原　著

Effects of Aging and Visual Acuity on the Legible Point Size for a Single Character on an E-paper Display
電子ペーパーディスプレイの単一文字の読み取れるポイントサイズに対する加齢と視力の影響

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Abstract

In recent years, manufacturers have increased the number of electronic book reading terminals with e-ink displays to meet consumer demand. Also called e-papers, these products have achieved high resolution on the display panels. The aim of this research was to collect basic data on the legibility of displayed characters of e-papers because many manufacturers have claimed that their products are close to paper text. We carried out an experiment of the effects of ageing, visual acuity, and cataract cloudiness on the legibility of different size characters on an e-paper device. The participants in the experiment included 133 males and females between the ages of 17 and 79 years. The participants read from a string of random set of capitalized letters whose font size declined from large (18pt) down to small (2pt). We used Times New Roman and Helvetica for the experiment. We asked each participant to read out loud the character string, and we used a systematic evaluation method to calculate for the correct reading each character. The participants were tested 20times for each font size in the trial. If the reader could recognize a letter of a font 16out of 20times (80%), then we defined the specific font size as sufficiently legible. When a reader reached this 80% point, then this was defined as the minimum legible character size for the participant. The results showed that with higher than 50cm visual acuity, the participants could read the smallest sizes for both font types. However, for older people with 50cm visual acuity above 1.0, the results indicate that they have greater difficulty reading the smaller characters compared to younger participants. Our study found that participants could read the smaller font points for Helvetica better than Times New Roman. This research, suggests that in the future we should compare the legible smallest character size among different types of font using character height (mm) instead of point size.

抄録

近年、情報機器メーカーは、消費者の需要に合わせて、e－インクを用いた電子書籍端末の出荷を増加させている。また、電子ペーパーと呼ばれるこれらの製品は、高い解像度のディスプレイパネルを実現した。この研究の目的は、情報機器メーカーが電子ペーパーを紙の上に書かれた文字列に近いと主張しているように、電子ペーパーに表示された文字が、そのように読みやすいのかという点を明らかにするための基礎資料を収集することであった。我々は、電子ペーパー端末の種々の文字サイズの読みやすさに、加齢、視力、および水晶体白濁度がいかに影響するかという実験を実施した。実験の参加者は、133 人の男女で、年齢は 17 歳から 79 歳に分布した。参加者は、大文字で書かれたランダムなアルファベットの文字列で、フォントサイズが大きい方（18pt）から小さい方（2pt）に順に 1pt ずつ小さくなっていく 17 文字の文字列を、大きい文字から順に読んだ。私達は実験のアルファベット文字に、タイムズ・ニュー・ローマンとヘルヴェティカの 2 種類を用いた。このようなサイズが漸減する文字列を、2 種のフォントごとに、20 行ずつ作製した。そして、参加者は、大きいサイズから順に、文字列を読める限界の小さいサイズまで 1 行ごとに読み、2 種のフォントごとにそれぞれ 20 行、読むこととした。こうした手順によって、我々は、文字サイズごとの可読性を算出する体系的な評価方法を確立した。参加者は 1 つのフォントサイズごとに 20 回の試験のうち、80％以上の正解率を得た場合に、そのサイズが可読であると定義した。そして、1 人ずつの参加者について、それぞれが可読であったもののうち最小のサイズを、その参加者の読み取れる最小の文字サイズと定義した。結果は、50cm 視力が高い参加者は、2 種のフォントの両方で、最も小さいサイズを読み取ることができた。しかし、同じ視力 1.0 以上の参加者のみで、比較すると、高齢者は、視力は同じでも、若い参加者よりも文字サイズが大きくないと読めない傾向を示した。我々の研究によって、ヘルヴェティカの方が、タイムズ・ニュー・ローマンよりも小さいサイズの文字を読み取ることができることを、明らかにした。読み取りやすさのフォント間の比較をポイントではなく、文字高（mm）で行うことが今後必要と思われる。

Key words: E-paper, E-book, the smallest legible size, E-Ink, 50cm visual acuity, ageing

キーワード : 電子ペーパー、電子書籍、最小可読文字サイズ、e インク、近見視力、加齢

1. Introduction

In 2013, the amount of money spent on books was $121.5 billion. Business forecasters predict that such spending expected to reach a plateau of 1.1% by 2018[1]. Meanwhile, expenditures for e-books represented about 12% of the book market in the years 2013-14 but should increase to 25% by 2018[1,2].

