Comparison of eye fatigue among readings on conventional book and two typical electronic books equipped with electrophoretic display and LC display

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Abstract

We have measured eye fatigue after each 90 minutes of reading on a paper (book), electronic paper (book reader using electrophoretic reflective display), and LCD (backlight type liquid crystal display). Increase of Near Point Distance was measured in each subject as an objective index. Subjective impression of eye fatigue was answered by subjects using fatigue scale of 5 ranks. As a result, the biggest fatigue was indicated by LCD while the smallest fatigue was indicated by a conventional paper book.

1. Introduction

Electronic books are expected to become more and more popular. Electronic paper, typically reflective display with electrophoretic display panel (EPD), is being eagerly researched; it is a promising medium by which we may 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.

We have shown, in our previous study, that free handling condition for reading medium offers lower fatigue than the fixed condition, regardless of media.[1)] In this study, we intend to reconfirm the difference of fatigue between a typical emissive medium and a typical reflective medium both on the market. Traditional paper book was also tested as a reference.

2. Experimental Methods

Evaluations of eye fatigue were performed on the three media (Figure 1), liquid crystal display with back light (LCD: iPad 2), electrophoretic display (EPD: Kindle DX), and paper book during reading task for 90 minutes. The increment of the near point distance (NPD) after the reading task was measured 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 [2)].

Experimental conditions are shown in Table 1. Measurement items are shown in Table 2. Subjects were requested to read the same novel sequentially on the three media. They read the novel from the first page on the first medium and then read the following part of the same novel on the 2nd medium in a different day, and then read the next part in the 3rd medium in another day. The order of medium was set differently for each subject shown in Table 3. Any reading style including handholding and lying flat on the desktop was allowed for the subjects. Typical scenes of the reading task are shown in Figure 2.

The near point distances (NPD) were measured as the nearest distance at which the subject could focus while moving the target toward the subject. Measurements were repeated 10 times in each measuring timing of every 30 minutes. Averaged values of NPD were calculated using eight measured values by ignoring the maximum and the minimum value of the ten measured values. Subjects were asked to answer subjective impression for the four items: eye fatigue, visual performance, physical and mental fatigue, sleepiness as listed in Table 4. They chose their subjective answer from the five levels of extent in each item; "level 5" means the maximum extent and "level 1" means the minimum extent. As a matter of fact, "physical and mental fatigue" and "sleepiness" are dummy questions for excluding other impressions which were not related to eye fatigue. The first two questions, "eye fatigue" and "visual performance" are the essential questions. We observed position of medium during the reading task every 5 minutes; the position of medium was classified by using the five categories shown in Table 5.

Table 1 Experimental conditions

Items	Contents		
Medium	Liquid crystal display (iPad2)	Electrophoretic display (Kindle DX)	Paper (Paper book)
Screen size	197x148 mm	203x139 mm	190x230 mm
Weight	601 g	536 g	515 g
Page turning	Touch screen	Paging key	Turn up paper
Contents	BLUE TOWER (Author: Ira Ishida) Vertical writing, in Japanese		
Subjects	6 students		
Reading time	90 minutes		
Illumination	600 lx on the desk		
Measuring instrument of NPD	Accommodometer (KOWA)		

Table 2 Measurement items

	Contents	Interval
Objective evaluation	Near point distance	every 30 minutes
Subjective evaluation	Answers by subjects for questions	
Observation of a subjects	Media position	every 5 minutes

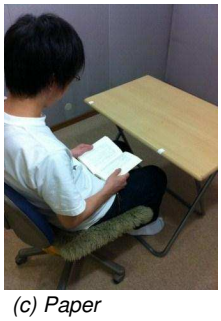
Table 3 Order of medium for reading tasks

Subjects	Order of reading		
	①	②	③
A	LCD	EPD	Paper
B	LCD	Paper	EPD
C	EPD	LCD	Paper
D	EPD	Paper	LCD
E	Paper	LCD	EPD
F	Paper	EPD	LCD

Figure 1. *Three media for reading tasks (left: LCD, center: EPD, right: paper)*

(a) Liquid crystal display (LCD: iPad2)

(b) Electrophoretic display (EPD: Kindle DX)



(c) Paper (Conventional book)

Figure 2. *Typical scenes of reading tasks*

Table 4 Items of subjective evaluation

Item	Purpose
Eye fatigue	Actual questions
Visual performance	
Physical and mental fatigue	Dammy questions
Sleepiness	

Table 5 Media position

	Desk top	Knee top	Holding on
Laying down	L-1	L-2	—
Hand holding	H-1	H-2	H-3

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 (%) =

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

Figure 3 shows averaged values of the increase rate of near point distance. We could find no clear difference among the results of the three media. Table 6 shows statistical significances calculated between the NPD value of every two media in the three medium after the 90 minutes of reading. Level of significance p is far larger than 5 % between every two media; no substantial fatigue difference was proved among the three media.

