The Effect of Screen Size of Mobile Devices on Reading Efficiency

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Abstract. Past research has shown that academia has no consensus on the advantages and disadvantages between paper-based reading and digital reading, which is why this research is an investigation of the differences between the two mediums for reading, whether it affects the performance of reading, and how do the different sizes of digital reading devices compare to the traditional paper. This researcher utilized questionnaires and behavioral observation as methods of investigation. The use of questionnaires was mainly to understand the operational habits of digital device users and the kinds of writing they read, and the behavior observation entailed asking 40 subjects to read on a given device or paper medium for an experiment on reading comprehension to gather data on user reading speed, comprehension, fatigue and other parameters. The results from this study will be used as a basis to formulate a more comprehensive research framework for a future study that more accurately measures the difference between digital devices of various sizes and paper medium.

Keywords: Digital reading · Reading efficacy · Screen-size

1 Introduction

Ever since Apple Inc. introduced the first iPhone in 2007, the sizes of smart phones and tablet PCs, particularly concerning the screen, have been diverging in order to meet consumer needs. Smart phones have had gradual size increase through periodic updates (Yang 2014) and the most popular of phones have gone from 3.5 in. (screen size) devices in 2010 to 4.3 in. devices in 2011, to the iPhone 6 Plus launched by Apple in September 2014 which has reached a size of 5.5 in. For tablet devices, however, it has developed from early 9.7 in. devices and both shrunken to 7–8 in. and enlarged to 10 in. or even 12 in. for more recent devices. The divergence of device sizes satisfies the demands of users with different needs, and has also given life to novel device usage habits. It used to be that bus stops and mass-transit stations would be filled with people waiting for transport who are reading books and magazines and newspapers. Today, the same places can be seen filled with heads looking down at phones and tablets. This ubiquity of personal handheld devices has affected the reading habits of people, and has transitioned

J. Zhou and G. Salvendy (Eds.): ITAP 2016, Part I, LNCS 9754, pp. 435–445, 2016.
DOI: 10.1007/978-3-319-39943-0_42

the habit of reading for many from one that used to be paper-based to one that is practiced with electronic material on handheld devices. Does this new reading behavior improve reading performance? Does this result in a difference in reading comprehension? How else does this new reading habit differ from reading on traditional paper mediums? These are the key points which this research tried to investigate.

This research hoped to reveal the difference in the ability to gather information between different sizes of digital devices and paper-based medium and primarily involved the following goals:

1. To investigate the difference in reading performance between different device screen-sizes.
2. To compare the ability of readers in how they extract information from different device screen-sizes and paper medium.
3. To investigate the fatigue levels of reading on devices of different screen-sizes and paper medium.

2 Literatures

2.1 The Change in the Size of Digital Devices

The Change in Smart Phone Screen Size. The size of the smart phone has grown gradually from the earliest 3.5 in. iPhone introduced in 2007 as various device makers made bigger and bigger products. In 2011, Samsung introduced the Galaxy note that pushed the boundaries of smart phone sizes to 5.3 in., the first device of its enlarged size. 2012 was the year when competition in the smart phone market was at its height. Various makers came out with plus-size products that sparked a 'battle of the phones'. The poster-child device for plus-size phones in this time was the Samsung Galaxy Note 2; it raised the benchmark of screen-size to an incredible 5.5 in. and a couple of years later devices between 5 to 5.5 in. was the market mainstream (Appier 2014a, b). Asian regions when compared to other regions significantly preferred plus-size devices; In China, 39 % of all devices sold were over 5 in., and in the entire Asia-Pacific region the figure reached 43 %. The trend of phones over 5 in. being mainstream by the end of 2014 (Appier 2014a, b) meant that even Apple Inc. who strongly resisted plus-size phones eventually introduced 6 in. devices in order to meet consumer demand.

