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Lightness Change as Perceived in Relation to the Size of Recognized Visual Space of Illumination

Yoko MIZOKAMI, Mitsuo IKEDA and Hiroyuki SHINODA

Department of Photonics, Faculty of Science and Engineering, Ritsumeikan University, 1-1-1, Nojihigashi, Kusatsu, Shiga, 525-8577 Japan

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According to the concept of the recognized visual space of illumination (RVSI) the lightness of an object surface is perceived in relation to its conceptualized size. To prove this proposition the lightness of gray test patches was judged when they were located at various positions inside an illuminated space composed of two rooms in the depth direction from a subject. No retinal image arrangement was changed in the test patch and its immediate surroundings, but the front room had walls, floors and furniture lower in lightness by the amount of N1.5 than the back room to make the RVSI of the former smaller despite the illuminance in the entire space being the same. The results showed that the apparent lightness of the patches was perceived higher by amount of about 13 in L^* units for the N4 test patch and about 20 for N6 when the patches were located in the front room, in accordance with the prediction. It was stressed that the experiment of lightness judgment should be conducted in a three dimensional space rather than two dimensional plane as done by several investigators.

Key words: lightness, apparent lightness, illumination, recognized visual space of illumination

1. Introduction

One important property of the recognized visual space of illumination (RVSI) is its size, for the perceived lightness and the change in color perception mode of an object can be explained in relation to the size.[1–3] The RVSI is the recognition for a space of the outside world in terms of illumination which is produced in the brain of an observer when he/she looks at the space. Size is a concept expressing the perception of brightness for the space recognized by the observer. If he/she felt that the space was brightly illuminated the size of his/her RVSI is said to be large and vice versa. To construct the RVSI he/she uses the initial visual information such as the appearance of objects in the space, the luminaires illuminating the space and the windows through which the daylight enters. If an object in the space appears too bright to the observer compared to the size of his/her RVSI, the feeling is of the surface unnatural and discrepant, and the only reasonable solution for that situation is for the observer to assume there is some additional local light illuminating the surface other than the existing room light, or that the object itself is emitting light, the latter solution giving rise to the perception of light source color.

If the appearance of an object is included within the RVSI, the observer feels the surface natural and perceives there the object color as in most cases. The perceived lightness of the surface is determined by the luminance of the surface with respect to the size of the RVSI. If the luminance is increased such as by a local illumination without altering the size, the perceived lightness simply becomes higher.[3] If the size of RVSI of a space is increased, the perceived lightness becomes lower even if the luminance of the object is unchanged.[4,5] This phenomenon was specifically shown in these papers[4,5] by altering the size of RVSI through the arrangement of objects and wallpaper with high lightness in a miniature room and with low lightness in another room while keeping the room illuminance the same. The lightness of a gray test patch was judged low in the former room while the same patch was judged high in the latter room as predicted. In the experiment, however, the two miniature rooms were placed side by side and the surroundings of the test patch differed, a wall with high lightness in one room and a wall with low lightness in the other room, thus presenting different retinal image arrangement. Although the effect of the size of RVSI upon the lightness judgment was clearly demonstrated there by replacing low lightness furniture with colored furniture to increase the size, where the apparent lightness of the test patch decreased, we conduct here a similar experiment but with the same surrounding situation for the test patch to eliminate the disadvantage of different retinal arrangement in the two rooms and to confirm the explanation of the lightness perception in terms of the RVSI.

2. Experiment

A miniature set of an illuminated space was constructed, composed of two rooms, a back room R_b and a front room R_f of which the side view is presented in Fig. 1. Both rooms had the same dimensions: 38 cm wide, 50 cm deep and 30 cm high and were arranged in the depth direction from a subject S, and connected or separated by a wall with a rectangular opening of 20 cm by 30 cm. In other words, there were projections 4 cm wide from the left and right walls and 5 cm wide from the ceiling and the floor. These projections were installed to clearly separate two RVSIs of the two rooms. The ceilings of the rooms were made of opal glasses and four 20 W daylight type fluorescent lamps above them, FL_b and FL_f, were placed to

E-mail: see30136@se.ritsumei.ac.jp

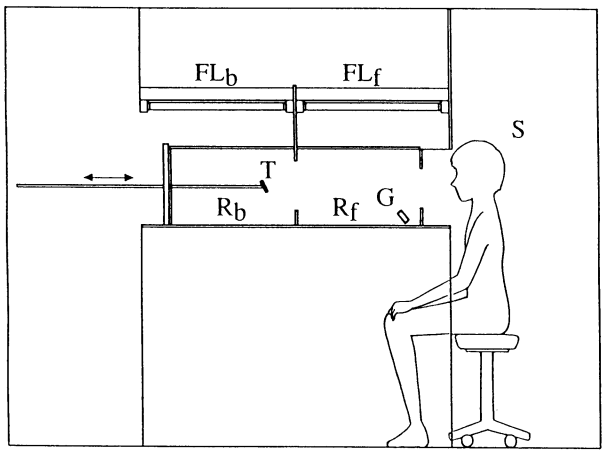

Fig. 1. Side view of the apparatus.

