Displays 32 (2011) 1–7

Contents lists available at ScienceDirect

Displays

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

Effect of light source, ambient illumination, character size and interline spacing on visual performance and visual fatigue with electronic paper displays

Der-Song Lee [a], Ya-Hsien Ko [b], I-Hsuan Shen [c,*], Chih-Yu Chao [d]

[a] Department of Industrial Management, Oriental Institute of Technology, Taipei 220, Taiwan
[b] Department of Business Management, De Lin Institute of Technology, Taipei 220, Taiwan
[c] Department of Occupational Therapy, Chang Gung University, 259, Wen-Hwa 1st Road, Kwei-Shan, Tao-Yuan 330, Taiwan
[d] Department of Industrial Management, National Taiwan University of Science and Technology, Taipei 106, Taiwan

ARTICLE INFO

Article history:
Received 2 April 2009
Received in revised form 5 July 2010
Accepted 10 September 2010
Available online 19 September 2010

Keywords:
Electronic paper
Visual performance
Ambient illumination
Character size
Interline spacing

ABSTRACT

This study investigated the effects of light source, ambient illuminance, character size, and interline spacing on visual performance and visual fatigue in using commercial electronic paper displays. Regarding visual performance the results showed that display type, character size, interline spacing had significant effects on search time. Electrophoretic electronic ink display had a shorter search time than chlorestic liquid crystal display. Searching time decreased as character size and interline spacing increased. Ambient illumination, display type, character size, and interline spacing had significant effects on accuracy. Accuracy was highest for 1500 lx ambient illumination. Accuracy of electrophoretic electronic ink display was greater than chlorestic liquid crystal display. Accuracy increased as character size and interline spacing increased. Regarding visual fatigue, results showed that light source and ambient illumination had non-significant effects on change of critical flicker fusion (CFF) and subjective visual fatigue. Results could be able to provide some guidelines for consumers to choose a suitable electronic paper according to lighting condition and set appropriate character size and interline spacing.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

With the advances of technology, the use of computer-based information systems to convert, store, process, transmit and retrieve information has increased immensely. Visual display units (VDUs) are the most convenient tools as human/computer interface. Because of the convenience and portability, pocket-sized displays will become the mainstream in the near future.

Light weight, low power consumption, portable, and paper-like readability make electronic paper (E-paper) displays the ideal technology solution for reading-intensive handheld devices [1]. E-paper displays can also reduce paper consumption and thus is environmentally friendly. As E-paper has become the headline in the latest visual display topics, there are plenty of related products with different technologies. Among these technologies, electronic paper made of cholesteric liquid crystal (Ch-LC) and electrophoretic electronic ink (E-ink) are the two products which are available in the market. Ch-LC has two stable states: reflective planar and focal conic texture. The planar texture reflects a specific colored light in a certain angle according to the pitch length. So that the Ch-LC shows a certain color. E-ink comprises millions of tiny microcapsules where a mixture of positively charged white particles and negatively charged black particles suspended in fluid. The black and white image is shown by applying an external electric field to attract the charged particles on the surface according to the polarity. Ch-LC and E-ink displays use different mechanisms to display images, therefore they have different visual performance. Although they have been available in the market for a while, there are limited studies for their visual performance based on ergonomic considerations. Among these studies, Isono et al. [2] found no significant differences in the level of visual fatigue between electronic reading and conventional reading. Jeng et al. [3] reported that legibility depends on the illumination intensity but not light source, and conventional paper has a higher visual comfort rating than electronic paper although they have similar performance in the letter-search task. Lee et al. [4] investigated the effects of character size under different level of ambient illumination and light sources on legibility of electronic paper displays and compared them with conventional paper. The results showed that searching speed depends on the luminance, not the light source. However, the effect of ambient illumination or light source on accuracy was not statistically significant. Shen et al. [5] conducted similar study and found that search speed depends on the ambient illumination but not light source. Accuracy was greater significantly for electrophoretic display and positive polarity.

Ambient illumination is an important factor affecting visual performance and visual fatigue. With regard to level of ambient illumination, recommendations have been reported. For CRT

* Corresponding author.
E-mail address: shenih@mail.cgu.edu.tw (I-Hsuan Shen).

0141-9382/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.displa.2010.09.001

workstations, an ambient lighting of 200–500 lx is generally suggested. The choice of illumination level greatly depends upon the task (Helander and Rupp [6]). Ostberg [7] reported that a lower ambient illumination might be more appropriate for CRT work. Xu and Zhu [8] studied the effect of ambient illumination and found that performance deteriorated as ambient illumination increased. Chen and Lin [9] suggested that lower ambient illumination (200 lx) was slightly better than higher ambient illumination (700 lx) in terms of both visual recognition and subjective preference. Shieh and Lin [10] found that visual performance was better under 450 lx ambient illumination versus 200 lx for TFT-LCD screen but not for CRT screen. To sum up, ambient illumination about 500 lx or lower is recommended for CRT and LCD screens because they are back lighted. A higher ambient illumination can wash out the images on the screens and possibly cause glares that interfere with visual tasks. However, these recommendations work only for VDUs with backlight. E-Paper displays are VDUs that are reflective, require no backlight, and have ultra-low power consumption. Reflective paper or E-Paper requires higher ambient illumination to reflect the messages on displays. This conjecture is supported in the findings of several studies [4,5,11]. These studies found that a greater illumination (700 lx or higher) results in greater search speed and accuracy. These findings were further investigated in this study.

