Analysis of Fatigue Difference between Paper and Displays

- Effects of Medium Handling Style -

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Abstract

Emissive screens are generally believed to be the main reason for eye fatigue when reading text on displays. This study examines the impact on eye fatigue of reading style and medium: reflective or emissive. We test three media, paper, LCD (liquid crystal display with backlight), and electronic paper (book reader using electrophoretic reflective display). Eye fatigue levels in a reading task are evaluated under two reading styles ("Free"condition and "Fixed" condition) for the three media by measuring the increment in near point distances after each reading task. Subjects were requested to read a novel for 180 minutes using the three media. "Fixed" reading condition yielded a statistically significant increase of the near point distance on the three medium, while "Free" condition showed no such increment regardless of the medium.

1. Introduction

Electronic paper is being eagerly researched; it is a promising medium by which we access documents with more readability and less fatigue than the conventional electronic displays. However, the main factors determining readability and eye fatigue have yet to be clarified. The emissive screen is generally believed to be the main reason for the eye fatigue experienced when reading texts on displays.

Here we should consider not only the impact of media style, reflective / emissive, but also the impact of reading style [1]. Paper and displays offer a significant difference in reading style since computer screens are usually stationary on the desk while paper documents are usually hand held. In this study, we focused on how the reading style influences eye fatigue[2].

2. Experimental Methods

Subjects were requested to read a novel for 180 minutes on paper: paper book, electronic paper (Electronic book reader with electrophoretic display), and display (Liquid Crystal Display with back light). Eye fatigue levels in the reading task were evaluated under two reading conditions for the three media. One was "Fixed" condition, the other was "Free" condition. The increment of the near point distance (NPD) after the reading task was used, in this study, as an index of eye fatigue. Near point distance is the shortest distance at which a subject can focus on an object. It has been confirmed that near point distance generally increases as our eyes become fatigued[3].

An instrument for measuring near point distance (accommodometer) was used in these experiments. Experimental conditions are shown in Table 1. Each medium used in this study allowed the hand-held reading style; a hand-held liquid crystal display was used in the reading task. Display parameters, i.e. display area, font size, and numbers of characters were made almost equal for the three media.

In the "Fixed" condition, the medium was fixed to the desk top by a support stand (the angle was set at 60 degrees from the desk top).Page turning during the reading task on the LCD was performed with pushing the buttons of a keyboard connected to the LCD. Paging action on the electronic paper was performed via the paging key on its top surface.

In the "Free" condition, any reading style including hand-holding and lying flat on the desktop was allowed except for using the supporting stand. Typical scenes of tasks are shown in Table 2. Figure 1 shows a time table. 90 minute reading periods were broken by a short rest of 10 minutes. Near point distance was measured every 30 minutes while reading.

The near point distances were measured as the nearest distance at which the subject could focus while moving the target toward the subject (Decrement method). Measurements were repeated 10 times each measurement and averaged values were obtained by ignoring the maximum and the minimum value of the ten measured values.

The posture of the subject was checked every 15 minutes during the reading task. Subjects were requested to provide relative evaluations between the two reading conditions, "Fixed" and "Free", after the two reading tasks periods for each medium. They were asked to provide information on four items: Eye fatigue, Eye performance, Physical and mental fatigue, Sleepiness. Relative superiority of the reading condition was indicated by the subject assigning one of five subjective assessments.

Table 1. Experimental conditions

	Paper	Electronic Paper	Display
Media	Paper book	Electrophoretic display	LCD with back light
Screen size	A6 (≒6 inch)	6 inch	7 inch
Character ×line number	38×14	30 ×16	42 ×16
Font Size	9 pt		
Illumination	600 lx on the desk		
Subjects	6 students	8 students	6 students

