International Journal of Industrial Ergonomics 51 (2016) 68–72

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Adaptive luminance difference between text and background for comfortable reading on a smartphone

Nooree Na, Kyungah Choi, Hyeon-Jeong Suk*

Department of Industrial Design, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon, Republic of Korea

ARTICLE INFO

Article history:
Received 5 June 2014
Received in revised form
28 August 2015
Accepted 6 September 2015
Available online 16 September 2015

Keywords:
Luminance difference
Display luminance
Reading performance
Visual comfort

ABSTRACT

This study proposes a model of adaptive luminance difference between text and background for comfortable reading on a smartphone display. The study is composed of two experiments. In Experiment I, the optimal luminance difference is identified in accordance with reading speed and preference. On the basis of the experimental results, the gradual decrease of luminance difference between text and background is developed. The change occurs while reading the text, and the model is applied to various illuminance levels. In Experiment II, the effect of adaptive luminance difference is validated in terms of reading speed, preference, and brainwave analysis using an electroencephalogram. Empirical evidence confirms that the developed model improves physiological comfort and psychological satisfaction, thereby it has a potential to be applied to the visual display industry.

1. Introduction

With an increase in various types of visual display terminals (VDTs), many daily activities are now done digitally, such as reading books. Electronic books, or e-book have been quickly becoming more popular than paper books, and subsequently a number of studies have been carried out to examine comfortable reading on displays. In particular, the relationship between display luminance and reading performance has been focused on in previous studies (Krupinski et al., 1999; Seetzen et al., 2006; Yoshida et al., 2006; Rempel et al., 2009). For example, Buchner and his colleagues (2009) determined that displays with higher luminance provide better reading performance. Similarly, Benedetto's research team (2014) argued that both visual performance and visual fatigue increase as the level of display luminance rises. However, inadequately high or low luminance leads to a decline in visual performance and visual fatigue (Hultgren and Knave, 1974; Swinkels et al., 2008; Chen et al., 2012). Moreover, some revealed that people prefer lower display luminance in the condition of low illuminance, whereas they prefer higher display luminance in bright conditions (Merrifield and Silverstein, 1988; Mantiuk et al., 2009). Meanwhile, a great effort has been made to examine the effect of luminance difference between text and background on a display. It is generally believed that higher luminance difference between text and background enhances legibility and reading speed (Legge and Rubin, 1986; Legge et al., 1990; Knoblauch et al., 1991; Ling and Van Schaik, 2002). On the contrary, some other studies claimed that excessively high luminance difference decreases visibility and visual comfort (Dixon and Di Lollo, 1991; Yang et al., 2014). Although the aforementioned studies attempted to find the optimal luminance for reading on a display, these suggestions lack careful consideration of the human visual system. Since human vision provides time-dependent adaptation to ambient environment (Adelson, 1982; Pattanaik et al., 2000; Ledda et al., 2004), it is relevant to change display luminance with the passage of time (Benya and Schwartz, 2001; Na et al., 2014), especially for long hours of reading on a display.

In this regard, this study intends to investigate optimal luminance difference between text and background for comfortable reading on smartphone displays in respect to reading time and ambient illuminance. Ultimately, the study aims at developing a model for adaptive luminance difference that gradually changes luminance difference with the lapse of time to improve users' physiological comfort and psychological satisfaction. In addition, the effect of the developed model is validated with multidimensional assessments.

* Corresponding author.
E-mail address: color@kaist.ac.kr (H.-J. Suk).

http://dx.doi.org/10.1016/j.ergon.2015.09.004
0169-8141/

2. Experiment I: development of adaptive luminance difference

2.1. Objective

The goal of Experiment I was to identify the optimal luminance difference between text and background under two different levels of illuminance in terms of physiological comfort and psychological satisfaction. It also attempts to develop a model of adaptive luminance difference for comfortable reading on a smartphone display.

2.2. Method

2.2.1. Display stimuli

Three types of luminance difference were created as display stimuli for the experiment: The first set was *text change*—the text starts from black and it becomes brighter as luminance difference decreases, while the background is fixed as white; the second set was *background change*—the text remains black and the background shifts from white and it gets darker; and last set was *text-background change*—the text begins as black and it grows brighter whereas the background starts from white and becomes darker at the same rate. Thereafter, it was defined the maximum luminance difference between text and background as 100% and the minimum luminance difference as 0%, and each set was divided into 10 levels, as shown in Table 1.

