Adaptive and Affective Luminance Contrast on Optimal Brightness of Displays

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Abstract

In this study was investigated the range of optimal luminance contrast needed to enhance user physiological comfort and psychological satisfaction while viewing displays. Diverse instances of luminance contrast were collected, of which both ambient luminance and object luminance were measured, and subjective judgment was notes for first-time viewing and after 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 viewing time increases, and in particular, it converges into a smaller range. The optimal brightness of object luminance in a dark environment needs to be increased, whereas that in bright environments needs to be decreased. Therefore, the duration of viewing should be considered to define optimal luminance contrast, and hence a dynamically adaptive luminance contrast is proper to maintain affective viewing quality of internally lit objects such as smartphone displays and e-books.

Introduction

Humans experience a variety of kinds of lights in daily life. They meet thousands of levels of brightness and darkness due to differing combinations of 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. In contrast with sunlight and indoor lighting, the light emitted from digital devices is relatively concentrated at a certain point rather than being scattered around. This brings about luminance contrast, and unfortunately, such contrast is the major cause of visual stress. Overly high luminance contrast provokes visual fatigue because of glare, whereas unduly low luminance contrast reduces visual performance [1]. Moreover, when using visual display terminals (VDT) users stare at the luminous display directly for hours, so that visual stress becomes a more serious problem.

In recent studies, therefore, optimal luminance contrast has become a topic of discussion. A great effort has been made to investigate the effect of the contrast between object luminance and ambient luminance on visual fatigue, and some practical guidelines have been proposed [2, 3]. However, the suggestions from these studies are not ideal solutions because they somewhat lack careful consideration of humans. To examine the optimal range of luminance contrast for users, consideration of psychological satisfaction should play a decisive role, in conjunction with physiological comfort. Besides, the human visual system must also be concerned because it provides time-dependent adaptation to ambient illuminance [4-6], and both physiological and psychological responses may be influenced as a result of this adaptation.

Thus, this study was intended to investigate the ideal range of luminance contrast considering the human visual system, as well as to explore a possibility to implement the result in an actual display that would provide users with both viewing comfort and natural brightness.

Objective

The aim of this study was to discover the range of ideal luminance contrast for improving users' physiological comfort and psychological satisfaction, as well as for accommodating the time-dependent adaptation of the human visual system. This study includes attempts to examine the subjective judgment of viewers about a variety of luminance contrast situations, 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 adaptable both visually and affectively will be proposed using its application to displays and the changing pattern of the range will be established. Hence ultimately, the goal is to have users experience natural brightness without any visual fatigue or displeasure while watching such displays. In this study, it was hypothesized that the optimal luminance contrast is determined by a synthesis of physiological and psychological responses, and that this synthesis shifts depending on the passage of time.

Method

A large number of instances were recorded from everyday life during which luminance contrast occurred (e.g., bright computer monitor in an office and lit sleeping lamp at night). In each instance, the numerical value corresponding to ambient luminance and object luminance were measured using a luminance meter (Konica Minolta CS-100A), as shown in Figure 1. To obtain more accurate values, the luminance of three random spots not influenced by object luminance, and which were also within a viewing angle of 30 degrees, were measured then used to calculate average values as ambient luminance [7].

After that, a subjective judgment was made for each instance considering visual comfort and aesthetic satisfaction. These represented physiological response and psychological response, respectively. Subject was visually adapted to ambient luminance at that time. First, a judgment was made at first sight of the object (*first-time viewing* hereafter) as to one of two categories: either appropriate or inappropriate conditions for viewing. A similar evaluation was carried out again under the same conditions 10 minutes after a user started to view an object, to identify the response after watching the object for a long time (*continuous viewing* hereafter).

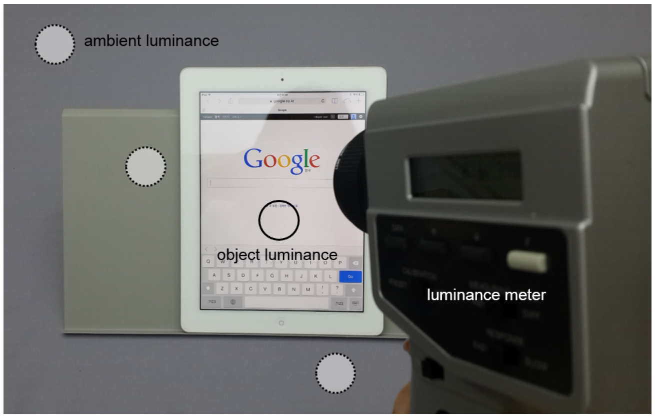

Figure 1*. Measurement of object luminance (solid circle) and ambient luminance (dotted circle)*

Result and Analysis

A total of 58 instances were collected during 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 2a shows the judgment result for *first-time viewing*, and Figure 2b illustrates the result for *continuous viewing*. Red dots indicate conditions assessed as inappropriate for viewing, whereas green dots indicate conditions judged appropriate for viewing. The trend line of the optimal range for viewing is represented as a line on the respective graph, and a couple of examples corresponding to each dot are listed in Table 1.