Table 2. Typical scenes of tasks

	Paper	Electronic Paper	Display
Free condition			
Fixed condition			
Media			

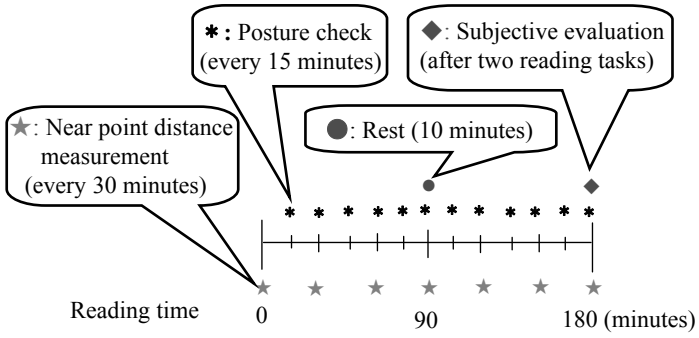

Figure 1. Time chart

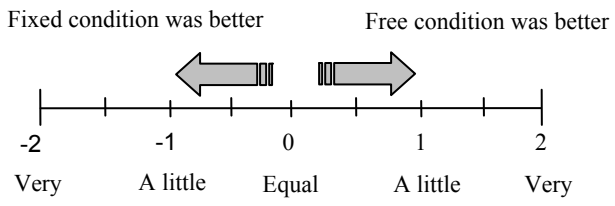

Figure 2. Scale of relative evaluations between "Fixed" and"Free"conditions.

3. Experimental Results

3.1 Near Point Distance

Rate of increase in the near point distance (NPD) was calculated every 30 minutes by using the following formula for each subject.

Increase rate of NPD (%) =

$$\frac{(\text{NPD before reading} - \text{NPD after reading})}{(\text{NPD before reading})} \times 100\ (\%)$$

Averaged values, for all subjects, of the increase rate of near point distance were calculated; they are plotted in Figure 2. NPD increased only for the "Fixed" condition, regardless of the medium.

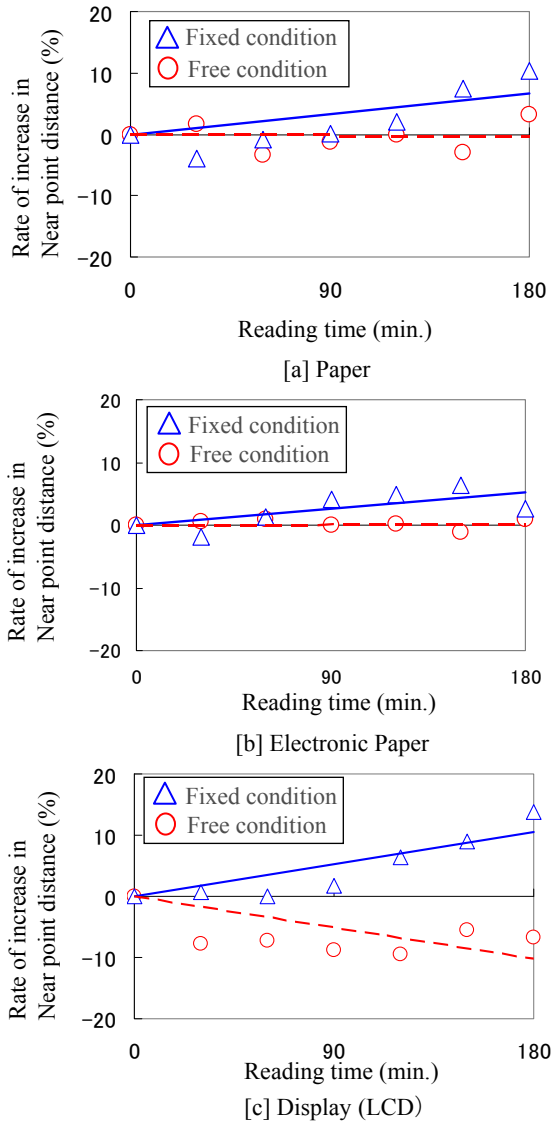

Figure 3. Rate of increase in near point distance

3.2 Subjective evaluation

Eye fatigue and eye performance are metrics of fatigue that are related to the near point distance. Figure 3 shows averaged results of the subjective evaluations, for all subjects, for eye fatigue and eye performance. The "Free" condition was superior for all media.

