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Effects of bending curvature and text/background color-combinations of e-paper on subjects' visual performance and subjective preferences under various ambient illuminance conditions

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Abstract

The study used the simulated e-paper to investigate how the bending radius of curvature (−10 cm, plane, and 10 cm) and 12 text/background color-combinations of e-paper affect subjects' visual performance and subjective preference under various ambient illuminance conditions (200 and 500 lx). Analysis results indicated that the bending curvature and ambient illuminance did not significantly affect subjects' visual performance. However, subjects visual performance differed significantly for different text/background color combinations of the simulated e-paper. When the background color of the simulated e-paper was set to yellow-like condition and the luminance of the text was low (2.2 and 4.6 cd/m^2), subjects' visual performance was best. Regarding the subjective preferences of subjects, the results of this research also demonstrated that the bending curvature, text/background color combinations and ambient illuminance all significantly affected the subjective preferences of subjects. Subjects exhibited the best preference under the following settings: bending curvature of the simulated e-paper set to plane; background color of the simulated e-paper set to yellow-like condition and low text luminance (2.2 or 4.6 cd/m^2); high ambient illuminance (500 lx).

Keywords: e-paper; Bending curvature; Visual performance; Subjective preference

1. Introduction

Given rapid advances in computer science, VDT (Visual Display Terminals) has progressed extremely quickly. A VDT revolution is developing, resulting in focusing on the production of flexible flat panel display (namely, e-paper). The potential advantages of flexible flat panel display technologies can be applied to thin profiles, lightweight, and robust display systems; additionally, the ability to flex, curve, conform, roll, and fold e-paper displays has make display for extreme portability, high-throughput manufacturing, wearable displays integrated in garments and textiles, providing ultimate freedom in engineering design [1]. Currently, e-paper techniques are divided into two categories: cholesterol liquid-crystal display (Ch. LCD) and electrophoretic display (EPD). Such reflective-type displays differ markedly from the conventional VDTs. These displays use ambient light as the reading source, and power only consumes when image refreshes. Furthermore, e-paper can be bent in the freehand holding condition. Currently available products show green-like and paper-white background colors for Ch. LCD and EPD, respectively [2]. Ch. LCD could show other background color due to Bragg reflection of different pitch [1].

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Consequently, the design guidelines for traditional VDT may not apply to e-paper. The effects of bending status, text/background color-combination of e-paper, and ambient illuminance need to be discussed further. Regarding research on e-paper, Kubota [3] investigated the lightness, contrast, and character size of reflective liquid-crystal display (LCD) for young and aged users. Kubota found that the required contrast ratio is approximately 4 given background lightness of 70; nevertheless, the required contrast ratio is about 6 or 7 given background lightness of 50. Matsumoto and Shinozaki [4] proposed that the reflectivity of paper-like images should exceed 60% and the luminance contrast ratio of the image also should exceed 5:1. Jeng et al. [5] reported that the background reflectance of e-paper is required to exceed 40% to achieve a satisfactory subjective preference. Jeng et al. also found that visual performance was maximized when the background reflectance exceeded 70%.

In previous studies on VDT working, text/background color-combination is always an important influence on the visual performance of users. Shieh and Chen [6] reported that text/background color difference was a significant factor for the subjects' viewing distance; moreover, a color combination with a color difference value of approximately 140 may be required to achieve adequate VDT screen design. Shieh and Lin [7] found that text/background color combination significantly influenced visual performance and subjective preference. Blue/yellow resulted in optimum visual performance and subjective preference, while purple/red resulted in the worst visual performance and subjective preference. Wang and Chen [8] also found that color difference significantly impacted subjects' reading performance at a leading display. When leading display jump length was larger, namely, 1.05 cm, the color combination had a much larger effect on visual performance. Wang et al. [9] found that leading display in VDT with larger color differences of the text/background color combinations resulted in higher subjects' comprehension.

Fig. 1. The simulated e-paper used in the experiment of this study.

Regarding the definition of color difference, Lippert [10] developed a formula for assessing the color difference between the text and background. According to the Commission International de1'Eclairage (CIE), in terms of text and background colors, the color difference is calculated as follows:

$$\Delta E(Y, u', v') = [(155\Delta Y/Y_M)^2 + (367\Delta u')^2 + (167\Delta v')^2]^{0.5},$$

where $u' = 4x/(x+15y+3z)$,

$v' = 9y/(x+15y+3z)$,
Y_M = brighter value between target and background,
ΔY = brightness difference between target and background,
$\Delta u'$ = difference value of the u' coordinate between the target and background,
$\Delta v'$ = difference value of the v' coordinate between the target and background.

Illuminance is another important influence on users' visual performance using VDT. Ambient illuminance influences the color luminance of e-paper, and the color luminance is based on the reflectance and illuminance which is calculated using the following formula:

$$\text{luminance}(\text{cd/m}^2) = (\text{Reflectance} \times \text{illuminance}(\text{lx})/\pi)$$

Consequently, it can be inferred that higher ambient luminance may increase user visual performance. However, Nemecek and Grandjean [11] did not suggest the high ambient illuminance because it is not suitable for visual tasks. Nemecek and Grandjea found that 23% of workers have experienced reflection and glare problems at ambient illuminance exceeding 1000 lx. Bennett et al. [12] proposed that increasing illuminance would result in decreasing improvements in performance until performance levels off. Additionally, most workers prefer to work under 400–850 lx illuminance conditions. Additionally, Boyce [13] suggested that lighting alone cannot produce work output, but merely makes details easier to see and colors easier to discriminate without producing discomfort or distraction. Wang et al. [14] did not find significant differences in visual identification performance on real hazardous material labels given illuminance settings of 200 or 400 lx. Additionally, Wang et al. [15] found that ambient illuminance (100 or 800 lx) did not significantly affect subjects' visual identification performance. The VDT research conducted by Shieh and Lin [7] found that ambient illuminance (200 and 450 lx) did not significantly influence subject visual performance and subjective preferences.

2. Method

2.1. Subjects'

The subjects consisted of 24 university undergraduates and graduates, all of whom were right handed. The subjects