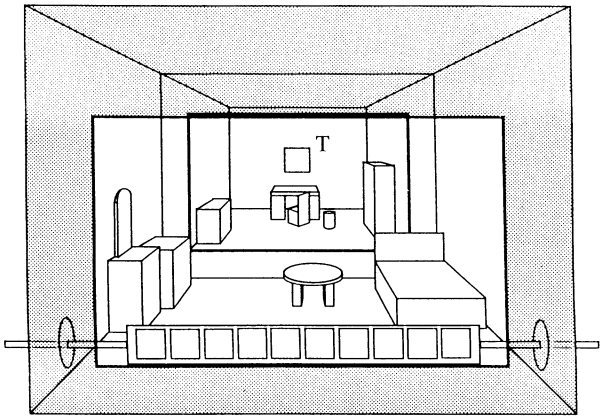

Fig. 2. Subject's view. T indicates the test patch.

illuminate the rooms, two lamps being used for each room. The illuminance of the two rooms was independently controlled by light controllers and was measured by illuminometers laid in the center of the floor of each room.

T in Fig. 1 represents a gray test patch for which the subject assessed the lightness by the matching method with the help of a gray scale G located in the front room, very close to the subject. The 5 cm×5 cm patch T was held at the tip of a pole projecting from the back wall toward the subject and slightly tilted upward so that its surface was illuminated by the ceiling light. The pole could be adjusted to any length by an experimenter as it was inserted through a pipe.

Furniture was placed in the rooms as shown in Fig. 2 from the subject's position. The small thick rectangle indicates the opening between the two rooms and the larger rectangle the 15 cm by 30 cm viewing window placed just in front of the subject. Because of the viewing window the shadowed portion of the space cannot be seen by the subject and the ceilings thus could not be the initial visual information. The small square denoted T is the test patch and it always appeared against the back wall of the back room as the surrounding giving a same retinal image arrangement regardless of its position in the space. The lightness of the test patch was assessed by the gray scale shown at the bottom of the figure. Ten gray patches were pasted on one side of the scale as shown and another ten were pasted on the other side, covering the lightness of 25 through 70 in steps of 2.5 in L^* units. The mid patch of the series, $L^*=47.5$ was duplicated on both sides of the gray scale. The gray scale could be rotated around the axis by the subject so that either side could be seen; it could also be slid along the axis.

The subject's task was to assess the lightness of the test patch located at various depth positions in the two rooms by matching it with the gray scale. Interpolation or extrapolation of lightness could be done. No chin rest was used and the subject could move his/her head freely. The subject was asked not to fix his/her eyes on the test patch alone but to look around the rooms to assess the lightness. With binocular vision the location of the test patch was clearly recognizable.

Table 1. Lightness specification of the back and front rooms in Munsell Value.

Back room		Front room	
Items	Value	Items	Value
Walls	N8.5	Walls	N7.0
Floor	N7.0	Floor	N5.5
Bookshelf	N7.0	Bed (upper)	N5.5
Chair	N6.0	Bed (side)	N4.5
Desk	N5.5	Dresser	N4.0
Wastebasket	N6.0	Table	N4.5
Chest	N6.0	Chest	N4.5

3. Experimental Conditions

The centers of both the back and front rooms were illuminated the same at 600 lx. In reality, however, the illuminance was not perfectly uniform over the entire depth of the miniature space because of the dividing wall between the two rooms, the back wall of the back room, and the limited length of the fluorescent lamps. The luminance of the test patches employed, namely N4 and N6, when measured from the subject's position, varied along the depth as shown in Fig. 3. The boundary of the two rooms was 50 cm distant. The shortcoming of the nonuniformity of luminance was corrected when the data was analyzed.