Legibility is the attribute of alphanumeric characters that makes it possible for each one to be identifiable from others. It is defined as the visual properties of a character or symbol that determine the ease with which it can be recognized in ISO 9241-3 [12]. This means that stroke width, form of characters, and the amount of space between characters and font size can determine legibility [13]. There is an agreement over most international ergonomic standards that the minimum character size for good readability should be from 16 to 22 min of arc as [16]. According to the ANSI/HFS standard [14], font size is required to be a minimum of 16 min of arc and a maximum of 24 min of arc with a preferred range of 20–22 min of arc. In ANSI/HFS standard [14] and Shurtleff' study [15], character sizes of 10–12 min of arc are the minimum size recommended to be used for legibility. Lee et al. [4] found that accuracy was about 90% when the character size was 2.2 mm (15.1 min visual angle) or greater for both conventional paper and E-paper. For smaller character size of 1.4 mm, accuracy decreased quickly. Character size is an important factor affecting visual legibility. The proper character size for electronic paper displays was examined in this study.

Kruk and Muter [17] reported that single spacing produced reading that was 10.9% slower than that produced by double spacing. A series of studies were conducted to examine the role of horizontal word spaces on reading eye movements and reading speed [18–21]. When horizontal word spaces were removed from text, reading speed decreased, compared with normal text with spaces. The reading speed decreased approximately 50% [18,21] although smaller magnitudes of the effect were also reported [19]. More recently, Susana [22] showed that increased vertical word spacing, which presumably decreased the adverse effect of crowding between adjacent lines of text, would benefit reading speed. Bailey suggested that distance between lines should be at least 50% of character height. A distance of 66% of character height was preferred. The two interline spacing were tested in this study [23].

In summary, many research addressed visual performance, comparing CRT with TFT-LCD [9–12]. Ergonomic studies related to electronic paper displays were still quite limited. Moreover, few research was found regarding interline spacing evaluation in electronic paper displays. Hence, in this study, we explored the effects of light source, ambient illumination, character size, and interline spacing on legibility of two reflective-type E-paper displays by using the method of letter-search task. The ergonomic evaluation and comparison between commercial electronic paper displays could reveal what specifications were good enough for reading.

2. Methods

2.1. Experimental design

The experiment evaluated five independent variables: display type, light source, ambient illumination, interline spacing, and character size. Two types of E-paper, Ch-LC display (Kolin i-library) [24] and E-ink display (Sony LIBRIe') [25], were used as display types. There were two light sources: daylight D65 (6500 K), and florescent TL84 (4000 K). Ambient illumination had three levels: 300, 700, and 1500 lx. Character size was defined as the height of a lowercase 'x' (x-height). Three character sizes used were 2.0, 2.5, and 3.0 mm. Interline spacing was defined distance between two adjacent lines (e.g. http://www.plainlanguagenetwork.org/type/utbo350.htm) which was conveniently expressed as a ratio relative to x height. Two interline spacing were selected: 50% and 66% of the height of character size. Sixty participants were randomly assigned to each of the six treatments of the between-subjects factor (2 light sources $\times$ 3 ambient illuminations) with 10 participants for each treatment. Each participant completed 12 combinations (2 display types $\times$ 2 interline spacings $\times$ 3 character sizes) of the within-subject factors.

The method of letter-search task was used in this experiment and this task was found to be practical to evaluate the legibility of a display [26,27]. Four dependent measures; searching time, accuracy, CFF change, and subjective visual fatigue, were analyzed by the method of analysis of variance (ANOVA). Tukey HSD *post hoc* test was used for multiple comparisons. Accuracy was defined as the number of searched targets divided by the number of total targets. Critical flicker frequency (CFF) was the frequency at which a flickering light appears steady. It was a measure method for assessing visual fatigue. CFF was always determined with the method of limits by which the flickering frequency progressively decreased (or increased) until the subject reported a change from fusion to flicker (or flicker to fusion) [28]. CFF change was the CFF difference before and after the experiment. Subjective visual fatigue was determined by the total score of subjective rating of visual fatigue. All calculations were made with the statistical analysis system (SAS). The level of significance was $\alpha = 0.05$.

2.2. Participants

The participants were 60 college or graduate students, right-handed, with ages ranging between 18 and 28 ($M = 24.32$, $SD = 2.54$). All had corrected 0.8 or better visual acuity with normal color vision.

2.3. Apparatus

A Topcon SS-3 screenscope and the Standard Pseudo-Isochromatic Charts were used to examine subjects' visual acuity and color vision. The CIE chromaticity coordinates of color were measured with a Minolta chroma meter CS-100. A Kolin cholesterol liquid crystal e-Book Reader (resolution: VGA 640 $\times$ 480 dots, CIE color value foreground 3.2 cd/m^2, 0.347, 0.380, background 12.9 cd/m^2, 0.374, 0.451) and a Sony E-Ink e-Book Reader (resolution: SVGA 800 $\times$ 600 dots, CIE color value foreground 5.7 cd/m^2, 0.323, 0.354, background 23.2 cd/m^2, 0.325, 0.356) as shown in Fig. 1 were used to present the experimental material. The color assessment cabinet (VeriVide CAC 120–5) was used to control light source and illumination. The illumination was measured with photometer LT Lutron (LX-103). The text was presented dark on light background. Target/Background luminance ratio (Lt:Lb) were set at 1:4 for Ch-LC and E-ink. Participants' critical flicker fusion frequency (CFF) was measured with Lafayette flick fusion control 12023.

Download English Version:

https://daneshyari.com/en/article/537910

Download Persian Version:

https://daneshyari.com/article/537910

Daneshyari.com