Characteristics of the Visual Perception under the Dark Adaptation Processing (The Lighting Systems for Signboards)

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Summary
Outdoor signboards on the street provide not only advertising but also effective scenery of the town, and they are useful for the activation of the town. Sometimes they have different faces according to the effect of the lighting systems in daytime and evening. In this experiment, we use lighted signboards to examine how human eyes see "object colors" under the dark conditions. Advertising signboards that we recognize as "object colors" begin to change into "light source colors", when it darkens gradually in the evening. When this change occurs, the horizontal illuminance decreases from 1000 to 100 lx. In addition, "brightness feeling" and the ratio of "light source colors" rise rapidly when the luminance difference between the sky and signboard falls below 200cd/m^2.

Key words:
Dark adaptation, Object color, Llight source color, Sky luminance, Lighting systems of signboards

1. Introduction

Humans get information from the outside world by means of their five senses, i.e., eyesight, hearing, smell, taste, and touch. Out of these senses, eyesight is most important, and it is said that the percentage of the information gotten with eyesight is 80% or more of the total amount of the information gotten with the five senses. We can see objects in the daylight as well as in the evening. Illuminance in direct sunlight in midsummer is very high, about 100,000 lx, but illuminance in the evening is very low, about 0.001 lx. Because our visual system changes its sensitivity appropriately, we can see visual objects properly in various environments with very high or very low illuminance. This sensitivity change of the visual system is called "adaptation." Especially, the visual sensitivity change caused when the light environment becomes dark is called "dark adaptation."

Color and light senses in our visual system largely change in the dark adaptation process because rod cells on the retina become active instead of cone cells. Therefore, illumination design must be performed by fully considering the characteristics of the visual dark adaptation. One of the familiar examples of this is tunnel lighting design, in which the illuminance near the portal of a tunnel is changed in a step-by-step manner according to the sky luminance depending on weather and time. That is, when a vehicle enters a tunnel and moves toward the inside of the tunnel, it takes time for the driver to adapt to darkness. For driver's clear eyesight and preventing black-out phenomenon, the tunnel must be lighted so that the portal of the tunnel gets higher illuminance. Such eyesight adjustment by ambient luminance level change in visual environment frequently occurs in our daily life.

(a) Signboard in daytime

(b) Signboard in evening

Figure 1 Visible condition of signboard in the daytime or the evening

A typical example of the effective eyesight adjustment

Manuscript received August 5, 2011
Manuscript revised August 20, 2011

is lighting of outdoor advertising signboards. Outside advertising signboards that are placed on the roofs of buildings or along streets are lighted by sunlight in the daylight and perceived as “object colors” (see Figure 1 (a)). On the other hand in the evening, these signboards are lighted with floodlights placed above or below the signboards, and are seen in a different way, that is, perceived as “light source colors” (see Figure 1 (b)). That is, we see these signboards in the dark of the night as if the signboards themselves are gleaming. The signboards that are perceived in the “object color mode” in the daytime are perceived in the “light source color mode” in the evening.

The purpose of outside signboards is to transmit information to more people at any time of the day or night. Therefore, more effective lighting of signboards is requested to make them more impressive also in the evening.

In addition, environmental measures mainly for “energy saving” have been advanced in all business fields according to, for example, the amended Law Regarding the Rationalization of Energy Use enacted in 2010. Designing the guideline for the concrete measures has been promoted to establish the standards for energy saving management. The important problem in this activity is to design the lighting that provides high efficiency and high quality without reducing lighting effects. Therefore, it is considered that effective lighting timing depending on human’s dark adaptation also contributes to energy consumption reduction.

The purpose of our study is to analyze and examine how the perception of lighted-up visual objects changes when the visual system changes from the light adaptation mode to the dark adaptation mode.

At the same time, we think that the basic data acquired regarding the visual property in brightness level change in visual environment will be very useful in the future signboard lighting system design.

2. Experimental Method

Figure 2 shows the advertising signboard used in our experiment, and Figure 3 shows the general view of the experimental system. Our observation and measurement using the signboards started in the daytime (photopic vision), continued to the twilight (mesopic vision), and terminated in the evening (scotopic vision).

In our study, we focused attention on the “light source color” phenomenon in which the signboard surface which was seen in “object color mode” in the daytime was seen in the evening as if it was gleaming. We called this phenomenon “light source color mode.” As the light source color mode and the object color mode could exist at the same time, we measured the ratio of the light source color mode to the object color mode on the signboard surface in each visual environment. By the way, the feeling of brightness that is perceived about visual objects depends on various elements such as luminance around the signboards. Therefore, also the feeling of brightness that was directly sensed by the participants of our experiment was measured as “brightness feeling.”