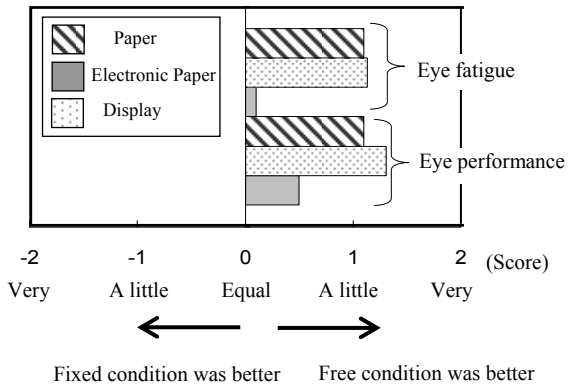

Figure 4. Subjective evaluation of three media (Eye fatigue & Eye performance)

3.3 Check of media position

We categorized the posture of the subjects (medium position and handling style) into the following 8 categories: 1) flat on desk, 2) leaning against desk edge, 3) holding in both hands on desk, 4) holding in one hand on desk, 5) holding in both hands on the knee, 6) holding with one hand on their knee, 7) holding in both hands in the air, 8) holding in one hand in the air. We then counted the frequency of posture changes when the categories of the observed postures were different between neighboring two timings. Table 3 shows averaged values, for all subjects, of the posture change rates for the three media and the two conditions. The posture change rates were naturally 0 % for the "Fixed" condition. The posture change rate exceeded 30% in the "Free" condition for all media.

Table 3. Rate of medium position change

	Free condition	Fixed condition
Paper	42% (4.7 times)	(0 %) 0 time
Electronic Paper	35% (3.9 times)	
Display(LCD)	29% (3.2 times)	

4. Discussion

4.1 Correspondence in the experiment results

It should be noted that the near point distance increased, which indicates fatigue, only in the "Fixed" condition regardless of the medium. This result corresponds to the subjective assessments for eye fatigue and eyes performance. The frequent change in posture indicated, in Table 3, for the "Free" condition suggests that the posture change might be the key factor preventing eye fatigue.

4.2 Statistical confirmation

We performed a test to confirm if the differences in the slopes of the near point distance curves were statistically significant for the "Fixed" and "Free"conditions, or for the reflective and emissive media. We used "Student's t test" to evaluate the statistical significance of the difference between the mean values of two independent groups "Student's t test" generally outputs probability p that confirms the null hypothesis that denies the difference in the mean values of two groups. A statistical significance is confirmed when $p<0.05$: that is the null hypothesis should be denied. We calculated the slopes of the near point distance curves by collinear approximation of the plots for each subject; starting points of the curves were fixed to the value before any reading task. We calculated averaged values for all subjects and then calculated the p values for the two pairs: "Fixed" and "Free", reflective and emissive media.

Table 4 shows the values calculated for the statistical evaluation. The probability p =0.642 (P>0.05) for reflective and emissive media, and p=0.024 (P<0.05) for "Fixed" and "Free". A statistical significance was confirmed only for the difference between "Fixed and "Free" in our experiments. These results suggest that the inability to move the computer screen is one of main causes of the fatigue common when performing tasks on a computer screen. That is, media should be hand-held to prevent eye fatigue and so should an important goal of readable electronic paper. Note that we are not claiming that the differences of reflective or emissive screens do not affect eye fatigue. That is, it should be noted that our experiments were performed using an ideal lighting environment for each condition.

Future work will examine the impact of lighting condition on the reading performance offered by reflective and emissive media.

Table 4. Effects of media and handling styles

			Increase rate of NPD (%/hour)			Difference (Level of significance)
			Free condition	Fixed condition	Average	
Increase rate of NPD (%/hour)	Reflective media	Paper	-1.00	3.13	1.06	-0.16 (0.94)
		Electronic paper	0.05	1.75	0.90	
		Average of reflective media	-0.40	2.34	0.97	**-0.92 (0.64)**
	LCD		-3.39	3.48	0.04	
	Average of all media		-1.30	2.68		
Difference (Level of significance)				**3.98 (0.024)**		

5. Conclusion

Evaluations of eye fatigue were performed on three media, paper, LCD, electronic paper, under two reading styles, free and fixed condition; the increment in near point distance after each reading task was taken as the main metric of eye fatigue. Main results are summarized as follows:

1) The free condition for media handling offers lower fatigue (statistically significant) than the fixed condition, regardless of media.
2) The media (reflective / emissive) showed no significant difference in terms of eye fatigue.
3) Electronic media that can be hand held are expected to reduce eye fatigue.
4) The influence of media type (reflective / emissive) should be examined for a wide range of ambient illumination conditions.

References

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Author Biography

Sonomi Inoue was born in 1987. She received her B.E. degree in 2009 from Tokai University. She is expected to receive her M.E. degree from the graduate school of Tokai University in 2011. She is now engaged in a study of readability as a target of Electronic Paper.