Also, error bars show the standard deviations. Since the measuring point P1 was in the same environment as in Experiment 1, the experimental results at P1 were identical with those in Experiment 1.

An explanation will be made of the results, using the subject HH as an example. First, the border luminance at the measuring points P1 and P2 in both environments is compared. Although there was a twofold difference in the local horizontal illuminance by the position of the test patch, there was definitely no difference in the border luminance in either interior environment. Thus, it can be said that the determination of the border luminance is not affected by changes of around twofold in the local illuminance as was set in this experiment. Then, the influence of the luminance contrast between the test patch and the adjacent background area was evaluated. Although the adjacent background luminance significantly changed from 36.1cd/m² at P1 to 1.8cd/m² at P3, or to 1/20, in environment N, the border luminance were 45.1cd/m² and 35.8cd/m², respec-

Figure 5 Results from Experiment 2

The left panels show the border luminances measured at three different positions in environment N; the right panels show the same for in environment L. ○ and ● show the border luminance of the measuring position P1 and □ and ■ show this for measuring position P2 in both environments. △ and ▲ indicate the border luminance for measuring position P3 in environment N and that for P4 in environment L. Error bars show the standard deviations.

tively, and did not greatly change. In environment L, although there was a twofold difference in the adjacent background luminance between P1 and P4, 1.76cd/m² and 3.2cd/m² respectively, there was no change in the border luminance, 17.1cd/m² and 18.6cd/m² respectively. Also, in regard to P3 in environment N (△ in the graph) and P1 in the environment L (● in the graph), although their adjacent background luminance were almost same, 1.8cd/m² and 1.76cd/m², the border luminances were 35.8cd/m² and 17.1cd/m² respectively, and, accordingly, P3 in the environment N took a two times higher value. From these results, it was clarified that the border luminance is not determined only by the lu-

minance contrast between the test patch and the adjacent background area. Although a little bit of an effect of the luminance contrast is seen when the adjacent background is significantly different, as was the case of P1 and P3 in environment N, its degree can be said to be small compared to the influence of limiting the lightness of the interior environment. Other subjects and an average of all the subjects showed the same results as for subject HH.

In view of the above results, information such as the local horizontal illuminance and the luminance contrast versus the adjacent background area, both at the position of the test patch, can not be determining factors for the border luminance by themselves. In other words, it is appropriate to understand that the border luminance is constant irrespective of the measuring position in an environment where general illumination, as is usually applied in a residence or office, and also as set in the interior environments in this experiment, is implemented. Also subjects reported in their subjective reports that they felt the experimental room was homogeneously illuminated, and the measured results and the subjects' perceptions are consistent. This is important for practical application of this method in illumination design. For example, it is possible not to express the uniformity of an illumination environment by the uniformity ratio of the illuminance but to define a new uniformity ratio based upon the perception of human beings. If the uniformity of illumination can be expressed by such an index based upon perception, it would be considered to be an effective tool for designing various illumination environments.

4. Summary of generalized comments

In this report, we have studied what factors vary the perception of brightness of an environment in a complex environment. From the results of the experiments, the brightness size of the recognized visual space of illumination, that is the perceived brightness of the environment, is almost constant in the interior environment illuminated by ceiling lights. Also, in a normal interior environment that is composed with various lightnesses and colors, the perception of the brightness can be defined by the luminance equivalent to the brightness of an object with the highest lightness or white in the environment. However, when the brightness size is made smaller by intentionally limiting the highest lightness in the environment to a low level, the perception does not fit with the luminance of the object with the highest lightness in the environment. Accordingly, it is inappropriate to say that the luminance of an object with the highest lightness universally determines the brightness size in any interior environment.

Now, we would like to consider what kind of visual in-

formation is needed for recognition of illumination status of an environment. The information that reaches the eyes of human being ultimately is the luminance information coming from reflecting objects or light-emitting material. The only light-emitting material in the environment in this experiment was the fluorescent lamp on the ceiling, and its luminance remained almost unchanged in the two interior environments. Thus, it is impossible to consider that the recognition of intensity of illumination in the two interior environments was changed by the luminance information from the illuminating light source. Therefore, it is concluded that the luminance information from the reflecting objects determines the recognition of the intensity of illumination or the perception of the brightness of a space.

Then, we would like to examine what kind of luminance information is important in concrete terms. As described before, it is impossible to predict the perception of brightness based upon a single datum of luminance information such as the luminance of the material with the highest lightness in the environment or the luminance of the adjacent background area of the test patch. Now, let us focus our attention on the distribution of the average luminance and luminance values in the overall visual field. While there were objects in the range from N2 to N9.5 in the normal interior environment N that was not limited in lightness in this experiment, there were only objects from N2 to N5 in environment L with limited lightness. Therefore, when the average luminance of the visual field is compared, it is lower in environment L compared to environment N, and the distribution of the luminance in the visual field in environment L is smaller than that in environment N. Simultaneously, the perception of the brightness of the space in environment L showed a lower level than for environment N. Also, when the average luminance of the visual field alone was reduced without limiting the lightness, or with nearly no change in the distribution of the luminance in the experiment in the previous report¹⁾, there was no significant difference observed in the perceived brightness of the space. Because of the above, it is assumed that changes in the perceived brightness of the space is generated when the average values and distribution of the luminance in the visual field are varied together.

Since the lightness or the reflectance ratio of each object to be placed in an interior environment is already known for designers, it is desirable to predict the perception of the brightness of a space from the luminance and reflectance ratio. Since human beings recognize the brightness of a space based upon luminance information in the visual field, as described before, it is useful to determine the border luminance after calculating the average luminance and the distribution of the luminance. It is a theme for future research to define the border lu-

minance as a function of the average luminance and the distribution of the luminance. The evaluation of the brightness perception of a space by measuring the border luminance will be further developed and proposed as an advantageous design method mainly for ambient illumination. For example, since it is possible to suppress the perceived brightness of a space while maintaining the horizontal illuminance at a certain level, as shown in the results of this experiment, a space lighting design is feasible to produce a dark and relaxing environment for the atmosphere of the whole room while securing simultaneously the horizontal illuminance required for tasks. As shown here, it will become possible to create a varied and rich illuminating environment by separating the task illumination and the ambient illumination in one environment and by applying the evaluation method for the brightness perception of a space, as described above, on the ambient illumination.

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