The Change in Tablet Computer Screen Size. The tablet computer started thriving in 2010 when Apple introduced the 9.7 in. iPad. Due to the convenience and portability of its size – over laptops – it quickly became a highly sought-after product, and other makers responded with similar tablets of their own. When the size of these larger-than-phone devices were deemed by their users to be still too heavy to carry or to read with, iPad introduced the 7.9 in. iPad mini in 2012, and Amazon introduced the Kindle Fire small tablet. According to a survey done by advertising firm Appier of cross-device usage habits of Asian users in the first half of 2014, consumers are preferring tablets under 8 in. and smart phones over 4.7 in., and in their survey of the second half of 2014,

they discovered that users of 9.7 in. large tablets have significantly dropped, with most users preferring small tablets between 7 and 8.9 in. (Appier 2014a, b)

Research Related to Screen Size and Effect on Reading. Lin et al. (2013) found that reading 12 pt font on devices between 6 in. and 9.7 in. took the shortest amount of time, and that reading 12 pt and 14 py font on 8.1 in. and 9.7 in. produced higher reading accuracy. Wang et al. (2012) on the other hand conducted experiments on three different sizes of reading devices in their investigation of the performance of reading Chinese articles from the devices and found that screen size does not affect reading performance, and that users preferred devices less than 7 in. in screen size and also devices that are 10.1 in. size.

2.2 The Advantages of Both Types of Mediums

The Advantages of Digital Reading.

Interactivity. Digital reading inherently contains the interactivity that paper based reading lacks. Content designers are able to incorporate pictures, sound, color, and animation to present ideas that are more complex, and this can also generate a sense of involvement for the user (Shneiderman and Plaisant 2010). In addition, for readers with special needs, such as those who are visually impaired, the content on the screen can be enlarged for easier reading, or a device could even convert the text into sound and read the text out loud (Blenkhorn et al. 2003).

Readability. Siegenthaler et al. (2011) compared the eye movement of reading on paper and on digital reading devices to study their difference. The experiment involved reading the same article on paper and 5 different devices while the eye movement of the readers were recorded. It revealed that there was no significant difference in the reading habit itself, and that reading on paper was very similar to reading on a digital device. This was due to the fact that digital readers had available the function to adjust font size and letter spacing, and allowed the reader to make further adjustments according to preference, while the same adjustments weren't possible on paper-based materials. Results also revealed that the fixation time on paper-based medium was longer than that on a digital reading device, which indicates that while readability of paper-based medium is lower than that of digital devices, their reading speeds were not significantly different.

The Advantage of Reading on Paper-Based Medium.

Reading on Paper Produces a Better State of Mind. A portion of scholars believe reading on paper to be better. Norwegian researchers (Mangen et al. 2012) gave Norwegian students an article to read on paper and digital medium then gave them a reading comprehension test on the computer. Results showed that digital reading produced poorer comprehension than paper, and the length of the article was an important factor of comprehension. The human mind is more adept at remembering images than it is at remembering text, and we tend to assist the memory storage of text by their visual position on a page or a book and try to recall the content based on that position. However,

since digital content can scroll up and down the screen or be presented on a page to page basis, the user is unable to use the same fixed position trick or the feel of the thickness of the book at a certain page number to aid in this process, and this interruption can make comprehension poorer.

More Suited for Reading Longer Text. In the regard of the length of a piece of text, a research by Macedo-Rouet et al. (2009) in which 122 college students were asked to answer 18 mathematical questions revealed that printed class notes and test-papers were more efficient to read on than computer screens. The study also suggested that reading a piece of text that is excessively long on screen should be avoided, as longer text requires a higher cognitive load, which lowers reading efficacy. This research suggests that it is possible to read longer text on paper than on a screen.

The research into the trend of device sizes for this study revealed that smart phones are increasing in size while tablets are both increasing and decreasing in size. Do the varieties of screen sizes affect reading efficiency and comprehension? What reading habits are exhibited by users of different device sizes? Does the preference of a certain font size make a difference? And what are the differences in reading performance and comprehension between the various device sizes and paper-based medium? As mentioned above are questions that this research delved into.

3 Method

This research is intended as a preliminary study before a formal study is conducted. A smaller scale experiment was used to examine the experiment process and observe data trends in order to make adjustments and later construct an experiment that can highlight the relevant effects. This study planned on using three sizes of devices and a book of a widely available size for comparison for a total of 4 groups. Each subject was asked to read a length and layout controlled passage while their operation and browsing process were observed and recorded. Then, they were asked to fill out tests and questionnaires once the reading was completed. The primary observations and recordings will be made of the following:

1. Reading behavior: posture when operating, font size of choice
2. Reading comprehension and efficacy: total reading time, reading comprehension test score
3. Reading fatigue: Based on the subjective visual fatigue questionnaire designed by Heuer et al. (1989)

3.1 Digital Devices for Experiment

To minimize the deviation that can be caused by software or hardware differences, this research used smart phones and tablets all made by the same maker. These mobile devices are a Samsung Galaxy Note Pro 12.2 (12 in.), a Samsung Galaxy Tab A (9.7 in.), and a Samsung Galaxy Note 3 (5.5 in.) for the coverage of devices that are commonly used today (as Table 1).

