

# Evaluation of Eye Fatigue at an Electronic Paper

## — Verification of near point measurement as a metric of eye fatigue —

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### Abstract

We study near point distance as a metric of eye fatigue in the reading task; the goal is to develop an objective scale for creating readable Electronic Paper. Near point distance can be measured by moving a target mark toward and away from subjects as they try to focus on it (Decrement method and Increment method). The correlation between the increase in the near point distance and subjective answers is evaluated in 120 minute reading tasks by using the two methods of the near point measurements. The measurement procedure based on near point decrement showed superior correlation: it is regarded adequate as a quantitative index of eye fatigue. The Decrement method is used to measure eye fatigue with 270 minute reading tasks on three media: paper, electronic paper (book reader using electrophoretic display), and conventional display (LCD). Only the display evidenced an increase in near point distance. This suggests that the electronic paper used in this study is superior to the conventional display with regards to avoiding fatigue in reading tasks.

### 1. Introduction

No reliable method that can quantitatively measure eye fatigue has been established yet. We consider here the use of near point distance as a metric of eye fatigue with the reading task. Such a metric is essential if we are to develop readable Electronic Paper [1]-[8]. Near point distance is the shortest distance at which a subject can focus on an object. Near point distance generally increases as our eyes become fatigued. The near point distance can be measured moving a target toward the subject (Decrement method) or away from the subject (Increment method), see (Fig. 1). While the Decrement method is used by most ophthalmologists, we seek to clarify which method is superior and should be used for measuring eye fatigue.

We compare the results yielded by the two methods against the fatigue as expressed by subjects after reading text on a liquid crystal display (LCD). Decrement method, the method that most accurately reproduced the subjective assessments, was then used to compare three media (paper, electronic paper -- book reader with electrophoretic display, and an LCD) in terms of reading task performance.

### 2. Evaluation of eye fatigue measurement methods [Experiment 1]

#### 2.1 Method

The correlation between results of subjective assessments and the results of NPD and Increment methods was evaluated. Experimental conditions are listed in Table 1. Subjects were

requested to read a novel for 120 minutes on an LCD. The near point distance of each subject was measured just before and just after the reading task by using the Decrement and Increment methods. Mean values of the near point distances determined from 10 measurements for each procedure were calculated for each subject.

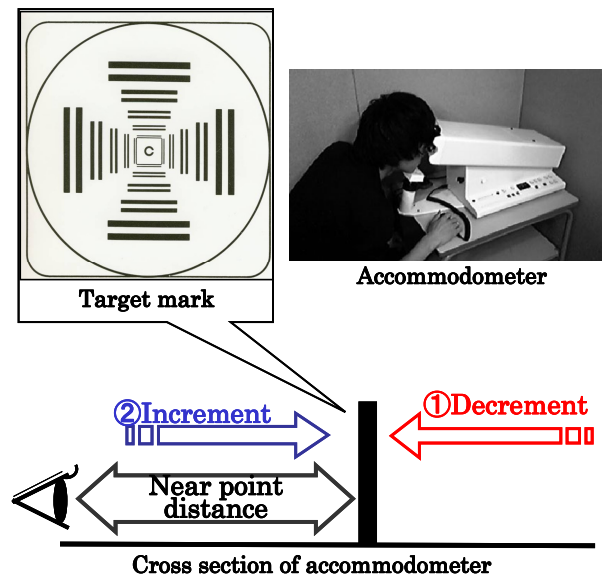


Fig. 1 Two near point measurement methods: Decrement method and Increment method.

Table 1 Experimental condition

Items	Contents
Subjects	10 students (twenties)
Reading time	120 minutes
Display	20.1 inch TFT LCD (Dell Co.)
Place	Sound-proof room
Illumination	650 lx on the desk
Instruments	NP Accommodometer (KOWA Co.)
Measured eye	Dominant eye (corrected vision)
Contents for reading	Japanese novel: Prison hotel Vol. 1 (by Jiro Asada)

