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ScienceDirect
Displays 29 (2008) 10–17
DISPLAYS
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# Effect of character size and lighting on legibility of electronic papers

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Received 22 April 2007; accepted 21 June 2007
Available online 27 June 2007

**Abstract**

Effects of character size under ambient illuminances and light sources on legibility of electronic paper displays (electrophoretic display and cholesteric liquid crystal display) were studied and compared with paper. Sixty subjects participated in a letter-search task in the experiment. The results showed that search speed depends on the illuminance but not light source. Search speed increased as the illuminance increase from 300, 700 to 1500 lx. Search speed also increased with the increase of character size, from character height of 1.4 mm (9.6 min visual angle), 2.2 mm (15.1 min visual angle) to 3.3 mm (22.7 min visual angle), and the increase leveled off at 4.3 mm (29.6 min visual angle). The effect of character size on accuracy was also significant. Accuracy increased with the increase of character size. However, the effect of illuminance and light source on accuracy was not statistically significant. Based on the results of this study, it seems that E-paper displays may need greater illumination (700 lx or higher), greater character size (3.3 mm or 22 min of visual angle).


*Keywords:* Legibility; Electronic paper displays; Electrophoretic display; Cholesteric liquid crystal display; Letter-search task

## 1. Introduction

With the advances in computer technology, the tasks which human rely on computers to execute have increased immensely – both in time and scope. Visual display unit (VDUs) is believed to be the most convenient and handy tool as human/computer interface. In order to get the information whenever as well as wherever needed, a pocket-sized display will become the mainstream in the near future.

Electronic paper displays have become a forefront topic in the new generation of visual displays due to the light weight, low power consumption and sunlight readability. The expectations of an electronic paper display have been summarized by Omodani [1] as flexibility, readability, and multi-functionality. Several technologies, such as liquid crystal display, electrophoretic display, interferometric modulation, and rotating ball display, have been developed to realize the requirements.

As E-paper has become the headline in the latest visual display topics, there are plenty of related products with different technologies are on the market. Among these technologies, electronic paper made of cholesteric liquid crystal (Ch-LC) and electrophoretic electronic ink (E-ink) are two available products in the market. The Ch-LC has two stable states: reflective planar and focal conic texture. The planar texture will reflect a specific colored light in a certain angle according to the pitch length. Therefore, 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. The Ch-LC and E-ink displays use different mechanisms to display image, therefore they show a very different visual performance. Although they have been available in the

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doi:10.1016/j.displa.2007.06.007

market for a while, there are limited studies for their visual performance based on the ergonomic consideration. Isono et al. [2] conducted an experiment in which 13 college students read electronic paper and conventional paper for 90 min. Results showed 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 the similar performance in the letter-search task.

Ambient illumination is an important consideration in VDT workplace design. Many recommendations exist regarding level of ambient illumination. For CRT workstations, an ambient lighting of 200 to 500 lx is generally suggested. The choice of illumination level greatly depends upon the task [4]. Ostberg [5] reported that a lower ambient illumination might be more appropriate for CRT work. Xu and Zhu [6] studied the effect of ambient illumination and found that performance deteriorated as ambient illumination increased. In the study of Shieh and Lin [7] visual performance was better under 450 lx ambient illumination, versus, 200 lx for the TFT-LCD screen but not for CRT screens. On the contrary Chen and Lin [8] suggested that lower ambient illumination (200 lx) was slightly better in terms of both visual recognition and subjective preference compared to higher ambient illumination (700 lx). Compared to the CRT, the TFT-LCD screen is generally considered to be more satisfactory in terms of visual performance [7–10]. However, studies about ambient illumination for electronic paper displays are rare.

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 [11]. Legibility depends on such features as stroke width, form of characters, the amount of space between characters and font size [12]. Character sizes of 10 to 12 min of arc are the minimum that should be used for legibility [13,14], but most international ergonomic standards stipulate anywhere from 16 to 22 min of arc as the minimum character size for good readability [15]. According to the ANSI/HFS-100 [13] standard, 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. Character size is an important factor affecting visual legibility. The proper character size for electronic paper display deserves study.

As mentioned above much research has addressed visual performance compared CRT to TFT-LCD [7–10]. Ergonomic studies on these regards for electronic paper display are quite limited. In the present paper, we studied the effects of character size and ambient illuminance and light source on legibility of two reflective-type bistable displays and compared them with paper. Legibility was evaluated by using the method of letter-search task. The method of letter-search task was found to be practical to evaluate the legibility of a display [16,17]. Since the displays utilize the ambient light as a reading source, it is expected that the legibility might be varying with the ambient light source and illuminance. Hence, the present study also investigated visual legibility under various illuminance and light sources. The ergonomic evaluation and comparison between commercial electronic paper displays and paper could reveal that whether the current specifications are good enough for reading.

## 2. Methods

### 2.1. Experimental design

The experiment evaluated four independent variables: light source, display medium, ambient illumination, and character size. There were two light sources: daylight D65 (6500 K), and florescent TL84 (4000 K). Two types of E-paper were Ch-LC display (Kolin i-library) [18] and E-ink display (Sony LIBRIe') [19] and conventional paper were used as three display mediums. Ambient illumination had three levels: 300, 700, and 1500 lx. Four character sizes were selected: 1.4, 2.2, 3.3, and 4.3 mm of capital letter height. Sixty participants were randomly assigned to each of the six treatments of the between-subjects factor (2 light sources $\times$ 3 display mediums), with 10 participants for each treatment. Every subject completed the 12 combinations (3 ambient illumination $\times$ 4 character sizes) of the within-subject factors.

### 2.2. Participants

The participants were 60 college or graduate students, right-handed, with ages ranging between 18 and 28 ($M = 23.5$, SD $= 2.0$). All had corrected 0.9 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 and regular Xerox office paper 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. Luminance contracts were set at 1:4 for Ch-LC and E-ink, and 1:10 for paper.