(a) Signboard in daytime (photopic vision)

(b) Signboard in evening (scotopic vision)

Figure 2 Experimented signboard in the daytime and the evening

The ratio of the light source color mode to the object color mode was calculated by the quantity estimation method. That is, when the illuminance of the visual environment of the signboards was 0 lx (complete darkness), the participants observed the signboards previously. In this state, the rate of the light source color mode on the signboard surface was counted as 10 points. Next, when the visual environment changed, the ratio of the light source color mode to the object color mode was newly counted so that the sum of the light source color mode and the object color mode was 10 points. For example, when the ratio of the sensed light source color mode to the sensed object color mode is the same, the color ratio is evaluated as 5:5. On the other hand, the brightness feeling was evaluated by the participants at seven levels: Very bright to very dark.

This experiment is a field experiment that is performed under natural light conditions by using the signboards actually placed under the open sky. The used signboards had different dimensions, and the visual distance to the signboards were determined by considering participant's observation easiness and safety.

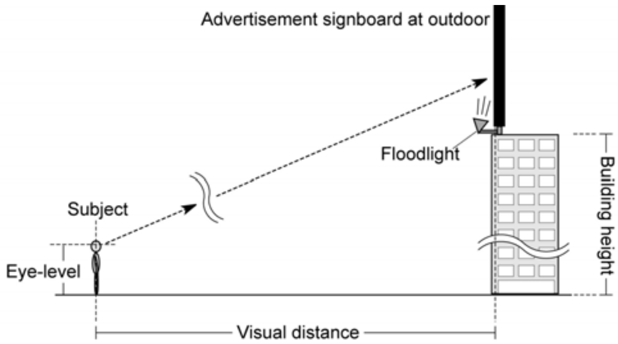
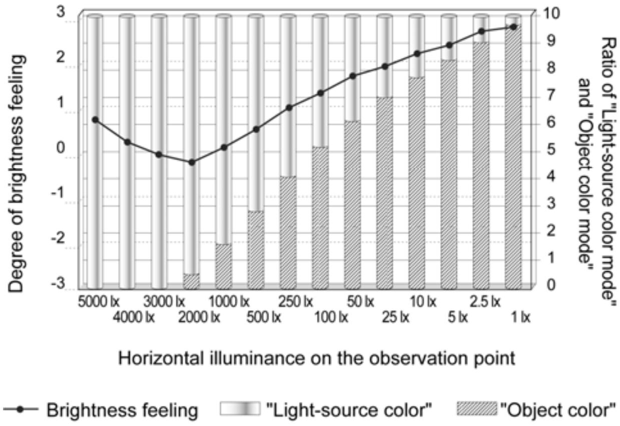


Figure 3 General view of experimental system

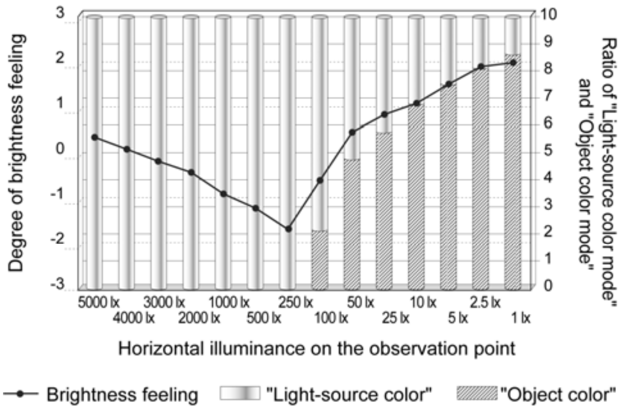
The experiment was performed as follows. First, the horizontal illuminance at the participant's eye level at the observation point was measured as the factor determining the participant's eye adaptation level. The experiment started when the horizontal illuminance at the observation point reached 5000 lx. Then, the experiment terminated when the illuminance in the visual environment reached the minimum level and did not decrease any more. The horizontal illuminance during the measurement period was divided into 14 levels, and the measured data was evaluated at respective levels. That is, at respective horizontal illuminance conditions, each participant evaluated the ratio of the light source color mode to the object color mode of the observed signboard, and also evaluated the brightness feeling. In parallel with these evaluations, also the signboard surface luminance and the ambient sky luminance were measured with a luminance meter. This experiment used six different signboards and 20 participants.

