Influences of anti-reflection surface treatment on legibility of reflective-type displays

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Abstract

Influences of anti-reflection surface treatment, radius of curvature and ambient illuminance on legibility of reflective-type displays were studied. The results showed that legibility mainly depended on the surface treatment. Better surface treatment also produced less visual fatigue after the letter-search task

1. Introduction

The industry of flexible display has been developing rapidly in recent years. One of the important applications for flexible display is electronic paper due to its light weight, low power consumption and sunlight readability. The main feature of electronic paper is its reflective-type. It is expected the legibility may be varying with ambient illumination since the electronic paper uses the ambient light as a reading source. However, there is always a surface reflection due to the index mismatch between the air and the top surface of the display. Higher illumination level may result in a more harsh reflection and degrade the legibility more. Our previous study of illumination effects on legibility of electronic papers showed that the legibility increased with the illuminance level in the range of 200 ~ 1500 lux, and it decreased in a higher illumination level regardless of reflectance of electronic papers. We suspected this phenomenon was due to the surface reflection [1-3].

In this work, we studied the influence of surface treatment on legibility and visual fatigue for reflective-type displays under different bending curvatures and illumination levels. Surface treatment samples of anti-reflection (AR) from Nitto Denko were applied on the reflective-type printing image. Legibility was evaluated by using the method of letter-search task [4].

2. Experimental methods

The current study evaluates three independent variables: surface treatment, illumination level and radius of curvature. Three surface treatments, anti-reflection (4% AR and 0.8% AR) and transparency (non-treatment), were laminated to the printing image with contrast ratio around 10, and they were served as the visual display unit (VDU). The VDUs were placed inside a color assessment cabinet (VeriVide CAC 120-5) with a diffuse light source of TL 84 (4000K) as shown in Fig. 1. Illuminance was set at 3 different levels, 200 lux, 1500 lux and 3000 lux. The VDU was also bent at 3 different radius of curvature of 10 cm, －10 cm and plane. Therefore, there were 3 (surface treatment) × 3 (illumination level) × 3 (radius of curvature) experimental conditions. Forty-five college students participated in this experiment. All had corrected visual acuity better than 0.8.

The experimental task configuration is shown in Fig. 2. A series of letter-search task was conducted to evaluate the legibility and visual fatigue. A paragraph of alphanumeric pseudo-text with 12 point font size of Thin Ming type was used for the task, where 8-13 targets of character 'A' were embedded in a random strings of capital letters, digits and spaces. The text was arranged in 19 lines, with 71 characters per line. The subjects were asked to scan the text and identify the target "A", "X" or "Y" as accurate and as quickly as possible. The search time and accuracy were recorded for legibility evaluation. Visual fatigue was evaluated by change of critical fusion frequency (CFF) before and after task. The subjective visual fatigue rating was determined by the questionnaire developed by Heuer et al. [5]. The questionnaire comprised the following six items:

1. I have difficulties in seeing,
2. I have a strange feeling around the eyes.
3. My eyes feel tired.
4. I feel numb
5. I have a headache
6. I feel dizzy looking at the display.

The subjects answered the items on a 10-point scale, with 1 presenting "not al all" and 10 presenting "yes, very much".

Four dependent measures, search time, accuracy, change of CFF and subjective visual fatigue rating were analyzed by the method of analysis of variance (ANOVA) and paired sample test.

3. Results

The results of ANOVA for search time are shown in Table 1-1, and the main effect plot is shown in Fig. 3. It indicates that surface treatment is the only significant factor regardless of the illumination level and bending curvature. Lower search time in this experiment corresponds to a higher searching speed and therefore a better legibility. The search time decreases as surface treatment is changed from non-treatment to 0.8% AR. The results are further analyzed by paired samples test to distinguish difference between levels as shown in Table 2. Significant difference between 0.8% AR and transparency is observed as shown in Table 2-1. Harsh surface reflection degrades the legibility. Thus, it is expected that a reflective-type display with a much better anti-reflection treatment on the surface could continue to improve legibility under a sunlight environment.

The ANOVA results of accuracy are shown in Table 1-2. It indicates that none of the independent variables has a significant effect on accuracy. The accuracy in the letter-search task is not very sensitive to evaluate the legibility because subjects like to slow down their searching speed to improve their accuracy.

