Legibility of Electronic Paper

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Abstract

Legibility of electronic paper was evaluated by using the method of letter-search task and subjective visual comfort scaling. The results show that legibility depends on the illumination level, and conventional paper has a higher visual comfort rating than electronic paper although they have the similar performance in the letter-search task.

1. Introduction

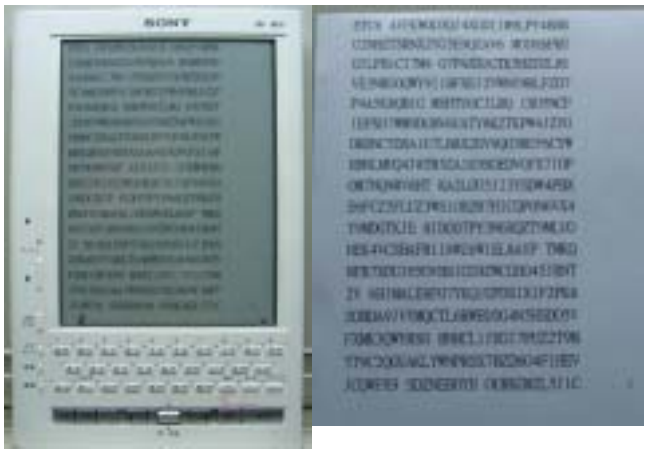
Electronic paper has become a forefront topic in the new generation of visual displays due to the light weight, low power consumption and sunlight readability. Among the developing technologies, electronic paper made of electrophoretic electronic ink (E-ink) is likely the only available product in the market with a paper-white appearance [1]. 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. For electronic paper to attract more public acceptance, its legibility should be comparable to conventional paper. Although visual fatigue from reading electronic paper has been studied recently [2], the ambient illumination influences on legibility of electronic paper has not been investigated. The reflective-type display utilizes the ambient light as a reading source, so it is expected that the legibility may be varying with the ambient light source and illuminance.

In this paper, we have studied the legibility of electronic paper under three different diffusive light sources with five different illumination levels. The ergonomic evaluation and comparison between electronic paper and conventional paper could reveal that whether the current specifications are good enough for reading.

2. Experimental design

Sony LIBRIé e-book made of E-ink [3] (CR:~4, reflectance: ~35 %) and conventional office paper (CR: ~10, reflectance: ~ 80%) were used as our test visual display units (VDUs) as shown in Fig. 1. The contrast ratio and reflectance were measured by the Minolta chroma meter (CS-100). A series of letter-search task was conducted to evaluate the legibility, and the subjective visual comfort scaling, from 1 (poor) to 10 (excellent), was conducted after each task. The method of letter-search task with alphanumeric pseudo-text was found to be practical to evaluate the legibility of a display [4]. A paragraph of alphanumeric pseudo-text with 12 point font size of Thin Ming type was used in

this work, where 10-15 targets of character 'A' were embedded in a random strings of capital letters, digits and spaces. The subjects were asked to scan the text and identify the target "A" as accurate and



(a) (b)

Figure 1 Visual display units used in this work. (a) Sony LIBRIé (b) regular office paper.

quickly as possible, and the subject's total search time and accuracy were recorded.

There were thirty subjects participated in this experiment aged from 19 to 28 (mean age: 23.3 yr). The VDUs were placed inside a color assessment cabinet (VeriVide CAC 120-5) as shown in Fig. 2, where three different diffusive light sources D65 (6500K), TL 84 (4000K) and tungsten filament (2800K) were used. Illuminance was set at five different levels, 200 lux, 400 lux, 800 lux, 1500 lux and 3000 lux, which cover the illumination intensity from indoor to outdoor. The viewing angle of 15^{o} and viewing distance of 37 cm were fixed during the experiment as shown in Fig. 3.

Figure 2 Experimental setup.

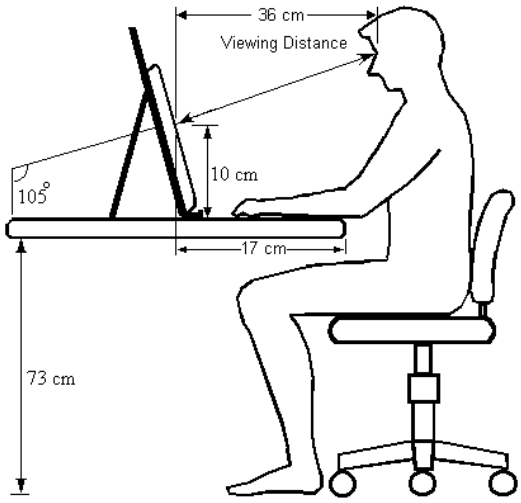


Figure 3 Experimental configurations.

3. Results and discussion

The search time and accuracy of letter-search task and the subjective comfort rating were analyzed by the method of analysis of variance (ANOVA), and the results are shown in Table 1 and Fig. 4. It indicates that illuminance is a significant factor especially for the search time and visual comfort. The search time decreases as illuminance increases from 200 lux to ~1500 lux, and then it increases at a higher illuminance (3000 lux) regardless of the VDU type and light source. It is expected that legibility will

Table 1 Results of Analysis of Variance
DF: degree of freedom; SS: sum of square error; MS: sum of mean square error

Table 1-1 ANOVA for Search Time

Source	DF	SS	MS	F	P
Display	1	158.7	158.7	0.92	0.34
Source	2	20.2	10.1	0.06	0.94
Illum.	4	4983.7	1245.9	7.24	0.00
Display*Source	2	13.3	6.7	0.04	0.96
Display*Illum.	4	126.9	31.7	0.18	0.95
Source*Illum.	8	77.4	9.7	0.06	1.00
Display*Source*Illum.	8	93.9	11.7	0.07	1.00
Error	150	25801.9	172.0		
Total	179	31276.0			