3. Experimental Results

Figure 4 shows the signboard observation transition characteristics based on the average values of the data acquired by 20 participants. Figure 4 (a) shows the average measurement values of the four different signboards that have earlier lighting-up timing, and Figure 4 (b) shows the average measurement values of the two different signboards that have later lighting-up timing. In each of Figure 4 (a) and 4 (b), the horizontal axis indicates the horizontal illuminance (lx) at the observation point, the vertical axis on the right side indicates the ratio of the light source color mode to the object color mode, and the vertical axis on the left side indicates the degree of brightness feeling. The observation started at the highest horizontal illuminance (5000 lx), and terminated at 1 lx.



(a) Average of measurement result to four signboards with early timing of lighting



(b) Average of measurement result to two signboards with late timing of lighting

Figure 4 Transition characteristics of horizontal illuminance and degree of brightness feeling

As shown in the ratio of the light source color mode to the object color mode in Figure 4 (a), the signboard status is clearly changed from the object color mode to the light source color mode by degrees with decreased amount of the horizontal illuminance. Especially, when the horizontal illuminance at the observation point reaches 1000 lx, the rate of the light source color mode obviously begins to increase. Next, when the horizontal illuminance decreases to 100 lx, the rate of the light source color mode exceeds the rate of the object color mode.

Such tendencies are found in all of the four samples shown in Figure 4 (a). This proves that the horizontal illuminance is 1000 lx or less when the signboard surfaces that are perceived in object color mode in the daytime begin to be perceived in light source color mode. It can be said that this horizontal illuminance value provides evident lighting effects on advertising signboards.

On the other hand, in the two signboards having later lighting-up timing (Figure 4 (b)), the horizontal illuminance at the observation point is very low when the rate of the light source color mode begins to increase. This tendency may be created by two causes: (1) The lighting-up timing is later, that is, the lighting up occurs when the ambient illuminance is 100 lx or lower, and (2) one of these two signboards is almost black in the surface colors. These show that determining appropriate lighting-up timing of advertising signboards according to the illuminance level of the visual environment is extremely important in the design of effective advertising signboard lighting.

The brightness feeling that is indicated on the vertical axis on the left in each of Figure 4 (a) and 4 (b) is divided into seven levels: “Very bright” (3) to “very dark” (-3).

In Figure 4 (a), the brightness feeling value begins to increase when the horizontal illuminance at the observation point reaches 1000 lx. It is clear that most participants sense “brightish state” (brightness feeling value “1”) when the horizontal illuminance reaches about 250 lx. It can be known that most participants evaluate that the signboard surfaces are quite bright when the horizontal illuminance reaches about 0 lx.

On the other hand, in Figure 4 (b), the brightness feeling evaluation value has a tendency similar to that shown in Figure 4 (a) when the horizontal illuminance is in the range of 5000 to 3000 lx, but decreases considerably when the horizontal illuminance decreases to lower than 3000 lx. Especially, when the horizontal illuminance is about 250 lx, the average evaluation value is -1.8 (quite dark). Next, when the signboard is lighted up at a horizontal illuminance of about 100 lx, the brightness feeling evaluation value increases sharply. Therefore, it can be considered that the lighting-up timing at 100 lx is slightly later than the approximate timing. By considering this, it can be considered that the most appropriate lighting-up should occur when the horizontal illuminance at the observation point is in the range of 1000 to 250 lx.

By the way, as the sunset time in Japan greatly depends on the season and month, the most appropriate lighting-up time depends on the season and month.

Figure 5 shows how three levels of horizontal illuminance (250, 500, and 1000 lx) change depending on the season (month) and time. As shown in this figure, the earliest time for illuminance decreasing to each of these levels is about 16:30 in December, and the latest time is about 19:00 in July.

It can be said that it is most important to construct the effective signboard lighting system by considering the optimal, variable lighting-up time and energy saving.

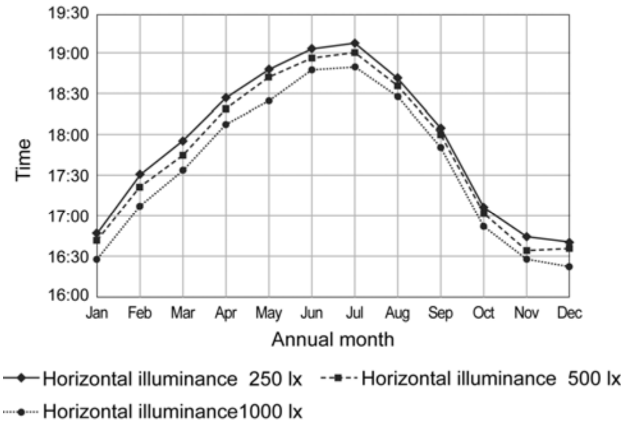


Figure5 Horizontal illuminance change depending on season and time

Figure 6 shows the ratio of the light source color mode to the object color mode and the brightness feeling that are replotted by considering the “luminance difference” between the sky and the signboards. In the same way as in Figure 4, the vertical axis on the left side indicates the degree of brightness feeling, and the vertical axis on the right side indicates the ratio of the light source color mode to the object color mode. However, in Figure 6, the horizontal axis indicates the difference between the sky luminance and the signboard luminance.