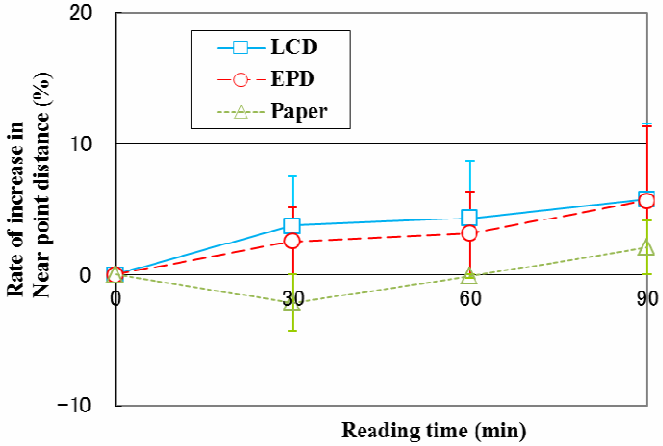


Figure 3. *Rate of increase in near point distance*

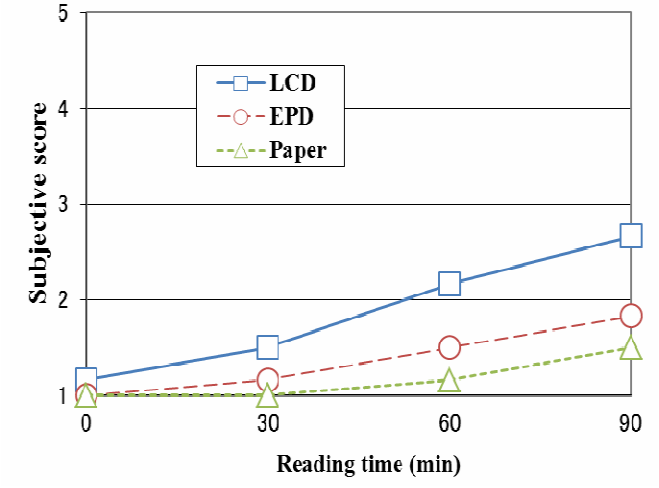
Table 6 Level of significance between the NPD values

Two media for comparison	Level of significance: p
LCD vs. EPD	98%
LCD vs. Paper	64%
EPD vs. Paper	66%

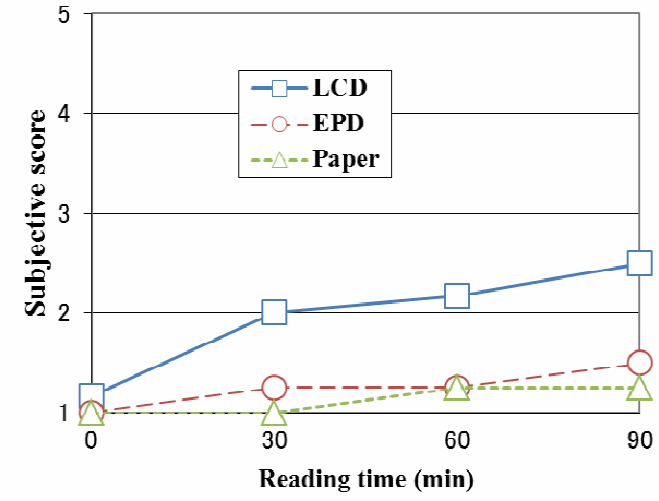
3.2 Subjective evaluation

Magnitude of eye fatigue and degradation of visual performance are indicated Figure 4 as the following order of strength: LCD > EPD > paper.

Table 7 shows the values of the statistical significance between every two media. Level of significance p is smaller than 5 % for the difference between “LCD" and “paper” in eye fatigue; statistical significance was confirmed for eye fatigue between “LCD" and “paper”.