Table 1. Handheld devices used in this study

Model	Samsung Galaxy Note Pro 12.2	Samsung Galaxy Tab A	Samsung Galaxy Note 3
Device size	295.6 mm × 204 mm × 7.95 mm	242.5 mm × 166.8 mm × 7.5 mm	153.5 mm × 78.6 mm × 8.5 mm
Screen size	12.2 in.	9.7 in.	5.5 in.
Weight	750 g	487 g	176 g

3.2 Choice of Software and Reading Content for Experiment

This research had selected Google Play Books App (as Fig. 1) as the reading software. This is a pre-installed software on all Android devices by Google Inc. that allows the user to access over 4 million eBooks. It is able to process PDF and EPUB file formats, and provides free trial-read and purchasing functions. The research was conducted using the EPUB format, its advantage being that it allows adjustment of font sizes for easier reading. Google Play Books also gives the user the following controls of EPUB files: a choice of three types of display (white text on black background, black text on white background, and black text on yellow background), screen brightness, font, font size, line spacing, etc. For this experiment, the subject was allowed to adjust the font size only and no other adjustments including the line spacing was allowed.

Fig. 1. Adjustments available on Google Play Books

To better suit general interest, This chosen passage to read was a passage from the book, '*Big Data'*, written by Viktor Mayer-Schönberger and Kenneth Cukier (Mayer-Schönberger and Cukier 2014), and for simplicity the passage in the digital as well as the paper version of the book were identical, including the reading from left to right layout. The passage is from early in the chapter 'Now-Letting the data speak' on pages 10 to 13, totally 1540 words.

3.3 Experimental Variables

The independent and dependent variables in the experimental design are as explained below:

Independent Variables. The type and size of the content carriers: three sizes of mobile devices: Samsung Galaxy Note Pro (12.2 in.), Samsung Galaxy Tab A (9.7 in.), Samsung Galaxy Note 3 (5.5 in.), and a book within normally acceptable dimensions (A5, 148 × 210 mm) are the four comparison groups.

Dependent Variables.

1. Reading comprehension variables: Total read time, comprehension test score.
2. Reading fatigue levels are 6 criteria's, in question form, from Heur's questionnaire: "I am having difficulty seeing", "A strange feeling is surrounding my eye", "I feel my eyes are tired", "I feel numb", "I am having a headache", "I feel dizzy when I stare at the screen" which are answered on a 10-point scale (Heuer et al. 1989).
3. Font size: This research let the subjects select a font size of their choice before they commence reading. In addition to making setting adjustments on the device, a font size chart is overlaid on the screen and books in order to obtained a standardized font size figure. Google play Books displays font size as a percentage, which was then converted to a 'pt' measurement using a standard conversion chart.

3.4 Subjects and the Experiment Procedure

This research was intended as a preliminary study before a formal experiment is conducted in order to verify preliminary experiment design and reveal a data trend. Ever group was assigned 10 subject for a total of 40 subjects for the experiment. Each subject was a college student with experience of at least one year with a mobile device. The experiment was conducted with one group given the book and 3 groups each given a different size device for a total of 4 groups. All subjects were required to participate in each step of the test, and in order to prevent memory from interfering with results, each subject conducted the experiment only once. The experiment proceeded in a quiet, well lit, and uninterrupted laboratory.

The experiment procedure was as follows:

1. The subject was asked to be seated, and given a briefing of the research objective.
2. The subject was then provided with a tablet while given explanation and precautions of the task, and then instructed on the functions of Google Play Book, including user interface functions and EPUB format inherent functions. Subjects were then allowed to make adjustments to the font size suitable to them, and the font size setting was then announced to the researcher for recording.
3. Researcher then asked the subject to turn or move or scroll to the cover page on their device or book, ready to begin the test.
4. Timer begins when the subject had turned to the appropriate page containing the passage to begin reading. The researcher observed and recorded reading behavior

and method of handling the device of the subject while the subjects were reading, and the timer stops when the subject has finished reading.

5. When reading was done, the researchers gave 5 questions relevant to the passage content for the subject to answer. The questions were 4-choice multiple choice questions. Once that was done, the subject was asked to fill out a Heuer's subjective visual fatigue questionnaire and basic personal information.

