The Effects Of Lightning Conditions On Reading Devices

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1. INTRODUCTION

Unlike the traditional book reading, E-reader is a tablet that makes it easy for the readers; it is light weight, portable and can be stored many books. E-readers may be only able to do one thing-E-book reading, but they do it well. Because of these advantages, some manufacturers still put their best efforts on designing and producing E-readers even though iPad is the dominated player in the tablet game. E-readers are convenient and have been on the market for years. However, there are very limited studies about the readabilities of them. Isono, Takahashi, Takiguchi, and Yamada (2004) conducted an experiment in which 13 college students read with an electronic paper display and with conventional paper for 90 minutes. The results showed no significant differences. Jeng, Lin, Liao, Wen, Chao and Lee (2005) reported that the legibility of text on the electronic displays depends on the ambient illuminance intensity but not on the light source, and that conventional paper had a higher visual comfort rating than electronic paper. Chang, Chou and Shieh (2012) pointed out that there are many factors influence visual performance and visual fatigue when using displays, such as the display medium, light source, ambient illuminance, polarity, and etc. The goal of this analysis is to understand the importance of lightning condition toward the average reading time and how they compare with those when performing the same task on ordinary paper.

Fig.0: from left to right: Amazon Kindle DX, Sony PRS-700 and iRex 1000S
Source: Google

The analysis in our paper is to test the effects of different levels of ambient illuminance (200, 500, 1000 and 1500lx) on participants' average reading time using three electronic devices: Amazon Kindle DX, Sony PRS-100, and iRex 1000S. A comparison test is also made between reading on the electronic devices and paper. Table 1 gives some real world example for each illuminance level.

Table 1: Lux Level

Activity	Illumination
Easy Office Work, Classes	200 lx
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500 lx
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1000 lx
Detailed Drawing Work, Very Detailed Mechanical Works	1500 lx
Source: www.EngineeringToolBox.com	

2. EXPERIMENT

2.1 Experimental Design

Because the E-readers (Amazon Kindle DX, Sony PRS 700 and iRex 1000S) could represent a potential source of variability, we decided to use randomized complete block design. E-ink, arguably the best display technology for eBook reading, is applied to these three E-readers. However, the screen sizes are different, from 6 inch to 10.2 inch. Table 2 shows the specifications of these three devices. Notice, the fixed treatments of the design are four levels of ambient illuminance (200 lx, 500 lx, 1000 lx and 1500 lx). Lastly, the factor we are interested in, the average reading time, is the responsible variable in our experiment. Obviously, there are 12 testing conditions we will consider in our experiment [**3** displays × **4** illuminance].

Table 2: E-Reader

	Device 1	Device 2	Device 3
Model and Manufacturer	Sony PRS 700	Amazon Kindle DX	iRex 1000S
E-Reader Screen Size	6 inch	9.7 inch	10.2 inch
Resolution	800*600	1200*824	1024*1280
Display Panel	E-Ink	E-Ink	E-Ink
Source: Amazon.com			

2.2 Data

The data we use was originally collected for Chang, Chou and Shieh (2012). As mentioned, there are three screen sizes for three E-readers, which might be a huge impact on average reading time. According to their paper, in order to make the experiment more realistic, the full screen size was used to display text for the test. The participants of the original study are sixty college students (30 female and 30 male) between the age of 19 and 26. All participants had zero experience on the E-reader displays and they are not familiar with the reading material. In addition, they have corrected visual acuity and normal color vision. Moreover, the E-readers are designated as Device 1, 2 and 3 for avoiding brand effects.

Finally, the reading times (in seconds) of the participants were recorded. In order to obtain "quality" reading times, each student was given NT$20 for each correctly answered

question regarding to the reading material. The total ten questions that a student needed to answer.