The results of ANOVA for change of critical fusion frequency are shown in Table 1-3, and the main effect plot is shown in Fig. 4. It indicates that surface treatment is the significant factors for visual fatigue. The results are further analyzed by paired samples as shown in Table 2-2. Significant difference between 0.8% AR and 4% AR is observed. Better surface treatment of 0.8% AR produces less visual fatigue than 0.4 % AR after the letter-search task.

The results of ANOVA for visual fatigue rating are shown in Table 1-4. It indicates that surface treatment and bending curvature is the significant factors for visual fatigue. The main effect plot of surface treatment is shown in Fig. 5. The results are further analyzed by paired samples as shown in Table 2-3. Significant differences between 0.8% AR and 4% AR, between 0.8% AR and transparency, and between 4% and transparency are observed. Surface treatment of 0.8% AR produces less visual fatigue than 0.4% AR and transparency after the letter-search task.

In conclusion, the ergonomic evaluations of surface treatment of reflective-type displays in this work have revealed that a better surface treatment can improve legibility and reduce visual fatigue based on letter-search task. Our results of surface treatment effects on legibility and visual fatigue suggest that a much better surface treatment is needed to meet the ergonomic demand.

4. Acknowledgement

We thank Nitto Denko Corporation for supporting the surface treatment samples.

5. References

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Figure 1 A color assessment cabinet used in this work for producing various illumination levels.

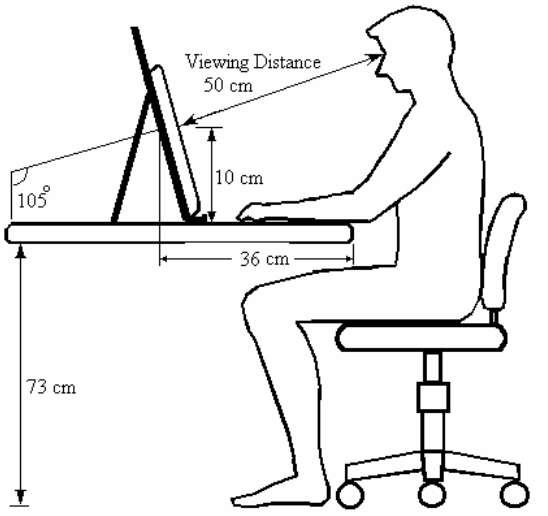

Figure 2 Experimental configurations for letter-search task.

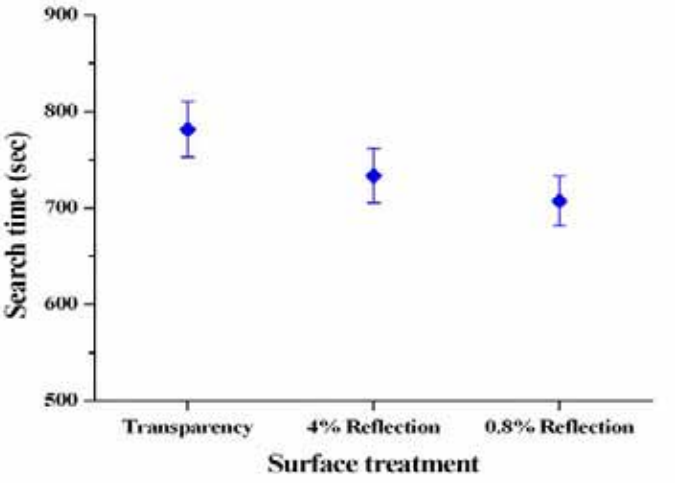

Figure 3 Search time as function of surface treatment.

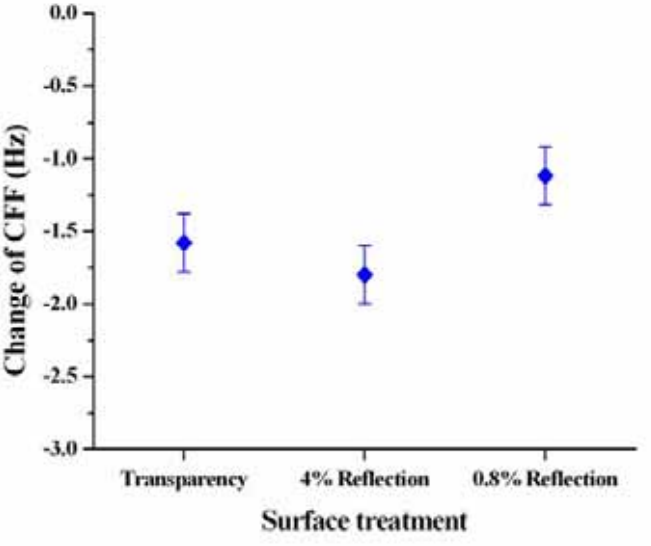

Figure 4 Change of CFF as function of surface treatment.

