Dynamics of Luminance Contrast for Comfortable Reading on Smartphone Display

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***Abstract*-- This study exploits the dynamics of luminance contrast between text and background for comfortable reading from a smartphone display. It involves two procedures: In Part I, a user test was conducted to identify the optimal luminance contrast with regard to the reading speed, preference and recognition point of contrast change; In Part II, results of Part I were used to derive the optimal dynamics of luminance contrast. The validation test involving users' preference, reading speed and brainwave analysis using the electroencephalogram, confirmed that the proposed dynamics supports comfortable reading of texts on smartphone displays.**

I. Introduction

Reading is one of the most important ways for communicating information. Issues related to legibility have been studied for decades, mainly focusing on printed texts [1], [2]. As portable digital devices become more accessible in everyday life, recent studies have been paying more attention to the appropriate luminance of e-books and tablet PCs [3], [4]. The studies suggest optimal luminance contrast ratios for displaying text contents. However, these suggestions are limited in that they are fixed variables (remain static). In this regard, this study attempts to develop dynamic luminance contrast between text and background, which changes gradually over time to enhance user comfort, particularly for reading texts on smartphone displays.

II. Objective

Previous studies revealed that the current luminance contrast between text and background is not necessarily the best solution for comfortable reading [5]. This study aims to develop a dynamic display of luminance contrast between text and background for comfortable text reading using a smartphone. It is hypothesized that a gradual decrease of luminance contrast helps reading by reducing visual stress.

III. Part I: finding the optimal luminance contrast

A. Objective

The user test in Part I attempts to discover the optimal luminance contrast for comfortable reading on a smartphone. It aims at collecting the scientific basis to design the dynamics of luminance contrast in Part II.

B. Stimuli

In order to assess the users' different perceptions of luminance contrast depending on how the luminance contrast is created, three sets of stimuli were prepared. The first set was *text change*; text color changes from black to white while background color is fixed at white. Second set was *background change*; text remains black while background shifts from white to black. The last set was *text-background change*; text gradually changes from black to white and background changes from white to black. Next, given that the maximum luminance contrast between text and background is 100 % and the minimum luminance contrast is 0%, each set was divided into 10 levels of contrast. Thus, there was a total of 28 stimuli, after excluding 2 overlapped black text-white backgrounds (*default* hereinafter).

C. Method

Fifty participants (26 males and 24 females) took part in the user test (M of age = 23.18, SD = 1.99). Every test was conducted using a Samsung Galaxy S3 smartphone.

1) Measuring the Reading Speed

Seven out of the 28 stimuli were selected as shown in Table I. Participants were asked to read 10 pages (2500 letters) of contents from the smartphone under the 7 contrasts, and their reading speeds was recorded respectively. In the case of *default*, the reading speed of each page was also recorded. From this, the starting point of change in luminance contrast could be determined due to the fact that reading speed does not change after the user starts concentrating on reading.

2) Assessing the Preference

Participants subjectively assessed their preference for luminance contrast for the 28 stimuli by using a 5 point Likert scale to indicate their level of visual comfort.

3) Exploring the Recognition Point of Contrast Change

The recognition point of the contrast change was investigated in order to derive an algorithm that gradually changes the luminance contrast without the users recognizing it. A video clip changing from 100 % to 0 % contrast at a rate of 5 %/sec was created for each of the 3 sets. Participants were asked to stop the video clip when they notice a change in the display's luminance contrast.

D. Results

For the *default* stimulus, ANOVA showed that there were significant differences between the reading speeds of each page ($p < .01$). Moreover, the result of correlation analysis indicated that the reading speed becomes faster as users turn over the pages. It noticeably increased from the 7th page or about 135 seconds after users began reading (average reading speed of 1-6 pages: 11.20 letter/s; 7-10 pages: 12.40 letter/s). This suggests that users generally start focusing on reading contents approximately 135 seconds into their reading.

When comparing the 7 stimuli, the reading speed of *background change* was highest, followed by *text-background change*, *text change* and *default* respectively as shown in Table I.