3. ANALYSIS AND RESULTS

3.1 Preliminary Analysis And Results

Table 3 includes some basic statistic of the mean reading time for different groups. Notice for the lightning conditions, there is negative relationship between the illuminance levels and mean reading times. The variances of the reading time are approximate the same under different lightning conditions. Furthermore, the mean reading time on Sony PRS 700 is the longest. Recall that the Sony E-reader has the smallest screen size and lowest resolution. Those might be the reason for the slowest reading time, but further analysis is needed to make the conclusion on this.

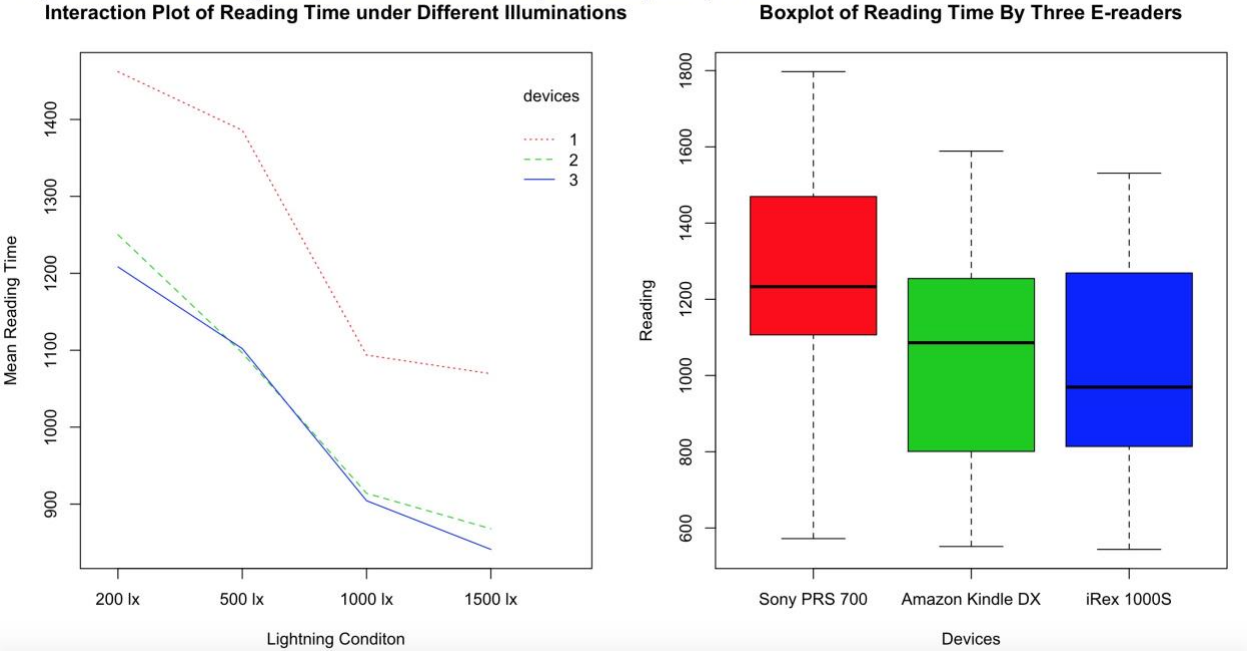
Table 3: Basic Statistic

		Reading Time	
Treatment/Block	Group	Mean	Standard Deviation
Illuminance Level	200 lx	1306.90	276.55
	500 lx	1194.90	276.74
	1000 lx	970.70	279.57
	1500 lx	926.20	285.55
E-readers	Device 1	1252.83	305.62
	Device 2	1032.20	307.44
	Device 3	1014.00	288.58

3.2 Analysis With Plots And Preliminary Results

Fig.1 should give a clearer picture on the comparison of reading time performances under different lightning conditions and by three devices. From the interaction plot of reading time under illumiance level, the lines of E-reader 2 and E-reader 3 cross over each other. Even though the interaction seem not very strong, we should consider the interaction effect between ambient illuminance levels and devices when we process our ANOVA test and fit our model. Furthermore, as the illumiance level increase, the reading time decreases. The boxplot of reading time by three devices verifies that the mean reading time decreases as the display size increases. Because the full screens of these three devices are used to display texts for this experiment, reader might need to turn the “pages” more often on devices with small screen size, such as Sony PRS 700. When readers need to turn the pages more often, the more interruptions they have, then the reading speed will decrease significantly.