For *first-time viewing*, there were many instances in which conditions were judged to be appropriate for viewing, and the range of conditions appropriate for viewing was wide. In contrast,

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

No.	Instance	Luminance (cd/m^2)		Subjective judgment	
		Object	Ambient	*First-time viewing*	*Continuous viewing*
1	Use of mobile phone at night	40	1	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 at computer in office	205	120	appropriate	appropriate
6	Watching mobile display in sunlight	150	6240	inappropriate	inappropriate

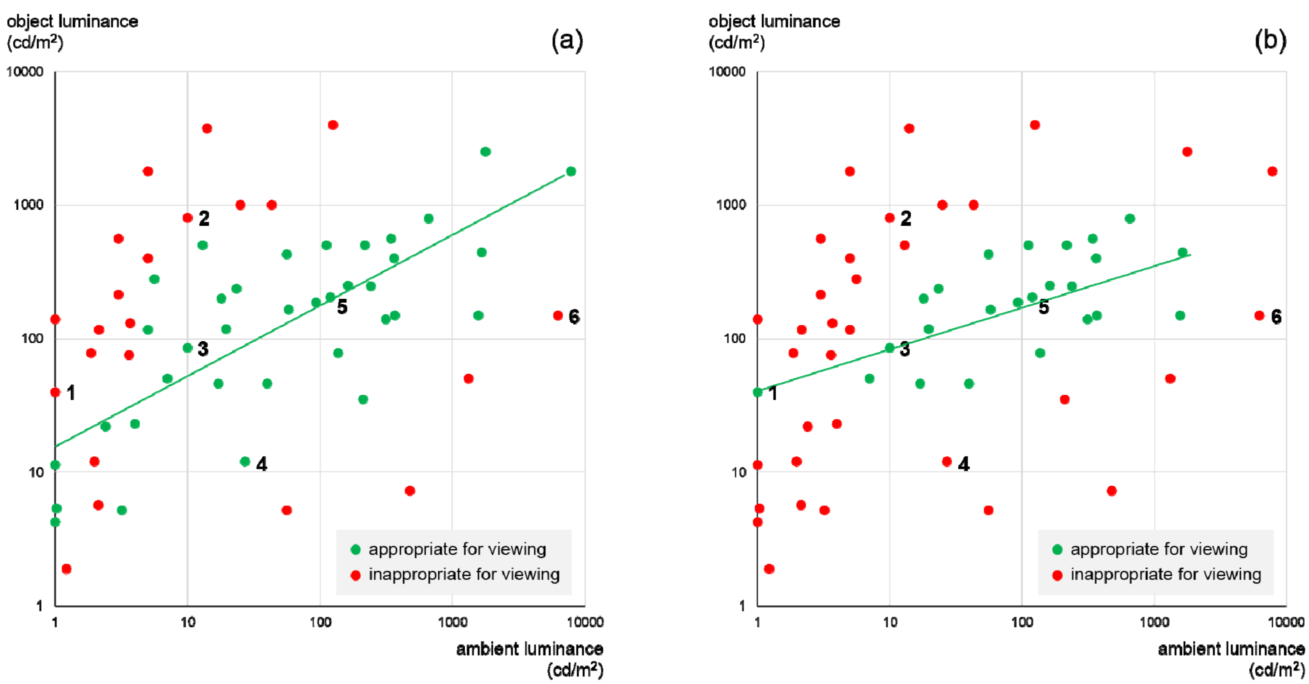

Figure 2*. Subjective judgment of instances for: (a) first-time viewing, (b) continuous viewing (The numbers on each plot correspond with the numbers in Table 1)*

the instances with conditions that were judged proper to watch after *continuous viewing* were not only relatively small in number but also confined within a narrower range compared to those at *first-time viewing*. Accordingly the slope of the trend line of the appropriate range was less. In other words, the optimal luminance contrast is not static. The ideal ratio between ambient luminance and object luminance changes gradually as viewing time increases, and in particular, it converges into a smaller range. For example, an illuminated LED status light in a dim room (Number 4 in Table 1) is regarded as an appropriate condition for viewing at first, but the judgment of the same conditions shifts to inappropriate conditions for viewing over time. On the other hand, in some cases like viewing with a lit mobile display with low illumination (Number 1 in Table 1), it was judged inadequate to watch at the beginning but the assessment was higher with the passage of time.