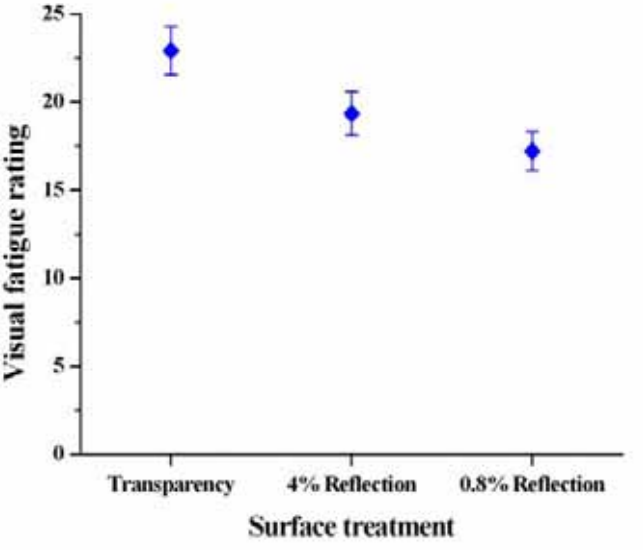

Figure 5 Visual fatigue rating as function of surface treatment.

Table 1 ANOVA results of search time , accuracy and change of CFF.

	Table 1-1 ANOVA of search time				Table 1-2 ANOVA of accuracy				Table 1-3 ANOVA of change of CFF				Table 1-4 ANOVA of visual fatigue rating			
Source	SS	df	MS	F	SS	df	MS	F	SS	df	MS	F	SS	df	MS	F
Between subjects																
Illuminance (I)	16721.0	2	8360.5	0.306	.001	2	.001	.09	1.89	2	.94	1.02	30.59	2	15.29	.28
curvature (C)	157182.4	2	78591.2	2.874	.006	2	.003	.50	2.67	2	1.33	1.44	361.78	2	180.89	3.39*
I * C	25934.6	4	6483.6	0.237	.026	4	.006	1.07	2.27	4	.56	.61	233.80	4	58.45	1.09
Error	984272.3	36	27340.8		.218	36	.006		33.38	36	.92		1916.40	36	53.23	
Within subjects																
Surface treatment (S)	128088.1	2	64044.0	**5.86****	.002	2	.001	.32	10.74	2	5.37	**3.66***	747.65	2	373.83	**21.05****
S * I	51719.2	4	12929.8	1.18	.013	4	.003	.82	3.21	4	.80	.54	7.23	4	1.80	.10
S * C	49559.3	4	12389.8	1.13	.004	4	.001	.29	2.07	4	.51	.35	17.27	4	4.3	.24
S * I* C	80024.4	8	10003.0	0.91	.013	8	.002	.42	7.66	8	.95	.65	174.37	8	21.79	1.23
Error (S)	786726.1	72	10926.7		.278	72	.004		105.63	72	1.46		1278.80	72	17.76	

**** significant at α=0.01 level, * significant at α=0.05 level**

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Table 2-1 Paired samples test of search time									
Pair 1	**4% - 0.8%**	26.33	141.75	21.13	-16.25	68.92	1.25	44	.219
Pair 2	**0.8% - Tran.**	-74.40	136.92	20.41	-115.54	-33.261	-3.65	44	.001
Pair 3	**4% - Tran.**	-48.07	164.81	24.57	-97.58	1.45	-1.96	44	.057
Table 2-2 Paired samples test of change of CFF									
Pair 1	**4% - 0.8%**	-.677	1.556	.232	-1.145	-.210	-2.921	44	.005
Pair 2	**0.8% - Tran.**	.456	1.548	.231	-.009	.921	1.974	44	.055
Pair 3	**4% - Tran.**	-.222	1.808	.270	-.765	.321	-.825	44	.414
Table 2-3 Paired samples test of visual fatigue rating									
Pair 1	**4% - 0.8%**	2.18	5.06	.75	.66	3.70	2.89	44	.006
Pair 2	**0.8% - Tran.**	-5.71	6.82	1.02	-7.76	-3.66	-5.62	44	.000
Pair 3	**4% - Tran.**	-3.53	5.35	.80	-5.14	-1.92	-4.43	44	.000