Adaptive and Affective Luminance Contrast for Optimal Brightness on Display

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ABSTRACT

This study investigated the range of optimal luminance contrast for enhancing users' physiological comfort and psychological satisfaction while they watching display. Diverse instances of luminance contrast were collected, of which both ambient luminance and object luminance were measured, and the subjective judgment was made at first-time viewing and at continuous viewing. The result revealed that the optimal luminance contrast is not static. The optimal ratio between ambient luminance and object luminance changes gradually as one's viewing time goes by, and particularly it converges into a smaller range. The optimal brightness of object luminance in dark environment needs to get increased, whereas that in bright environment needs to get decreased. Therefore the time duration should be concerned to define an optimal luminance contrast, and hence a dynamically adaptive luminance contrast is proper to maintain the affective quality of viewing the lit objects such as smartphone displays and e-books.

Keywords: luminance contrast, adaptive luminance, affective luminance, display brightness, visual adaptation

INTRODUCTION

Humans experience a variety of kinds of lights in daily lives. They meet thousands of levels of brightness and darkness due to differing artificial lights and varying sunlight. Nowadays, light emitted from products, such as LED status lights or display backlights, have begun to emerge as part of a new lighting element in everyday life. Contrary to sun and indoor lightings, the light emitted from digital devices is relatively concentrated on a certain point rather than scattered around. It brings about luminance contrast, and unfortunately, such contrast in luminance is the major cause of visual stress. Overly high luminance contrast provokes visual fatigue because of glares whereas luminance contrast in unduly low reduces visual performance[1]. In case of using visual display terminals (VDT), moreover, users stare the luminous display directly for hours so visual stress becomes more serious problem.

In recent studies, therefore, the optimal luminance contrast has become a topic of discussion. A great effort has been made to investigate the effect of contrast between object luminance and ambient luminance on visual fatigue, and some practical guidelines have been proposed[2,3]. However, the suggestions from the studies cannot be an ideal solution because they lack careful consideration on human. To examine the optimal range on luminance contrast for users, the concern about psychological satisfaction should plays a decisive role in conjunction with physiological comfort. Besides, human visual system must also be considered because it operates time-dependent adaptation to ambient illuminance[4,5,6] and both physiological and psychological responses might be influenced with the adaptation.

Thus, this study intends to investigate the ideal range of luminance contrast considering human visual system as well as to explore a possibility to implement the result on actual display for experiencing comfortable and natural brightness.

OBJECTIVE

The aim of this study is to discover the range of ideal luminance contrast for improving both users' physiological comfort and psychological satisfaction as well as for supporting the time-dependent adaptation of the human visual system. It attempts to examine the subjective judgment on diverse kinds of luminance contrast instances, and to investigate whether the optimal brightness changes or not according to the visual adaptive process. Based on the result, the ideal range of luminance contrast, which is able to adapt visually and affectively, will be proposed by its application to displays and the changing pattern of the range will be established. Hence ultimately, users experience the natural brightness without any visual fatigue or displeasure while they watching display. In the study, it was hypothesized that the optimal luminance contrast is determined by synthesizing physiological and psychological responses, and it shifts depending on the passage of time.

METHOD

A large number of instances that occurs luminance contrast in everyday lives such as 'bright computer monitor in office' and 'lit sleeping lamp at night' were collected. About each instance, the numerical value corresponding to ambient luminance and object luminance were measured by luminance meter (Konica Minolta CS-100A) as shown in Figure 1. Ambient luminance was measured using a white-colored panel that is regarded as perfectly reflecting body. Besides, for obtaining more accurate value, the luminance of three random spots which are not influenced by object luminance as well as within a viewing angle of 30 degrees were measured then calculated average of the values[7].

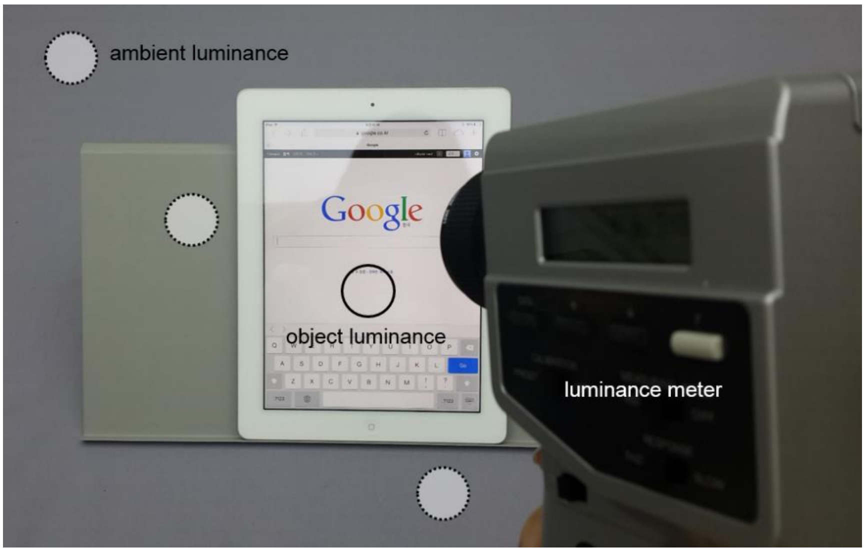

Figure 1. Measurement of object luminance (solid circle) and ambient luminance (dotted circle)

After that, a subjective judgment was made on each instance considering visual comfort and aesthetic satisfaction which represented by physiological response and psychological response respectively. First, the judgment at first sight of the object (*first-time viewing* hereinafter) was classified into two categories – either appropriate or inappropriate condition for staring. Also, the evaluation was carried out again under the same instance 10 minutes after user starts to view an object to identify the response while watching the object for a long time (*continuous viewing* hereinafter).