One of the concerns for readers has been with the reading of characters on small screens with low resolution displays. Since 2007, Amazon's e-paper products such as Kindle Paperwhite have grown in popularity. One of the reasons for this growing appeal has been due to the improvement in the device's resolution, going from 167 ppi to 300 ppi, and at a lower price. While e-paper devices have become increasingly popular, they include numerous font types with multiple sizes that need testing for legibility. Therefore, we conducted an experiment to compare and evaluate the smallest point sizes that could be read from two main types: Helvetica and Times New Roman.

2. Methods

2.1 Participants

This study included the participation of 133 people aged 17 to 79 years old. All participants signed a consent form and approval for experiment was received from the Ethical Review Board of the Graduate School of Information Science at Nagoya University.

Individuals who needed to wear corrective lens during the procedure were allowed to do so in order to complete the tests. All participants, regardless of whether or not they needed corrective lenses, were measured for binocular near visual acuity for 50cm[3]. The near visual acuity was expressed in the following way: 0.1, 0.3, 0.5, 0.7, 1.0, or 1.2. We calculated the visual function of a single eye with cataract cloudiness (CC) in the lens[3-6] with the use of an anterior ocular segment measuring instrument called the EAS-1000TM (NIDEK Inc.). There were 256 levels of cataract cloudiness (0= no cloudiness and 255=the maximum)[6]. We defined an individual's level

of cloudiness based on the lens clarity in the best eye; for example, if a person had a level 100 in the left eye and 150 in the right eye, then we considered them as having a 100 for cloudiness.

2.2 Devices and Experimental Environment

For this experiment, we used the Amazon Paperwhite which has a screen size of 6 inches and a resolution of 300 ppi[7]. We set the illuminance level at 750 *lx* as recommended by the International Organization for Standardization (ISO)[8] and the Japan Industrial Standards (JIS) which recommends higher than 500 *lx* for reading books[9].

2.3 Procedures

Figure 1 below represents a photo of the experimental room. Figure 2 below presents an example of the Paperwhite displaying English characters. Figure 3 below shows how the task was performed.

Figure 1. Photo of the experiment

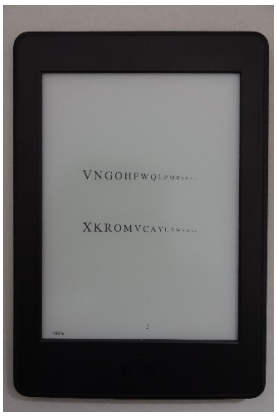

Figure 2. Photo of e-paper device

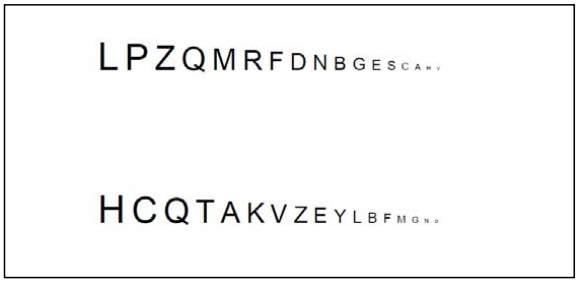

Figure 3. Example of the reading task

The participants were asked to read a string of English alphabetic letters out loud. There were 20 lines and each line contained a random selection of seventeen English letters in upper case for both font types. Seventeen letters were displayed left to right, from 18 pt to 2 pt. While there are 26 letters in the English alphabet, we excluded the letters "I" and "J" in order to avoid any confusion for the participants. We used Helvetica, which is a sans serif font type (fig 4-a), and Times New Roman as the serif type (fig 4-b).