To produce a different size of RVSI between the back and front rooms, different lightness was used for the two rooms as shown in Table 1. Both were furnished with achromatic papers, but those of the front room were of lower lightness than the back room by the amount of N1.5 in Munsell Value at corresponding places to make the RVSI of the front room smaller.[5,6]

The assessment of lightness was conducted at seven test patch locations at distances of 20, 30, 40, 50, 60, 70, and 80 cm from the back wall. The location at 50 cm coincided with the boundary of the two rooms. Two test patches with nominal Munsell Value of N4 and N6 were em-

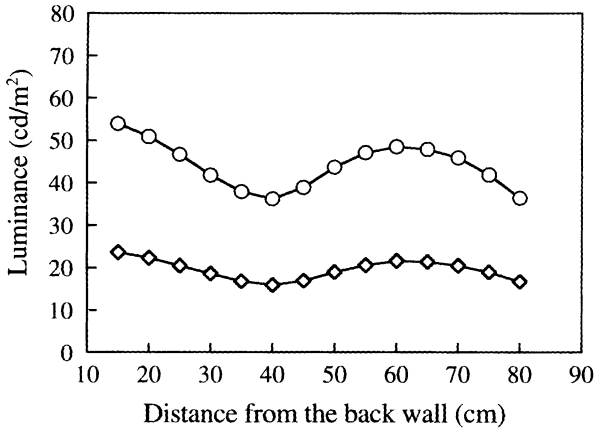

Fig. 3. Luminance of the test patches N4(◇) and N6 (○) at various positions in the space.

ployed; their lightness was 41.9 and 61.5, respectively, when measured by a spectrophotometer. The two patches and the locations were randomly presented to the subject within one experimental block and two or three such blocks were carried out in one session. Ten experimental blocks were used in an experiment for one subject. No time regulation was imposed on the subject at the assessment. Five subjects, MI (64, male), HS(31, male), YM(23, female), RY(22, female) and YH(21, female) participated in the experiment, and for the last two this was the first experience of serving as a subject for this kind of psychophysical experiment.

4. Results

It should be pointed out that none of the subjects was at all perplexed about the lightness of a test patch, and when the patch was placed at various positions along the depth of the rooms it simply appeared to them to be of different lightness. In particular, it changed to a patch with a higher lightness when it was shifted from the back room into the front room. The raw data of the assessed apparent lightness of the test patches N4 and N6 are shown in Fig. 4 for the subject YM. Here, we express the assessed lightness as the raw apparent lightness L_{raw}^* and plotted it along the ordinate. The distance of the test patch from the back wall is taken along the abscissa in cm. At each distance there are ten points for a test patch, but some of them are not seen because of overlap. The variation of the ten points is not large at any position. The solid curves in the figure represent the averages of the ten respective points. It is clearly seen that the test patch appeared brighter when it was placed in the front room and this should imply a smaller size of RVSI of the front room compared to the back room. Filled circles on the left ordinate indicate the L^* of the test patches as determined by spectrophotometer. The apparent lightness nearly coincides with these values when the test patches were located in the front room where the gray scale was also placed.

Some correction of these raw data is needed as stated before. The luminance of the test patches varied depending on the positions as shown in Fig. 3. A correction was applied to the lightness assessed by the subjects in the following way. Suppose that the assessed raw lightness L_{raw}^* was obtained for the test patch of luminance Y_{raw} instead of the intended luminance Y. Then, according to

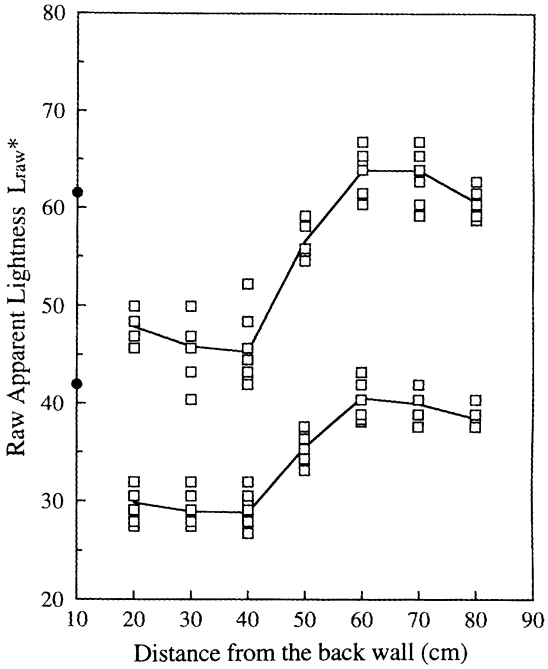

Fig. 4. Raw data of apparent lightness assessed by subject YM for N4 (lower) and N6 (upper) plotted against the distance from the back wall. Solid curves are the average.