Table 1-2 ANOVA for Accuracy

SS	MS	F	P
0.0127	0.0127	1.76	0.186
0.0110	0.0055	0.77	0.467
0.1116	0.0279	3.89	0.005
0.0061	0.0030	0.42	0.655
0.0024	0.0006	0.08	0.987
0.0095	0.0012	0.17	0.995
0.0036	0.0005	0.06	1.000
1.0767	0.0072		
1.2335			

Table 1-3 ANOVA for Comfort

SS	MS	F	P
18.1	18.1	11.0	0.001
14.1	7.1	4.30	0.015
44.2	11.0	6.71	0.000
3.9	1.95	1.19	0.309
0.59	0.15	0.09	0.986
3.24	0.41	0.25	0.981
3.38	0.42	0.26	0.978
246.8	1.65		
334.3			

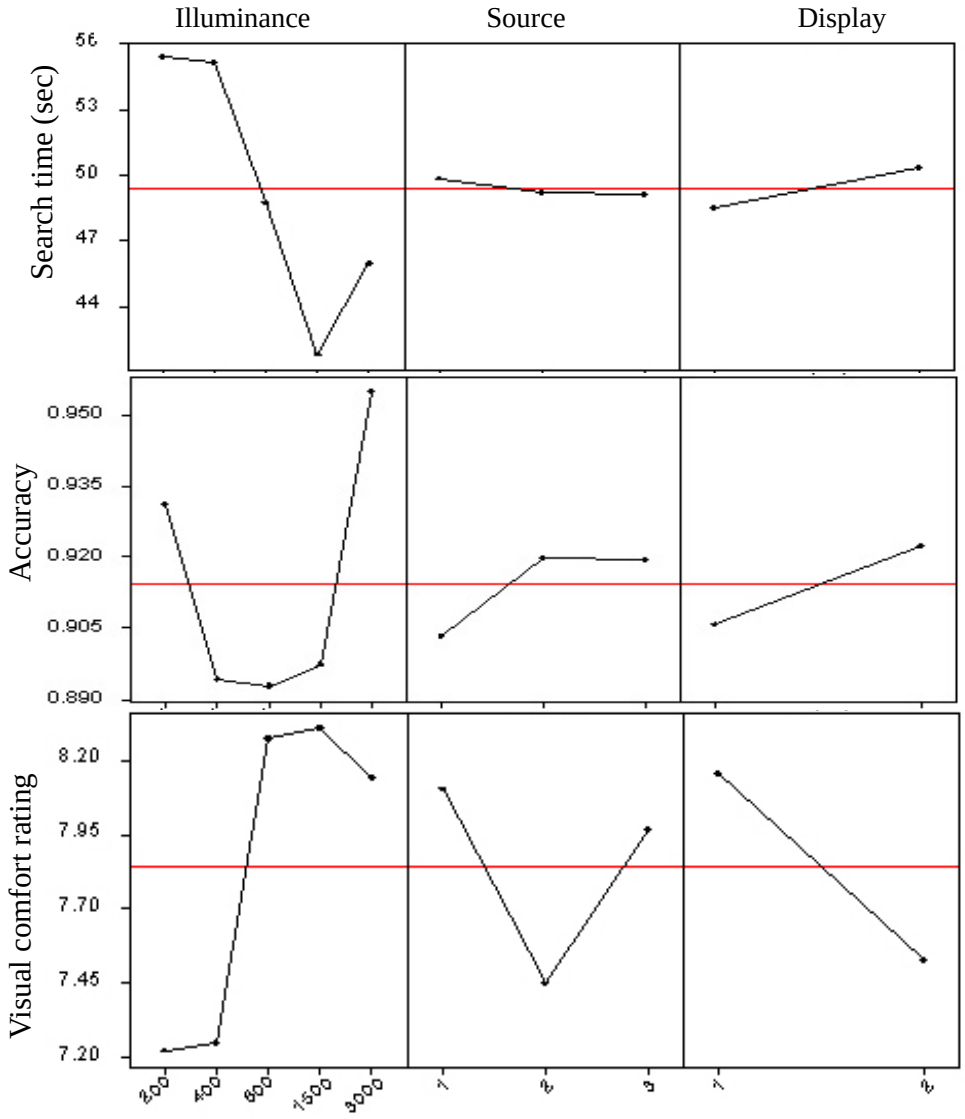


Figure 4 Main effects plot - LS means for (a) search time (b) visual comfort rating.
Source: 1: D65; 2: Filament; 3: TL84; Display: 1: paper; 2: Sony LIBRIé e-book.

increase as illuminance increases since the VDU uses the ambient light as its reading source. The degradation of legibility beyond ~1500 lux may be due to the disturbance from surface reflection although the surface has been treated by anti-glare coating. Subjective comfort rating after the task has shown paper display has higher rating than electronic paper although they have similar performance in the letter-search task. The e-book may need to have a higher reflectance to compete with a paper for the visual comfort. A reflectance around ~70 % might be enough to reach the same visual comfort as a printing image [5,6]. Other factor, such as light source, is also significant for visual comfort rating, and the filament light source seems less preferred for legibility.

4. Conclusion

In conclusion, the ergonomic evaluations of commercial electronic paper in this work could reveal that whether the current specifications are good enough to compete with office paper for reading. Moreover, our results perhaps will provide some guidelines for consumers to choose a suitable electronic paper according to their lighting condition, and will give some suggestions to manufactures for making market-acceptable products. Human factor study for another e-paper technology, cholesteric LCD, is in progress.

5. References

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