ABCDEFGHKLMN
OPQRSTUVWXYZ

(a) Helvetica

ABCDEFGHKLMN
OPQRSTUVWXYZ

(b) Times New Roman

Figure 4. Examples of both font types

The participants sat down in a chair and held the reading device at a set distance. The visual distance from the eye to the device was limited to 50cm. The participants were asked to read aloud the test letters that were displayed on the screen. Reading from left to right, the participant would start at 18pt and read down to 2pt. Meanwhile, the tester recorded the answers whether correct or error depending on what was read.

For each font, the participants had to read twenty lines; therefore, they read a total of 40lines for both font types. In order to exclude for the effect of ordering, each reader started with a different font type, and the letters were randomly selected. As long as the participant could read a font at 80% then it was considered legible. The definition of smallest legibility is the specific point size where a person can read a font size correctly at 80％ [10]. For example, if participant A could read 16 of 20 letters at the 4point character size (80%) but 15 of 20 at the 3pt size (75%), then the smallest point of legibility would have been at the 4point size.

3 Results

Figures 5 and 6 shows the correlation between 50 cm visual acuity and the smallest legible font size for the Helvetica and Times New Roman. As illustrated in the figures, the results found that the smallest point of legibility for the Helvetica font was an average of 3.75 pt + 0.95 (height 0.94 mm) and for Times New Roman 4.27 pt + 1.08 (height 0.99 mm). This means that most of the readers with 50 cm visual acuity could not read the font size for Helvetica on average below 3.75 pt and for Times New Roman below 4.27 pt.

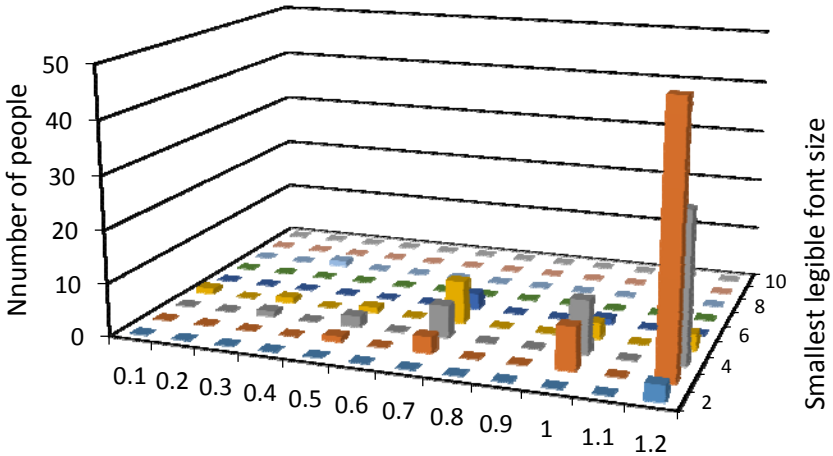

Figure 5. Correlation between 50cm visual acuity and font size for Helvetica

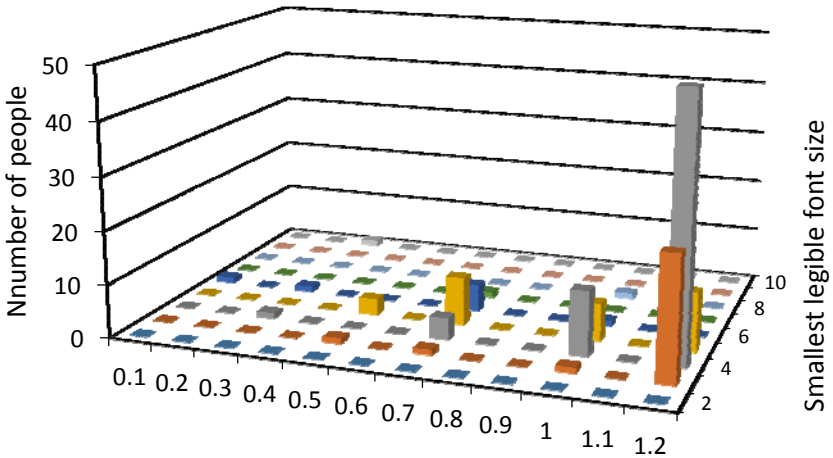

Figure 6. Correlation between 50cm visual acuity and font size at the Times New Roman

Table1 provides a nonparametric correlation coefficient and comparison between the independent variables (age, 50cm visual acuity, cataract cloudiness) and the smallest legible font size. As shown, the smallest legible font size had a positive correlation with age and cataract cloudiness (p<0.01) and a negative correlation with 50cm visual acuity (p<0.01).