4 Results

4.1 Reading Speed

The average reading time for the 3 different device groups and paper are displayed on Fig. 2. As can be seen, the book took the longest to read through, at around 4 min, and the 9.7 in. tablet took the shortest, at less than 3 min. The 12.2 in. and 5.5 in. devices were about the same at just over 3 min.

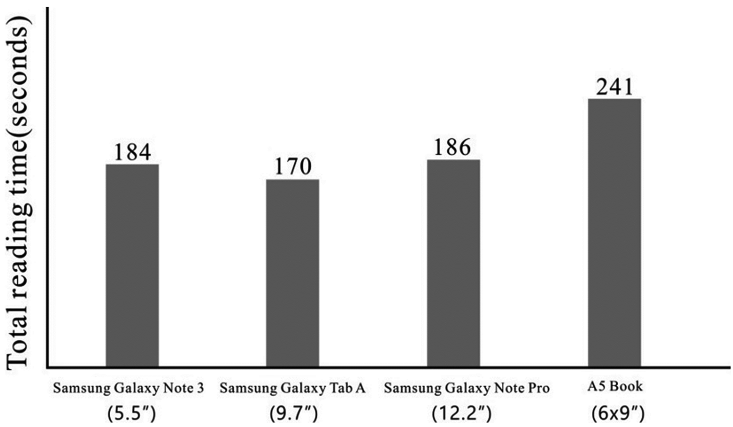

Fig. 2. Average read time on the different devices and paper

One-way ANOVE is then applied to compare each variable, the F-value of the variables and their significance are as Table 2.

Table 2. Experimental results through One-way ANOVA

Comparisons	F Value	P
Screen size and read time	0.130	.879
Content carrier type and read time	5.649	.023[a]
Content carrier type and comprehension score	5.523	.024[a]
Screen size and comprehension score	.233	.794

[a]$P < 0.05$ significant.

As seen in Table 2, screen size and read time showed no significance($F = 0.130$, $p = 0.879 > 0.05$), indicating that the size of the screen did not affect read time significantly. But if the digital devices were combined into one group in comparison with the paper group, statics show a significant difference ($F = 5.649$, $p = 0.023 > 0.05$). It can therefore be postulated that reading on paper takes longer than reading on screens, as the reading time on a screen is between 170 and 186 s while on paper it is 241 s.

4.2 Font Size Selection

In regards to screen size and the selection of the font size, Chart 5 shows that most users in the 5.5 in. smart phone group selected 11 pt to conduct their reading, and 9.7 in. tablet users mostly had 14 pt as their font size of choice. The 12.2 in. tablet users were less grouped, with some opting for large 19 pt font which allowed them to read every word with ease, while there were ones who preferred 9 pt font that allowed them to fit the entire passage on one page (see Fig. 3).

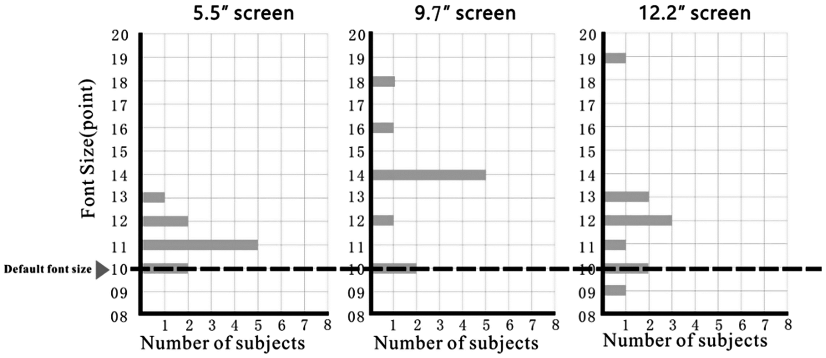

Fig. 3. Font size selection numbers in relation to screen size

4.3 Reading Comprehension

As Table 3 indicates, in regards to whether the two types of content carrier, digital screen and paper, had a substantial effect on reading comprehension, results showed a significant difference ($F = 5.523$, $p = 0.024 < 0.05$), which confirms a difference between comprehension reading on the two mediums. The average comprehension rate of reading on paper was higher, at a score of 4.6 out of 5, and according to the definition of comprehension as described, is a fairly high level. Meanwhile, the digital devices scored an average of 3.6 out of 5, signifying the higher level of comprehension of reading on paper. Chart 3 indicates that the size of the screen itself does have a significant relations to comprehension levels ($F = 0.233$, $p = 0.794 > 0.05$), it can therefore be said that regardless of screen size, those who read on digital devices had about the same level of comprehension.