Prior to the main experiment, 10 people were instructed to select the stimulus with the smallest but still acceptable luminance difference for each of the three sets. The results indicated that the minimum acceptable luminance difference for each set was found to be 40% (stimulus 3), 70% (stimulus 5), and 40% (stimulus 7), respectively (see Table 2). In addition to the three stimuli, 100% (stimulus 1) as well as an intermediate luminance difference between the 100% and the minimum acceptable luminance difference for each set—stimuli 2, 4, and 6 were inserted, hence a total of seven stimuli were finally determined for the experiment.

2.2.2. Experimental setup

The experiment was carried out under the two different levels of illuminance—in the bright condition (600 lx) and in the dim condition (50 lx), and the correlated color temperature of the two conditions was equal (approximately 6300 K). The two illuminance levels were selected since the illuminance of indoor working place and that of dark room are about 600 lx and 50 lx, respectively (Lehto and Landry, 2012).

The stimuli were displayed on a 4.8-inch diagonal screen smartphone, and the auto brightness function was operated. Subjects were instructed to view a smartphone from a distance of about 30 cm throughout the experiment, a typical viewing distance of a smartphone display (Spencer et al., 2013). They were involved in one of the two illuminance levels. Fifty people composed of 26 males and 24 females (Mean age = 23.18; SD = 1.99) participated in the experiment in the bright condition, whereas 30 people including 16 males and 14 females (Mean age = 22.00; SD = 2.82) took part in the experiment in the dim condition. All of the subjects were paid volunteers, and they had normal or corrected-to-normal vision.

2.2.3. Procedure

The subjects were asked to read a 10-page (approximately 800 words) article on a smartphone display with the seven display stimuli, and a 1-min break was allowed before moving on to the next reading sessions. Each article contained different but similar content in order to prevent the influence of reading content. The display stimuli and reading content were shown in a random order, and both physiological comfort and psychological satisfaction were evaluated. The subjects' reading speeds were measured for investigating physiological response because people read faster under visually comfortable conditions (Roufs and Boschman, 1997; Smith and Wilkins, 2007). Besides, the preference was assessed for examining psychological comfort regarding the seven stimuli with a 5-point Likert scale wherein a 1-point indicates not preferred whereas a 5-point means highly preferred as well as felt comfortable with the given stimulus.

2.3. Results and analysis

The reading speeds for each page were compared, and the results indicated that speed became faster over reading time. It gradually increased until the subject reached the 6th page, or about 150 s after they began reading, and then maintained the speed from the 7th page. The mean reading speed of the 7th to 10th page (237.78 word/min) was statistically significantly higher than that of the 1st to 6th page (215.06 word/min), $t(49) = -4.87$, $p < 0.05$. This implies that the subjects generally focus their attention on reading approximately 150 s after they start reading, hence luminance difference should be changed after that time to circumvent an interruption of concentration on reading content.

In regard to the bright condition, an analysis of variance showed that the effect of luminance difference on reading speed was significant, $F(6, 343) = 4.35$, $p < 0.05$. The highest reading speed was observed in stimuli 5 and 4 and followed closely by stimuli 7 and 6, whereas reading speed of stimulus 1 was the lowest as shown in Table 2. Contrary to reading speed, preference was significantly higher in stimulus 1 than in other stimuli, $F(6, 343) = 5.12$, $p < 0.05$, and stimuli 6 and 2 followed. The stimuli with relatively lower luminance difference between text and background (stimuli 3, 5, and 7) received low preference scores, which implies that the preference decreased as the luminance difference declines. Consequently, it is discovered that stimulus 1, the maximum luminance difference between text and background, has higher preference but leads to poorer reading performance, whereas two

Table 1
Three types of luminance difference: *text change*, *background change* and *text-background change*.

Luminance difference (%)	100	90	80	70	60	50	40	30	20	10
text change		A	A	A	A	A	A	A	A	A
background change	A	A	A	A	A	A	A	A	A	A
text-background change		A	A	A	A	A	A	A	A	A