Table 1. Coefficient between smallest legible font size and independent variables

		The smallest legible font size above the correct response rate of 80%	
		Helvetica	Times New Roman
Age (years)	Correlation Coefficient	0.438**	0.395**
	Significance (bilateral)	0.000	0.000
	No. of Participants	133	133
Less Cataract Cloudiness	Correlation Coefficient	0.383**	0.359**
	Significance (bilateral)	0.000	0.000
	No. of Participants	133	133
Visual acuity (Binocular)	Correlation Coefficient	-0.500**	-0.527**
	Significance (bilateral)	0.000	0.000
	No. of Participants	133	133

**: p<0.01

After making these comparisons, we decided to look at the 105 participants who had good to excellent visual acuity (above 1.0). Table2 below provides the results from this analysis. The smallest legible characters were 3.48pt+0.70(character height:0.88 mm) for Helvetica, and 4.00pt+0.77(0.93mm) for Times New Roman.

Table2 provides a nonparametric correlation coefficient and comparison between the independent variables (age, 50cm visual acuity, cataract cloudiness) and the smallest legible font size. As shown, for Helvetica, the smallest legible font size had a positive correlation with age and cataract cloudiness (p<0.05) and a negative correlation with 50cm visual acuity (p<0.01). For Times New Roman, there was a negative correlation with 50cm visual acuity (p<0.01).

Table 2. Coefficient of font sizes and independent variables for those with 50 cm visual acuity above 1.0

		The smallest legible font size above the correct response rate of 80%	
		Helvetica	Times New Roman
Age (years)	Correlation Coefficient	0.238*	0.189
	Significance (bilateral)	0.014	0.053
	Participants	105	105
Less Cataract Cloudiness	Correlation Coefficient	0.216*	0.166
	Significance (bilateral)	0.027	0.091
	Participants	105	105
Visual acuity (Binocular)	Correlation Coefficient	-0.255**	-0.328**
	Significance (bilateral)	0.009	0.001
	Participants	105	105

*: p<0.05, **: p<0.01

4 Discussion

In this experiment, we had a large sampling of participants. Most of them have been in engaged in our human experiments for more than 10 years and are very skilled individuals in working with near vision experiments. Most of these individuals have appropriate glasses for 50 cm visual distance. In this experiment, the smallest point of legibility for the Helvetica font was an average of 3.75 pt + 0.95 (height 0.94 mm) and for Times New Roman 4.27 pt + 1.08 (height 0.99 mm). For these readers, the smallest font sizes were surprisingly legible. When compared to the available literature, the participants in this study were able to read font sizes half the size of most other studies. Therefore, we cannot recommend a minimum standard font size based on this experiment.

In general, visual acuity carries a lot of weight in the legibility of characters. In order to avoid the effects of low visual acuity, we analyzed those participants who had visual acuity of more than 1.0 with 50 cm binocular vision. In this group, the legibility for Helvetica also decreased according to age while Time New Roman had a lower correlation with age.

Previous studies have reported that elderly people had lower legibility with e-papers[10-14]. In this study, we defined the font size by point instead of character height. However, the character height of the Times New Roman is 92% of the size of a Helvetica single character. Therefore, a precise comparison of the different characters in the number of points between these two font types is difficult. In actuality, it would be better to compare these fonts according to height.

5 Conclusion

The results from this experiment revealed that the legibility of e-paper displays is influenced by age, cataract cloudiness, and 50 cm visual acuity. Recently, e-paper displays were developed with a front light system in order to assist in reading in darker environments. In addition, the increase contrast ratios and brightness have been especially helpful to the elderly. While E-ink displays are designed to be similar to conventional paper, they have the added advantage of allowing the reader magnify the size of characters manually. As a result, these devices are becoming more popular for the elderly.

The results of this study suggests that the font type might change the legibility of e-paper devices. However, in order to compare the various font types, a more accurate approach to looking at fonts is necessary. Further study is needed to investigate the effects of font type and character height on legibility.

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