In terms of preference, it was observed that *text-background change* was most preferred whereas *background change* was the least preferred. Preference decreased rapidly in every set when luminance contrast became smaller. However, there was no noticeable difference between 100 % contrast to 80 % contrast for both *text change* and *text-background change*.

TABLE I
READING SPEED, PREFERENCE, RECOGNITION POINT OF CONTRAST CHANGE ON EACH STIMULI SET

Set	*default*	*text changing*		*background changing*		*text-background changing*	
Luminance contrast	100%	70%	40%	80%	70%	70%	40%
Example of stimuli	example luminance contrast	example luminance contrast	example luminance contrast	example luminance contrast	example luminance contrast	example luminance contrast	example luminance contrast
reading speed (letter/sec)	11.54	13.35	13.00	13.80	13.89	13.60	13.72
preference (scale:1-5)	-	2.43		2.09		2.85	
recognition point of contrast change (%)	-	55.70		75.10		60.40	

Lastly, ANOVA showed there were significant differences between the recognition points of contrast change in each set ($p < .01$). In *background change*, the recognition point of change was at 75 % contrast whereas in *text change* and *text-background change*, it was at 60 %.

IV. PART II: DEVELOPING THE "DYNAMICS OF LUMINANCE CONTRAST"

By using the empirical results of the user test, the dynamics of luminance contrast for comfortable reading on a smartphone was designed as shown in Fig. 1.

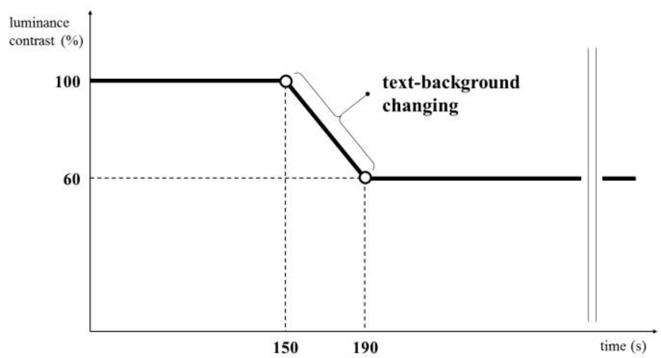

Fig. 1. Dynamics of luminance contrast: gradual decrease between text and background as time passes

The luminance contrast starts from 100 % (*default*) because high contrast helps users to concentrate on reading. It begins to change at 150 seconds after the user starts reading. In addition, by taking into account both readability and preference, a set of *text-background change* was selected. The final luminance contrast was decided at 60 % considering the average recognition point of contrast change. In order to avoid users becoming aware of the change, the luminance contrast shifts slowly at the rate of 1 %/sec.

The effectiveness of the dynamics of luminance contrast was verified by a validation test. Twelve participants were asked to read for 5 minutes using a smartphone under three conditions; dynamics of luminance contrast, *default* and *background changing* with 40% contrast. In addition to assessing users' reading speed and subjective preference levels, the ratio of high beta rhythm was also measured using the electroencephalogram (EEG).

The ratio of high beta rhythm (20~30 Hz) to the entire range (3.5 ~ 50 Hz) that indicates stress degree during reading was lowest when viewing the dynamics of luminance contrast (7.01%; *default*: 8.66%; *background changing*: 7.23%). On the other hand, the reading speed (14.60 letter/s; *default*: 14.06 letter/s; *background changing*: 13.07 letter/s) and preference (3.3; *default*: 3.1; *background changing*: 2.5) were highest for all the three conditions. These results from validation test confirmed that the dynamic change in luminance contrast supports comfortable text reading on smartphones.

V. CONCLUSION

In this study, dynamic luminance contrast, which gradually changes luminance contrast between text and background as time passes, was developed, and its effectiveness was verified. By applying this algorithm, it is possible to comfortably read contents for long hours using a smartphone. It is with hope that this study extends the opportunity for prolonged reading using diverse kinds of visual display terminals such as tablet PCs and e-books.

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