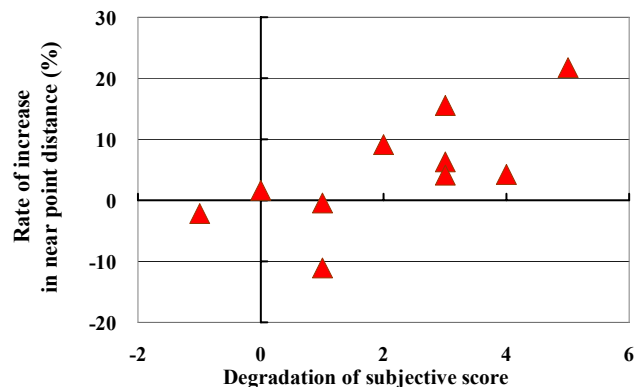
The subjects indicated the level of their eye fatigue by choosing one of five answers for each of five questions (Table 2). Rates of increments were calculated between before and after the reading task both for the near point distances and a mean value of the subjective answers for the five questions. The correlations between the rates were evaluated.

**Table 2 Subjective evaluations of eye fatigue [Experiment 1]**

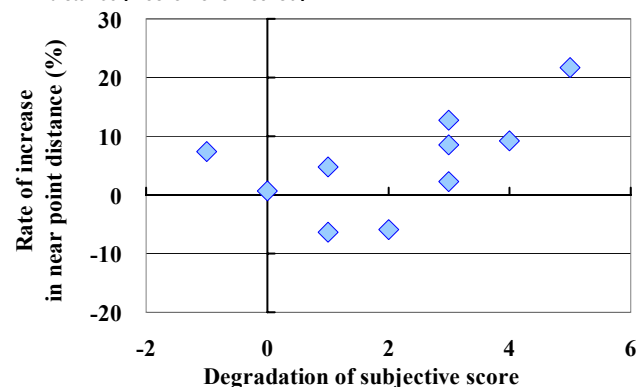
Questions	1) Tired, 2) Painful, 3) Dry, 4) Bleary, 5) Blurred
Criterion	5 : Very strongly felt
	4 : Strongly felt
	3 : Felt
	2 : Weakly felt
	1 : Felt nothing

## 2.2 Results

Figure 2 and Figure 3 plot score correlation. Decrement method and Increment method indicated correlations coefficients of 0.72 and 0.56, respectively. Significance of the calculated correlation coefficients was then evaluated by Piasson's method. Piasson's method indicates a general level of significance (p) for the calculated value of correlation coefficients. Calculated p-values were 0.02 for the Decrement method and 0.09 for the Increment method. The statistical association is generally considered significant when the p-value is < 0.05, so only the Decrement method provides an assessment of reading fatigue.






*Fig. 2 Correlation between subjective score and near point distance [Decrement method].*



*Fig. 3 Correlation between subjective score and near point distance [Increment method].*

**Table 3 Three media**

	Display (Dell Co.)	Electronic LIBRle [EBR-1000EP] (Sony Co.)	paper: Paper
Form	TFT LCD with backlight	Electrophoretic display	Paperback
Size	20.1 inch	6 inch	A6
Simultaneously displayed pages	2 pages	1 page	2 pages
Font	16 point	9 point	9 point
Total page No.	2,122 pages	2,122 pages	1,463 pages
Contrast	10 : 1	9 : 1	7 : 1
Position of medium	Fixed	Free	Free
Typical scene			

### 3. Comparison of eye fatigue by reading tasks on three media [Experiment 2]

#### 3.1 Method

Eye fatigue was evaluated when performing the same reading task on paper, electronic paper, and an LCD. The media are detailed in Table 3. Experimental conditions are listed in Table 4. Subjects were allowed to free handle the paper and electronic paper. The LCD was ordinarily positioned on a desk. Near point distances (mean value of 10 times of measurements) were measured every 30 minutes during the reading task. Every 90 minutes, the subjects were asked to choose one of five subjective evaluations of their fatigue for each of the four questions (Table 5).