Fig.1 Interaction Plot of Reading Time under 4 Illuminations AND Boxplot of Reading Time by 3 Devices



Also, Bartlett's test of homogeneity of variances was applied to test if the variances are the same under different lightning conditions and E-readers. The test results are shown in Table 4. We can conclude the variances are the same for different lightning or different E-readers.

Table 4: Bartlett's Test of Homogeneity Variances

Subject	P-value
Lightning Conditions	0.9993
E-readers	0.9562

3.3 Analysis Of Variances And Results

Next, ANOVA was applied to the data and the results are shown in Table 5. Recall that the interaction between lightning conditions and devices is a potential concern. So the interaction was added to our first analysis of variances. Based on the ANOVA result, the interaction between two independent variables is insignificant. A first order ANOVA was applied and the results are shown in Table 6. We can see the independent variables are still significant at 5% after the interaction term is removed. In other words, the mean reading time is significantly different by three devices (or specifically, the screen size). Also, the different ambient illuminance levels will statistically affect the reader's reading speed.

Table 5: ANOVA with Interaction Term

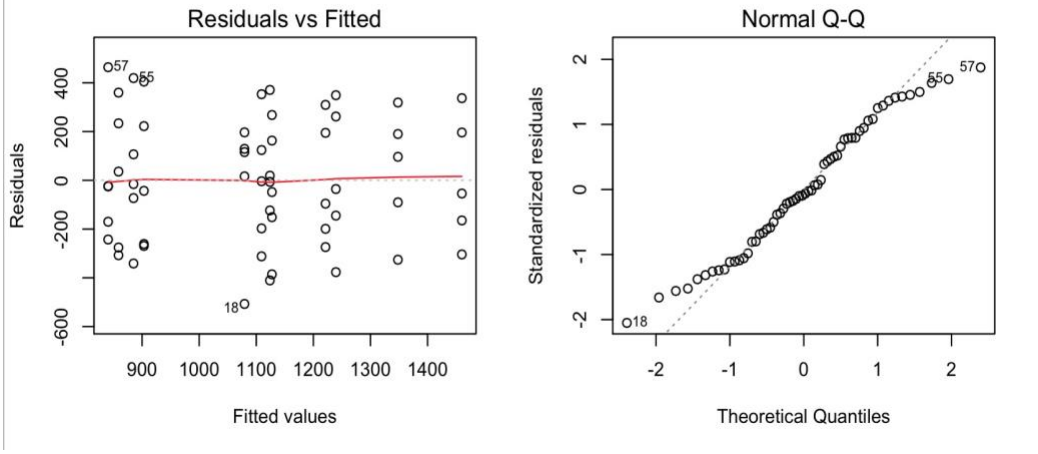
	Df	Sum Square	Mean Square	F-Value	P-Value	
E-readers	2	706968	353484	4.648	0.014279	*
Illumination	3	1481064	493688	6.492	0.000891	*
E-readers*Illumination	6	21543	3591	0.047	0.999525	
Residuals	48	3650203	76046			
Significant at α=0.05						

Table 6: ANOVA without Interaction

	Df	Sum Square	Mean Square	F-Value	P-Value	
E-readers	2	706968	353484	5.199	0.008614	*
Illumination	3	1481064	493688	7.261	0.000353	*
Residuals	54	3671746	67995			
Significant at α=0.05						

Based on the normal Q-Q plot and residuals vs. fitted values plot (Fig.2), the assumption of normality and constant residuals are not violated. Also, our Box-Cox transformation shows $\boldsymbol{\lambda \approx 0.91}$. As the result, we decided not to have any model transformation on the responsible variable, the reading time.