(a) Increase of eye fatigue



(b) Degradation of visual performance

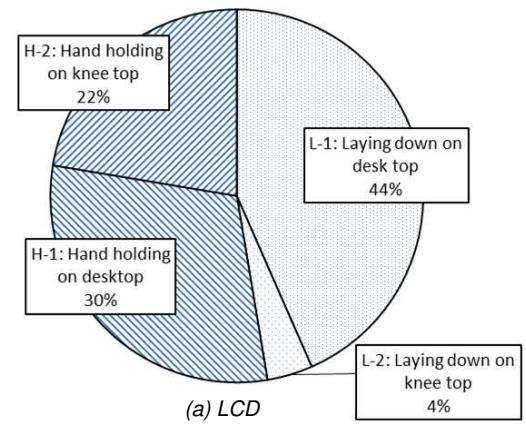
Figure 4. *Subjective evaluation of the three media*

Table 7 Level of significance between the subjective evaluation values of any of two media

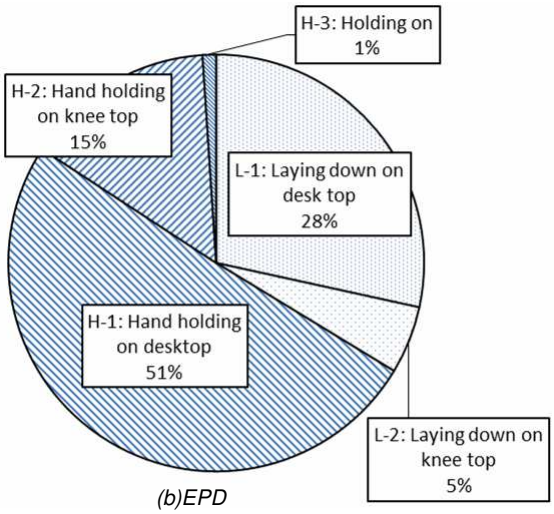
Two media for comparison	Level of significance: p	
	Eye fatigue	Visual performance
LCD vs. EPD	9%	17%
LCD vs. Paper	4%	6%
EPD vs. Paper	48%	44%

3.2 Check of media position

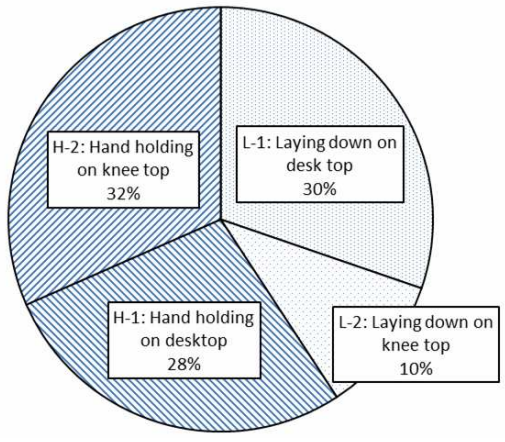
Figure 5 shows averaged rates of each medium position during reading with each media. Major position was “laying down on desktop” in LCD, “hand holding on desktop” in EPD, and “hand holding on the knee” in paper, respectively. It is noted that the rate of “laying down on desktop” is remarkably larger at LCD than the other media.



(a) LCD



(b)EPD



(c) Paper

Figure 5. *Rate of medium position during reading task*

4. Discussion

Clear difference of fatigue between the media was shown not in the objective evaluation using NPD but in the subjective evaluation. It is not curious results because NPD is not always a sensitive metrics.

The reasons why LCD showed the largest eye fatigue has not been clarified yet. Emissive screen of LCD can be a candidate but it has not been certified as a main reason. Observation results of the media position can suggest the reason of largest eye fatigue in LCD. Our previous study have suggested that free condition for media handling offers lower fatigue than the fixed condition, regardless of media.

Observation results, in this study, have shown that the rate of "laying down on desktop" is remarkably larger than the other medium. This means that LCD was relatively fixed on the desk as a result. Thus, relatively fixed LCD could bring the readers the larger fatigue. By the way, LCD is the heaviest medium in the tested three medium in this study. That is considered to be the reason why it is tend to be used in the fixed condition of "laying down on desktop".

5. Conclusion

1) Our experimental results have shown largest fatigue in LC display and the smallest fatigue in paper book. Electrophoretic display was the middle.

2) Fixed medium position of "laying down on desktop" was observed most frequently during reading on LC display in the three medium. We consider that the relatively fixed medium position of the heavy LC display could bring the readers stronger eye fatigue.

References

[1] S. Inoue, M. Omodani, Analysis of Fatigue Difference between Paper and Display-Evaluation of Effects of Medium Handling Styles-, Proc. Imaging Conference Japan 2009, pp. 41-44 (2009) [in Japanese].

[2] M. Sakamoto, J. Imai, M. Omodani: "Verification of Near Point Measurement as a Metrics of Eye Fatigue –An Approach to Getting Objective Scale for Readable Electronic Paper -", Journal of The Imaging Society of Japan, 47, No. 3, pp. 142-146(2008) [in Japanese].

Author Biography

Satoshi Mori was born in 1988. He received his B.E. degree in 2010 from Tokai University. He is expected to receive his M.E. degree from the graduate school of Tokai University in 2013.

He is now engaged in studies of readability as a target of Electronic Paper.