**Table 4 Experimental conditions**

Items	Contents
Subjects	6 students (twenties)
Reading time	270 minutes
Rest	10 minutes for every 90 minutes
Place	Sound-proof room
Illumination	600 lx on the desk
Instruments	NP Accommodometer (KOWA Co.)
Measured eye	Dominant eye (corrected vision)
Contents for reading	Japanese novel: Prison hotel Vol. 1 ~ 4 (by Jiro Asada)

**Table 5 Subjective evaluation [Experiment 2]**

Questions	Typical complaints	Criterion
A) Eye ability	Bleary or blurred view	5 : Very strongly felt 4 : Strongly felt 3 : Felt 2 : Weakly felt 1 : Felt nothing
B) Eye fatigue	Dry, itchy, or painful	
C) Physical and mental fatigue	Tired body (except eyes), Mental fatigue	
D) Sleepiness	Sleepy, Faint	

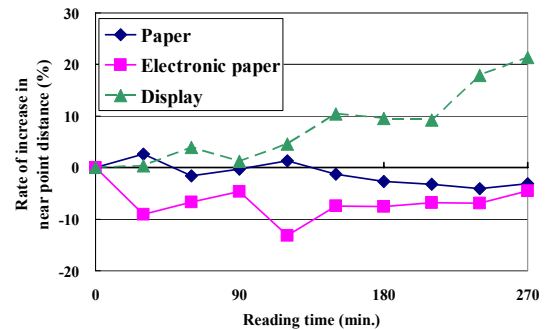
#### 3.2 Results

Figure 4 shows the rate of increase in the near point distance over the 270 minute reading task. A clear increase in near point distance was shown only for the display (LCD), see Fig. 4. Degradation of subjective score were indicated both for ability of eyes and fatigue of eyes commonly for the three media in Fig.5 and Fig.6.

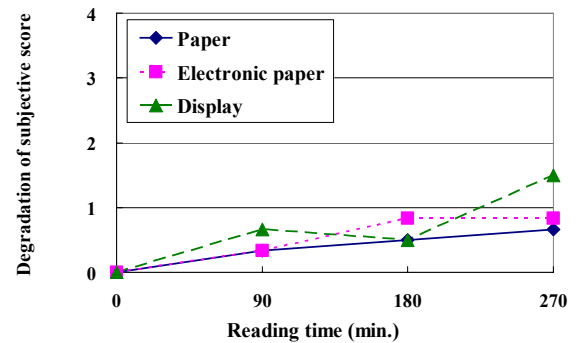
An unexpected result is that paper and electronic paper showed no increase in near point distance although their subjective assessments indicated an increase in fatigue. The reason for this disagreement between the objective and subjective results can be

understood by explanations that eye fatigue does not always yield a near point extension, or near point extension does not occur if eye fatigue is rather slight.

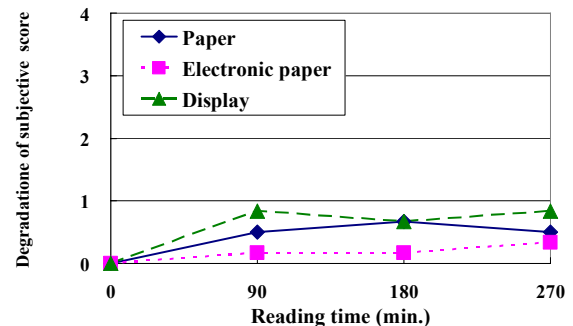
Thus, the near point distance should be regarded as a useful, not a comprehensive, metric for eye fatigue assessment. It should also be noted that electronic paper showed similar performance to paper with regard to eye fatigue. The reason for this may be explained by their common characteristics; both are reflective media that can be freely handled.



*Fig. 4 Rate of increase in near point distance in the three media.*



*Fig. 5 Degradation of subjective score for eye ability.*



*Fig. 6 Degradation of subjective score for eye fatigue.*

## 4. Summary

Validity of the near point distance as a metric of eye fatigue was evaluated in 120 minute reading tasks. Eye fatigue was measured for a 270 minute reading task on three media: paper, electronic paper (book reader using electrophoretic display), and a conventional display (LCD).

- 1) Compared to the Increment method, the Decrement method yielded superior correlation with subjective fatigue assessment (coefficient is 0.72) and so is a reasonable metric for assessing eye fatigue.
- 2) Near point distance is seen as a useful, not a comprehensive, metric for eye fatigue, since it can indicate rather heavy eye fatigue or a part of eye fatigue.
- 3) A noticeable increase in near point distance was shown only by the conventional display (LCD) for a 270 minute reading task.
- 4) These results suggest that the electronic paper used in this study is superior to conventional displays (LCD) with regard to avoiding fatigue in reading tasks.

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