4.4 Visual Fatigue Questionnaire

This research uses Heuer's visual fatigue questionnaire to obtain the figures in Fig. 4, in which can be seen that out of the 6 assessment questions, paper scored the lowest for everyone, signifying that reading on paper causes the least amount of fatigue. Of the three mobile device sizes, the 9.7 in. tablet scored the lowest, meaning that 9.7 in. tablets is the most suitable size of the three device sizes for reading due to the least amount of fatigue that it generates.

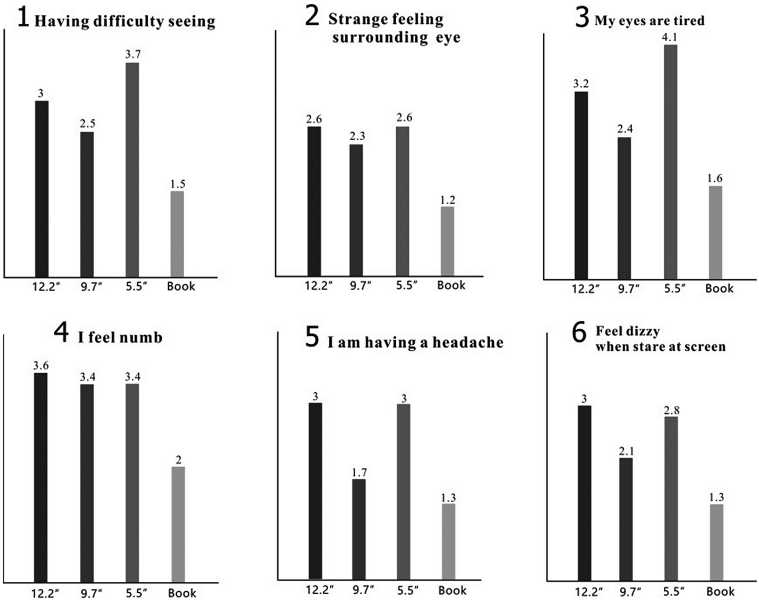

Fig. 4. Average scores from the visual fatigue questionnaire for the different device sizes and paper.

5 Discussion

5.1 Reading Efficiency and Comprehension of the Content Carriers

According to the preliminary experiment in this study, in terms of reading speed, reading on a mobile device happens faster than on paper regardless of the size of the device. The figures from this experiment showed reading on screen to be up to 33.33 % faster than reading on paper, but we cannot conclude that reading on screen is better performance wise than reading on paper because, in terms of comprehension, reading on paper is superior to reading on screen, with an average difference of 27.78 % in favor of paper. Our researchers have therefore inferred that, when reading on screen and using a mobile device, because of the properties of the digital screen, behaviors such as speed-reading or skim-reading can occur, speeding up the reading process but at the same time lowering comprehension of what was read. This portion of the results concurs with past research

which showed similar results, which is that reading on screen will generate a poorer comprehension of the content than reading on paper, and therefore digital screens are less suited for reading long passages.

5.2 Font Selection on the Content Carriers

Examining the relationship between screen size and font size revealed that the size of the screen can affect the font size that the user selects. The size of font chosen on the comparatively small 5.5 in. devices were not made much larger for easier reading but instead have concentrated at around 11 pt (approx. 16 words per line), which is only slightly larger than the standard 10 pt font. On 9.7 in. tablets, the majority of subject selected 14 pt or above (approx. 25 words per line). On the 12.2 in. devices, due to the size of the screen, although it was possible to select even bigger fonts, most subjects selected 12–13 pt font (approx. 28 and 32 words per line). Taken together, although users of bigger devices could potentially select larger fonts, an upper-limit seems to be present and tends to be close to a size that is commonly used for reading of any type. Since the nature of this study is preliminary and the sample size is small, the trend in terms of font size will require an increased sample in order to be more accurately ascertained.