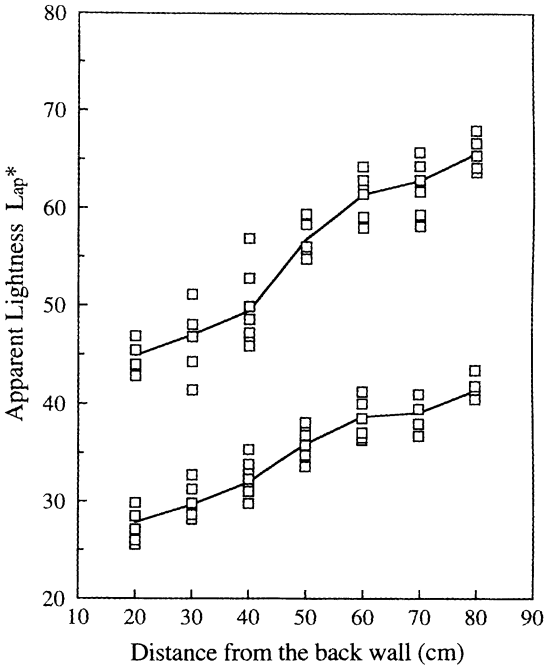

Fig. 5. Apparent lightness at various positions of the test patches corrected for nonuniformity of patch luminance. Lower group, test patch of N4; upper, N6. Subject, YM. Solid curves are the average.

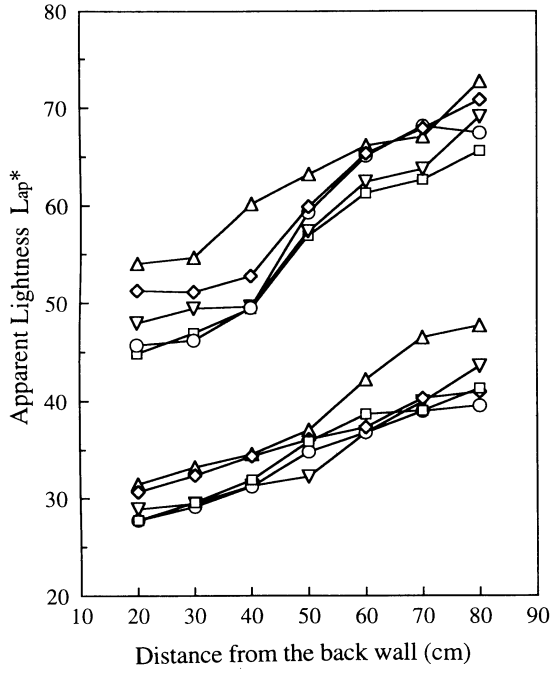

Fig. 6. Apparent lightness at the various positions of test patches. Different symbols correspond to subjects. Lower group, test patch of N4; upper, N6. ○, the subject MI; ◇, HS; □, YM; ▽, RY; △, YH.

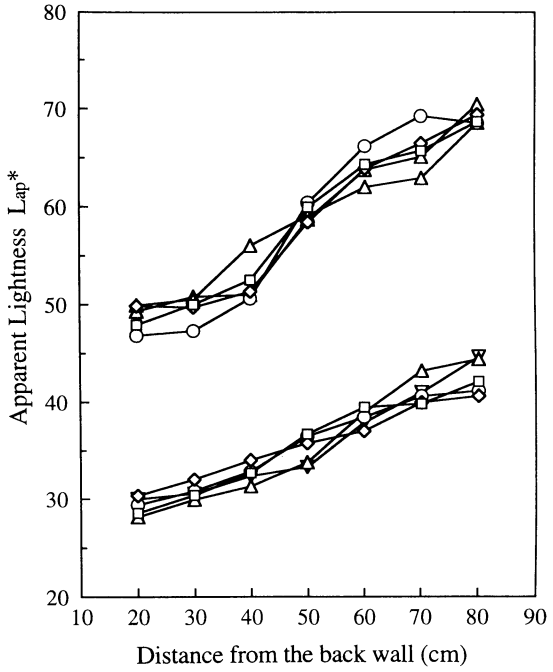

Fig. 7. Same as in Fig. 6 but vertically adjusted to compare the curve shape of individuals. Lower group, test patch of N4; upper, N6. ○, the subject MI; ◇, HS; □, YM; ▽, RY; △, YH.