Based on these results, two areas of changing subjective judgment with a lapse of time were observed. The first area includes the range within 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 produces an unpleasant feeling due to its darkness. To sum it up, physiological comfort plays a more significant role at first, so low psychological satisfaction does not initially have great influence on judgment. However, the importance of physiological comfort and of psychological satisfaction becomes more similar over time, so that judgment of conditions becomes less acceptable unless psychological satisfaction improves. That is, this area is too dark to watch. Therefore in the case of viewing a luminous display for long hours, higher object luminance is recommended, assuming the same ambient luminance. Hence it is necessary to increase object luminance in dark environments.

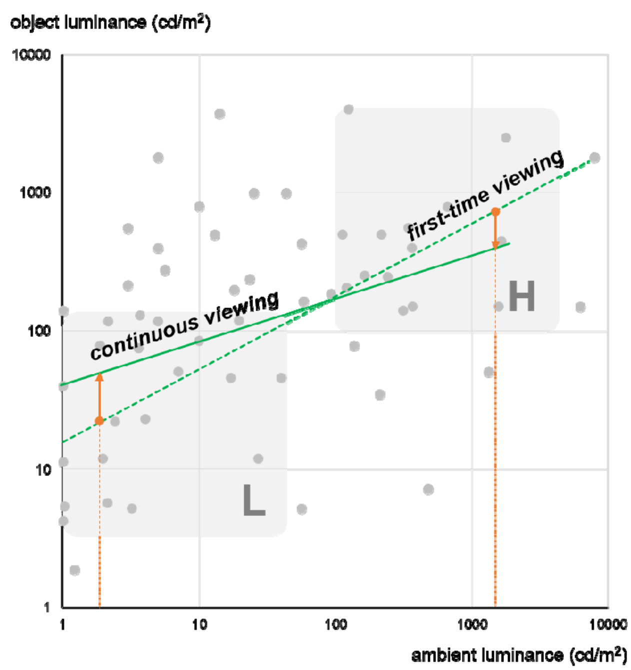

Figure 3*. Trend lines of optimal luminance contrast for first-time viewing and continuous viewing*

By contrast, another area has high ambient luminance and high object luminance (marked H in Figure 3). This area is proper to watch at first because the object is bright enough, but sooner or later it arouses visual stress. In contrast with the previous area, psychological satisfaction holds a dominant position at the beginning of viewing. However, the role of physiological comfort increases as time passes but the comfort level remains unaffected, so the overall judgment result drops. In this case, the object luminance is too bright to watch. Thus lower object luminance is more appropriate to view assuming the same ambient luminance. This means that optimal brightness of object luminance in bright environments needs to be decreased over time.

Conclusion

By means of these empirical results, it was determined that the range of optimal luminance contrast gradually changes with regard to time-dependent adaptation of the human visual system, and the pattern of that change was discovered. Consequently, there is a need for solution to keep the optimal brightness consistently.

The study achieved two major findings. The first was that the optimal ratio between ambient luminance and objective luminance changes gradually as viewing time increases, and that it converges into a smaller range. The second was that it was found that there were two areas for which object luminance should be adjusted with the passage of time. It is therefore recommended to increase object luminance in dark environments. In other words, object luminance changes from low to high as a result of the adaptive process of human vision. On the other hand, object luminance needs to be decreased in bright environments. In this case, the object luminance should be kept high enough not to ruin the appearance of the display in the early phase, and then gradually decreased to reduce visual stress. In conclusion, the duration of viewing should be of concern for defining optimal luminance contrast. Thus, a dynamically adaptive luminance contrast is appropriate for maintaining the affective quality of viewing internally lit objects. This is consistent with other studies, which suggest that the backlight luminance of a mobile display in a dark environment should be gradually increased [8], whereas it is desirable that the luminance of a display in a bright environment should be decreases with the passage of time [9].

This research is an initial stage in the examination of optimal luminance contrast; therefore, more instances should be collected to improve the relevancy of the theory. As a next stage, formulae and an algorithm on optimal brightness will be derived by conducting a series of user tests to apply these results to actual usage display situations. Using this data, the superiority of the developed algorithm will be verified. Once this is accomplished, users could always experience both physiological comfort and psychological satisfaction while using visual display terminals such as smartphones, tablet PCs and e-books. It is hoped that this study will provide a foundation of research helpful for developing applications for determining the optimal brightness of displays.

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Author Biography

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