5.3 Visual Fatigue of the Content Carriers

From the questionnaires the subjects were asked to complete, a fatigue score of over 8 was rare, which may have been due to the length of the content used for the experiment. The passage was 1540 words and took about 3 to 5 min to finish reading, which was not enough to induce strong fatigue. The data still showed that reading on paper was superior to reading on a screen under every question, which may be due to the nature of paper displaying content through reflected light; when the eye receives reflected light over an extended period of reading, visual fatigue is not easily generated. The screen on digital devices today, however, emits light from its light emitting diodes (LED) behind the liquid crystal panel, which produces more flare and can cause higher visual fatigue over an extended period of reading. Furthermore, of the three device sizes, 9.7 in. devices produced less fatigue across the board compared to the other two device types. Our researchers postulated that the 9.7 in. device is closest to conventional book sizes of the three device types, which means that the experience perceived by the user in terms of searching on page, perceived font size, paragraph layout, the behavior of glancing, etc. most closely approximate the experience of reading on book, and therefore generates the least fatigue. We can infer that screens that most closely simulate conventional book sizes can avert a greater amount of fatigue.

6 Conclusions

The preliminary experiments performed in this study shows that screen size does not affect reading performance, but readers obtain a higher level of comprehension reading on paper compared to reading on screen, and therefore the paper is still the more optimal

medium of conveying information. Iin terms of fatigue from reading, the book is still a more comfortable form of content carrier, although out of the three device sizes used in this experiment, the 9.7 in. tablet produced less visual fatigue compared to the other two device sizes, and so 9.7 in. is the optimal screen size for a device when reading a extended piece of text, and any increase in screen size would not be able to increase reading performance or reduce fatigue.

Furthermore, under conditions where letters are plainly readable, people will tend to make adjustments to the font size according to the size of the screen, primarily due to the need to closely approximate traditional paper-based reading in terms of the ratio of font size and word count to the page, whereby users with smaller screens will shrink the font, and those with larger screen will enlarge it accordingly in order to maintain an acceptable layout in terms of number of words per line that is found in books and paper articles.

This research was intended as a preliminary run prior to formal testing, and so the sample size was set to 40. In order to bolster the credibility and persuasiveness of this line of study, a sample size of at least 120 is planned for the formal experiment, allowing the related data to be more definite as well as more objective.

References

Appier: Appier Research Report: Cross-Screen User Behavior Insights, Asia 1H 2014 (2014a)

Appier: Appier Research Report: Cross-Screen User Behavior Insights, Asia 2H 2014 (2014b)

Mayer-Schönberger, V., Cukier, K.: Big Data: A Revolution That Will Transform How We Live, Work, and Think. Eamon Dolan/Mariner Books; Reprint edition, 4 March 2014 (2014). ISBN-10:0544227751, ISBN-13:978-0544227750

Blenkhorn, P., Evans, G., King, A., Kurniawan, S.H., Sutcliffe, A.: Screen magnifiers: evolution and evaluation. IEEE Comput. Graph. Appl. **23**(5), 54–61 (2003)

Lin, H., Wu, F.G., Cheng, Y.Y.: Legibility and visual fatigue affected by text direction, screen size and character size on color LCD e-reader. Displays **34**, 49–58 (2013)

Heuer, H., Hollendiek, G., Kröger, H., Römer, T.: Die Ruhelage der Augen und ihr Einfluß auf Beobachtungsabatand und visuelle Ermüdung bei Bildschirmarbeit. Zeitschrift für experimentelle und angewandte psychologie **36**, 538–566 (1989)

Mangen, A., Walgermo, B.R., Brønnick, K.: Reading linear texts on paper versus computer screen: effect on reading comprehension. Int. J. Educ. Res. **2013**(58), 61–68 (2012)

Macedo-Rouet, M., Ney, M., Charles, S., Lallich-Boidin, G.: Students' performance and satisfaction with Web vs. Paper-based practice quizzes and lecture notes. Comput. Educ. **53**(2), 375–384 (2009)

Siegenthaler, E., Wurtz, P., Bergamin, P., Groner, R.: Comparing reading processes on e-ink displays and print. Display **32**(5), 268–273 (2011)

Wang, Y, Zhao, Z.H., Wang, D., Feng, G.H., Luo, B.: How screen size influences Chinese readability. State Key Laboratory for Novel Software Technology, Nanjing University (2012)

Yang, C.Y.: An observation on the trend of Tablet Design from CES 2014, Nankang IC Design Incubation Center, Taiwan (2014)

Shneiderman, B., Plaisant, C.: Designing the User Interface: Strategies for Effective Human-Computer Interaction, vol. 5. Addison-Wesley, Reading (2010)