the CIE1976L* formula L_{raw}* and the apparent lightness L_{ap}* to be obtained for Y can be given, respectively, by

$$L_{raw}^*=116(Y_{raw}/Y_0)^{1/3}-16\,,$$

$$L_{ap}^*=116(Y/Y_0)^{1/3}-16\,.$$

If we put $Y/Y_{raw}=m$, we have

$$\begin{aligned}L_{ap}^*&=116(mY_{raw}/Y_0)^{1/3}-16\\&=m^{1/3}[L_{raw}^*+16(1-1/m^{1/3})]\,.\end{aligned}\qquad(1)$$

We did not specifically define the intended luminance Y beforehand but only the illuminance of 600 lx on the floor. Therefore, we arbitrarily employed the mean luminance of raw Y_{raw} given in Fig. 3 as the intended Y, and it was 19.5 cd/m^2 for the test patch N4 and 44.1 cd/m^2 for N6. Hereafter we use L_{ap}* calculated by Eq. (1) to show the results.

Figure 5 shows the apparent lightness L_{ap}* which is a replot of Fig. 4 but with the correction of Eq. (1). The change of L_{ap}* for the test patch positions is now more gradual than in Fig. 4, but it is still clear that the apparent lightness is significantly different depending on the placement of the test patch in the space.

All five subjects showed a similar result of the change of apparent lightness (Fig. 6). Only the averaged curve is shown here for each subject. The five curves scatter along the ordinate to some extent, but the shape of the curve is the same among the subjects. That can be seen more clearly by shifting the curves along the ordinate so that the average of seven points of each subject is equated among them as shown in Fig. 7. It is surprising to note that the curves of three subjects, HS(◇), YM(□) and RY(▽) coincide almost exactly in the case of N6, which should indicate the stability and reliability of the judgment of lightness.

The change in L_{ap}* along the depth of the space is quite remarkable. In the case of N6 it is 48.8 at the distance of 20 cm and 69.1 at 80 cm, a difference of 20.3 in the average of the five subjects. Again, it must be emphasized that the illuminance was kept the same for the two places and only the lightness of the room surfaces and the furniture differed. This is nicely explained by the concept of the Recognized Visual Space of Illumination by saying that the size of the RVSI of the front room is smaller than that of the back room because of the lower lightness of the interior, which acted as the initial visual information to construct the RVSI, and the same test patch of N6 appears brighter as the lightness of the patch is recognized in relation to the RVSI of smaller size. The difference in the case of N4 is 13.3, less than that of N6. However, if we take the percentage of the difference to the original lightness of the test patches, 61.5 and 41.9, it is 33.0 and 31.7%, which are relatively close.

As pointed out earlier, the change in L_{ap}* along the depth of the space is rather gradual. In a preliminary experiment where the back room was made the same as the front room in lightness of interior we confirmed that there was no change in the apparent lightness L_{ap}* of the test patch regardless of its location. Of course, this should be true when we consider our daily experience that the lightness of any object does not change while it is approaching an observer. Therefore, the gradual change of

L_{ap}* should mean that the distinction between the two RVSIs for the rooms, R_b and R_f, is not abrupt at the boundary in spite of the projections from the four sides of the space. The effect of the projections on the independence between two RVSI remains to be investigated.

5. Discussion

We clearly showed that the apparent lightness of a test patch was determined in relation to the size of RVSI which was controlled by the surface lightness of the space. The lightness of the test patch was judged at various positions in the space without changing its luminance, at least in principle, or without changing the illuminance in the space where the patch was placed, and without changing the surrounding lightness of the patch in the retinal image which eliminated the change due to the effect of simultaneous contrast or lateral inhibition.[7] Yet, the lightness changed. The lightness was judged for the test patch located in the air of the space. In other words the present results show the three dimensionality of RVSI; lightness of the test patch is perceived in relation to the RVSI as long as the patch is located within the space, whether in contact with the surfaces of the space or separated from them. There is no need to emphasize that a target is in the same plane in order for its lightness to be perceived in relation to the plane as asserted by Gilchrist,[8] proposing the coplanar theory.

Several investigators have carried out a lightness judgment experiment on a CRT display.[9–11] This method inevitably restricts the presentation of stimuli as a plane. The Mondrian pattern made of color chips was often used as a stimulus,[12] but it is still a plane. It would be hard for them to extrapolate their explanation into a three dimensional space, although an ingenious idea of initiating a three dimensional pattern from a two dimensional picture was introduced by Spehar *et al.*[13] Human beings live in a space and their recognition of lightness, color and other factors is all exercised in the three dimensional space. More experiments are needed where the real world is simulated in other than just a two dimensional way.

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