RESULT AND ANALYSIS

Total 58 instances were collected through the experiment. All the instances were positioned on a 2-dimensional graph represented by ambient luminance in the horizontal axis and object luminance in the vertical axis as shown in Figure 2. Figure 2(a) shows the judgment result of *first-time viewing*, and Figure 2(b) illustrates the result of *continuous viewing*. Red dot means an instance which was assessed inappropriate to watch, whereas green dot indicates appropriate instance to stare. The trend line of optimal range for viewing is represented as a line on the respective graph, and a couple of examples corresponding to each dot are listed on the Table 1.

Table 1. Ambient luminance, object luminance and subjective judgment of instances

no.	**instance**	**luminance (cd/m²)**		**subjective judgment**	
		object	**ambient**	**first-time viewing**	**continuous viewing**
1	use of mobile phone at night	1	40	inappropriate	appropriate
2	neon light at night	800	10	inappropriate	inappropriate
3	navigation system in car	85	10	appropriate	appropriate
4	LED status light in room	12	27	appropriate	inappropriate
5	work on computer in office	205	120	appropriate	appropriate
6	watching mobile display under sunlight	150	6240	inappropriate	inappropriate

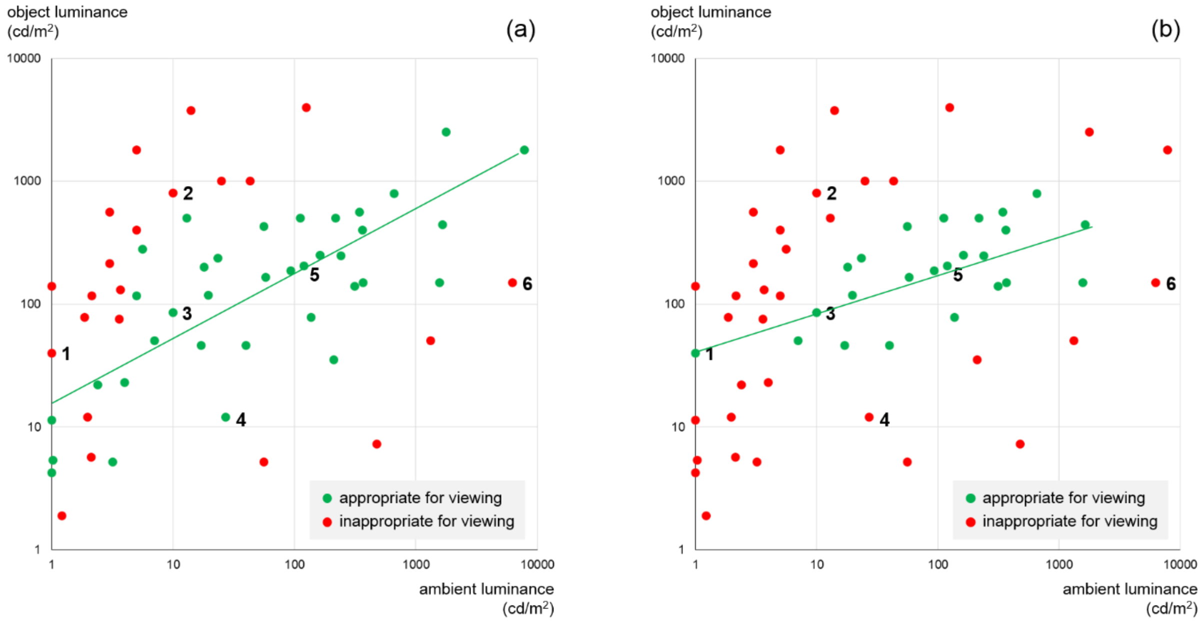

Figure 2. Subjective judgment on instances: (a) *first-time viewing*, (b) *continuous viewing* (numbers on each plot are corresponded with the numbers on Table 1)

At *first-time viewing*, there are many instances which are judged to be an appropriate condition for viewing as well as the appropriate range distributes widely. On the contrary, instances that proper to watch at *continuous viewing* are not only relatively small in number but also confined within a narrow range compared to *first-time viewing*. Accordingly a slope of trend line on the appropriate range were lower. In other words, the optimal luminance contrast is not static. The ideal ratio between ambient luminance and object luminance changes gradually as one’s viewing time passes, and particularly it converges into a smaller range. For example, illuminated LED status light in a dim room (number 4 in Table 1) is regarded as appropriate condition for viewing at first, but the judgment on same instance shifts to inappropriate condition over time. On the other hand, in some cases like starting lit mobile display with low illumination (number 1 in Table 1), it is inadequate to watch at the beginning but the judgment becomes higher with passage of time.