Fig.2: Residuals vs Fitted Values Plot and Normall Q-Q Plot



3.4 LSD And Tukey HSD Tests And Results

We also used the Fisher LSD method to make comparisons among the four levels of illuminations to decide which lightning condition differ in the mean response rate. The result is shown in Table 7 and Table 8. Based on LSD test result, the insignificantly different mean reading time happened between illuminance levels 200 lx and 500 lx, and the levels between 1000 lx and 1500 lx. Tukey HSD test gave similar result, except the mean reading speed is insignificantly different between illuminant levels 500 lx and 1000 lx.

Table 7: LSD Test Result

Comparison	Difference	P-Value	Significant	Lower Bound	Upper Bound
200 lx - 500 lx	111.9987	0.244649739		-78.89743	302.8948
200 lx - 1000 lx	336.1987	0.000856014	*	145.30257	527.0948
200 lx - 1500 lx	380.6987	0.000195203	*	189.80257	571.5948
500 lx - 1000 lx	224.2	0.022205521	*	33.30391	415.0961
500 lx - 1500 lx	268.7	0.006665873	*	77.80391	459.5961
1000 lx–1500 lx	44.5	0.642123111		-146.39609	235.3961
Significant at 5%					

Table 8: Tukey HSD Result

Comparison	Difference	Adjusted P-Value	Significant	Lower Bound	Upper Bound
200 lx - 500 lx	111.9987	0.6442676		-364.4038	140.40644
200 lx - 1000 lx	336.1987	0.0046176	*	-588.6038	-83.79356
200 lx - 1500 lx	380.6987	0.001091	*	-633.1038	-128.29356
500 lx - 1000 lx	224.2	0.0984819		-476.6051	28.2051
500 lx - 1500 lx	268.7	0.0327612	*	-521.1051	-16.2949
1000 lx - 1500 lx	44.5	0.9658741		-296.9051	207.9051
Significant at 5%					

4. CONCLUSION

4.1 Conclusion

The motivation of the study was to see how the reading time, and consequently how the reading speed was affected by different e-readers and the level of illumination of the text. Hence different E-readers and the levels of illumination impact reading speed significantly. Full screen was used for all the devices. So, obviously the smallest device had the maximum number of pages and the device with the biggest screen had the least number of pages. More number of pages would mean more frequent turning of pages and thus disruption in the flow of reading. This was reflected in the highest reading time and hence lowest reading speed for the smallest device A. Therefore, the size of the e reader should considered while designing it, as smaller size and better portability might have the price of poor reading efficiency to pay.

The effect of illumination of the place of reading, also affected the reading time of the reader. The reading speed increased (reading time decreased) as the quality of the illuminance level increased. Illuminance levels of 1000 lx and 1500 lx improved reading speed than did 200 lx or 500 lx. However, this factor affects reading speed more significantly when it comes to reading for longer duration. In conclusion, (1). E-readers with larger screens improve the reading speed. Hence, this factor should be considered while designing the e-reader while giving more

importance to the portability of the device, and (2). Lower ambient illuminance causes slower reading speed and hence worse reading performance.

4.2 Future Studies

The main purpose of this paper is to study how ambient illumiance levels affect the reading speed on E-readers. However, there is one important factor left out—the screen resolution. Generally, text characters are sharper on displays with higher resolutions, and we want to test if shorter reading time comes with sharper text. Unfortunately, we cannot isolate this factor out from the data for this paper because the device with larger screen size is also the one with higher resolution displays. In this case, a new experiment is needed.

In addition, for the past few years, more people are willing to spend a little more to buy real tablets, which come with color screens and more functions/features. So in the future, we may shift our focus point to study the reading time on color displays.

Reference

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