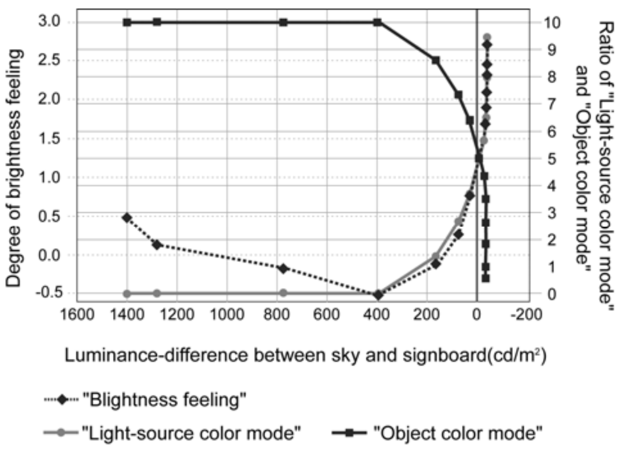


Figure 6 Luminance difference between sky and signboards, ratio of light source color mode to object color mode, and brightness feeling

On the other hand, in Figure 4, the perception status sharply changes when the horizontal illuminance on the observation point reaches 1000 lx or lower. However, in Figure 6, in which the luminance difference is plotted on the horizontal axis, the rate of the light source color mode hardly changes until the luminance difference reaches 200 cd/m^2, but the brightness feeling gradually decreases.

As shown in Figure 6, when the luminance difference decreases to a value less than 200 cd/m^2, both the rate of light source color mode and the brightness feeling have a tendency to rapidly increase. Next, these values increase sharply when the luminance difference is less than 0 cd/m^2, that is, when the signboard luminance is higher than the sky luminance. Thus, it was found that the lighting-up effect was sharply increased at a luminance difference of 200 cd/m^2 or less.

4. Conclusion

This study measured and examined the perception transition of the surfaces of advertising signboards (as lighted-up visual objects) in a dark adaptation process. As a result, it was found that the surfaces of advertising signboards, which were perceived in object color mode in daytime, were perceived in light source color mode in a specific visual environment. This tendency was found in a visual environment in which the horizontal illuminance at the observation point was 1000 lx or lower. When the horizontal illuminance at the observation point was 250 lx, the brightness feeling evaluation value was 1. The above results were acquired regarding the transition of the horizontal illuminance. Similarly, the signboards were perceived in the light source color mode when the luminance difference was 200 cd/m^2 or less.

It can be said, from the above, that designing the lighting-up timing of outdoor advertising signboards is effective by considering the eye adaptation at an illuminance of about 250 lx (in which brightness feeling is 1). In addition, it can be considered that the most effective lighting up is performed when the difference between the sky luminance and the signboard luminance is less than 200 cd/m^2.

By the way, as the sunset time depends on the season and month as explained before, the most appropriate lighting-up time depends on the season and month. It can be said that it is more effective to control the lighting-up time more carefully by using a luminance sensor as well as the lighting-up system that has a year timer adjusted according to the sunset time in each season. It is increasingly expected to construct the optimal outside-signboard lighting-up control system for superior lighting control by considering the results of our study about the difference between the sky luminance and the signboard luminance.

In the meantime, there are amazing results in recent technological development for new light sources. Highly-efficient HID light sources, which will replace conventional mercury lamps, have been developed one after another and put to practical use for ordinary advertising signboard lighting. In addition, highly-efficient LED for providing a large light flux will be used practically. Therefore, it can be expected that the results of our study will affect the outdoor advertising signboard lighting design and will contribute to energy saving much more. After the Great East Japan Earthquake occurred, it has been announced that positive activities for further energy saving are demanded. In the conventional advertising signboard lighting design, only the lighting up and out functions have been simply considered. However, sophisticated lighting design for high efficiency and energy saving will be provided for appropriately changing the signboard surface luminance depending on the visual environment illuminance by optimizing lighting-up time and season conditions. Our study will contribute to developing such future design techniques.

We hope that our study will advance the energy and power saving design for the advertising signboard lighting and other lightings.

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