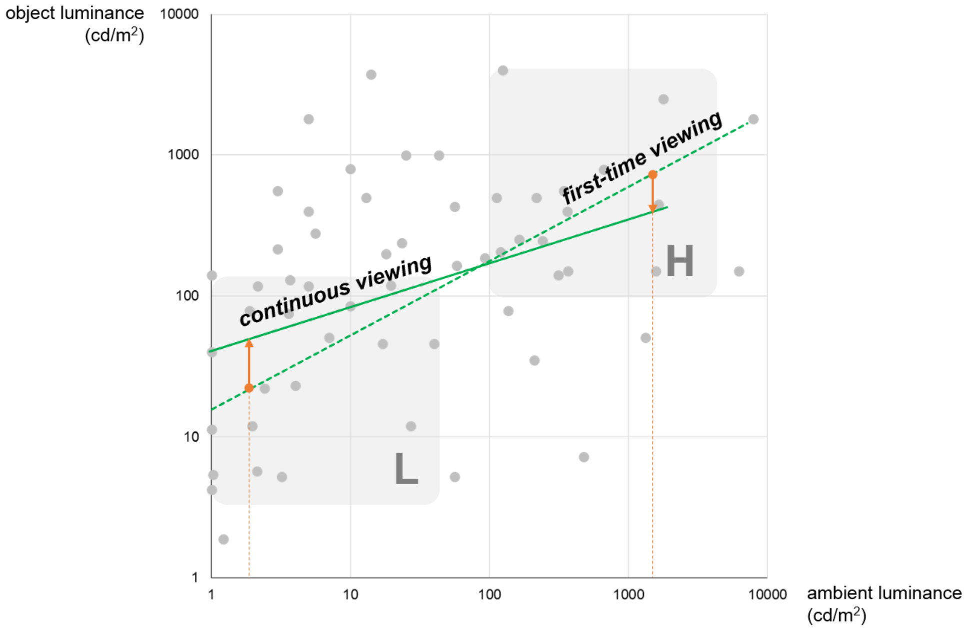

Figure 3. Trend lines of optimal luminance contrast for *first-time viewing* and *continuous viewing*

Based on the result, two areas changing subjective judgment with a lapse of time were observed. First area includes the range in which both ambient luminance and object luminance are relatively low (marked as L in Figure 3). At the beginning, the area is evaluated as appropriate for viewing because it is not hard on eyes but it soon conveys unpleasant feeling due to a dark object. To sum it up, physiological comfort plays more significant role at first so low psychological satisfaction does not have great influence on judgment. However, the importance of physiological comfort and psychological satisfaction gets similar over time, so the judgment result becomes unpopular unless psychological satisfaction improves. That is, this area is too dark to watch. Therefore in case of watching luminous display long hours, higher object luminance is recommended under same ambient luminance. Hence it is necessary to increase object luminance in dark environment.

By contrast, another area has high ambient luminance and high object luminance (marked as H in Figure 3). This area is proper to see at first because the object is bright enough, but sooner or later it arouses visual stress. Opposite to the previous area, psychological satisfaction holds a dominant position at the beginning of watching. However the role of physiological comfort is on the increase as time passes but the comfort level remains unaffected, so overall judgment result gets drop. In here, object luminance is too bright to watch. Thus lower object luminance is more appropriate to stare under same ambient luminance. It means that optimal brightness of object luminance in bright environment needs to get decreased.

CONCLUSION

Through the empirical results, it was investigated that the range of optimal luminance contrast gradually changes with regard to time-dependent adaptation of the human visual system as well as the changing pattern was discovered. Consequently, it is awakened to the need for solution to keep the optimal brightness consistently.

The study achieved two major findings as described in the following. First, optimal ratio between ambient luminance and objective luminance changes gradually as viewing time pass, and it converges into a smaller range. Second, it is found that the two areas which should shift object luminance with a lapse of time. It is recommended to increase object luminance in dark environment. In other words, object luminance changes from low to high with adaptive process of human vision. On the contrary, object luminance needs to get decreased in bright environment. Again, object luminance keeps high enough for not ruining the appearance of display in early phase and it gradually decreases to reduce visual stress. In conclusion, the time duration should be concerned to define an optimal luminance contrast, and hence a dynamically adaptive luminance contrast is proper to maintain the affective quality of viewing the lit objects. This is consistent with other studies, which suggest that a backlight luminance of mobile display under dark environment should be gradually increases[8] whereas it is desirable that a display luminance get decreases with passage of time in bright space[9].

This research is an initial stage for examining optimal luminance contrast, hence more instances should be collected to improve relevancy of the theory. As a next stage, the formulae and algorithm on optimal brightness will be derived through conducting a series of user test for applying to the result on actual usage situation of display, as well as the superiority of the developed algorithm will be verified. With this, users can always experience both physiological comfort and psychological satisfaction while they using visual display terminals such as smartphones, tablet PCs and e-books. It is hoped that this study will be a foundation research to develop applications for finding optimal brightness on display.

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