Reading Chinese in e-Book Readers: A Review

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Abstract. In this paper, a comprehensive review of related studies concerning reading Chinese in eBook readers is presented. This review aims at finding out related factors influencing the reading performance on eBook readers, especially for Chinese readers. The result of this paper could be useful for designing appropriate eBook readers to Chinese customers.

1 Introduction

An electronic book (also e-book, eBook, digital book) is a "text- and image-based publication in digital form produced on, published by, and readable on computers and other digital devices." [1]. In comparison to conventional printed books, Ebooks have several advantages. The electronic version does not only provide a new method of publication, but also is environment friendly. Ebooks are much more efficient than printed books from various perspectives, such as storage, transfer, and delivery [2].

Besides personal computers and mobile phones, eBooks are often read on dedicated eBook reading devices (e-Readers). Currently, there is no strict definition concerning e-Book readers. In this paper, e-Book readers are defined as a handheld device on which e-Book is readable. An e-Book reader can be identified by the following characteristics: light weight, portable, and low-power consumption. In recent year, a number of e-Readers have been launched in the market, such as Kindle DX, Hanvon, iPad etc. Those e-Readers can be roughly classified according to their display characteristics, such as display size, resolution, paper-like characteristics, and so on. Due to these characteristics, the e-Book readers provide an ideal solution for reading-intensive tasks, especially for those e-Readers with paper-like electronic paper displays [3].

Only in mainland China, Chinese e-Reader market has entered the rapid development stage since 2009. The sales volume of e-reader in China exceeded 300,000 with the market scale of about CNY 450 million in 2009, and it is promising that an increase of the sale for e-Readers is huge in the coming years [4]. However, most of the e-Readers developed out of the mainland China and Taiwan do not support Chinese language quite well. For instance, Chinese fonts are not easily installed or used in those e-Readers. In addition, there are still some design factors remained unknown for designing a suitable e-Reader for Chinese readers.

Reading Chinese differs from reading other alphabetic orthographies in many special features, such as the fundamental linguistic unit, the relative transparency of the orthography, and the orthographic boundaries between units [5, 6]. Previous

P.L.P. Rau (Ed.): Internationalization, Design, HCII 2011, LNCS 6775, pp. 211–219, 2011.

research has been done and contributed on the legibility and readability from different types of displays, such as computer displays, mobile devices, dynamic line displays, etc. Only a few studies have been contributed to Chinese e-Readers. In this paper, special technical requirements for e-Readers will be analyzed by reviewing studies on different displays, especially for e-Readers.

The structure of this paper is organized as follows: in Section 2, several basic definitions concerning reading performance are addressed at first, and then different measurements regarding reading performance are classified and analyzed into different groups; in Section 3, several linguistic features in Chinese will be summarized and described in comparison to alphabetic languages (e.g., English); in Section 4, different factors influencing performance of reading Chinese on different displays are collected and classified according to their hardware dependency and task dependency; in Section 5, some design suggestions are proposed in order to improve current Chinese e-Readers' design in the future.

2 Reading Performance

2.1 Basic Definitions

Before the discussion on key factors influencing designing Chinese e-Readers, there are several important basic terms used in previous studies for assessing different reading tasks on different displays. Those terms are general concepts or basic definition framing the discussion in this paper, and they are: reading, legibility, readability, and visual fatigue.

In Rayner and Pollatsek's work [7], reading is defined as:

Definition 1. Reading is the ability to "extract visual information from the page and comprehend the meaning of the text."

The reading performance can be analyzed from different aspects, and it is closely related to two issues from the script aspect: legibility and readability.

Legibility is defined in [8] and [9] as:

Definition 2. Legibility refers to "the degree to which text items can be identified".

Readability is defined in [10] and [11] as:

Definition 3. Readability refers to "the ease or difficulty with which the meaning of the text can be understood".

Legibility and **readability** are two terms indicating the user's perception while completing certain reading tasks. The former one indicates how easy a text item can be identified, while the latter one indicates how easy the text can be understood. Both terms can generate potential influences on the usability of a given text displayed on a given screen.

Besides reading performance, another objective measurement is often used to assess reading operations by combining reading activities and display factors, and that is so called visual fatigue. It is defined as [12, 13].

Definition 4. Visual fatigue refers to phenomena related to intensive use of the eyes. It includes complaints of eye or periocular pain, itching or burning, tearing, etc.

"eyestrain" and "asthenopia" are used as synonyms of visual fatigue to characterize the pain, discomfort, or fatigue in and around the eyes.

2.2 Measurements

Several measurements are used for measuring reading performance. The evaluation of reading performance includes different aspects, such as reading speed, searching speed, accuracy, comprehension, fatigue and preference [6, 14]. Different reading task types have different requirements for reading performance, and different aspect of reading performance is actually influenced by different factors. Therefore, the contribution of the different factors should be analyzed according to different reading tasks.

Different reading tasks are required to be performed, and those task related factors are not distinguished well in previous researches. Normally, the tasks can be roughly classified into browsing tasks (searching tasks, target searching tasks) and reading tasks. Different tasks have different requirements for readers engaged in those reading activities; and therefore, different tasks might use different performance index to assess the reading performance. Generally, for a searching task, two measurements are used for evaluating the reading performance: searching time and searching accuracy; for a reading task, two similar measurements are used for evaluating reading performance: reading time and comprehension scores.

Visual fatigue can also be assessed objectively for different reading tasks. Seven quantitative methods have been summarized and compared for their sensitivity to visual load in [15], and those methods are accommodation power, visual acuity, pupil diameter, critical fusion frequency (CFF), eye movement velocity, subjective rating of visual fatigue, and task performance. CFF method has been used in the literature for assessing visual fatigue of reading on an electronic paper display [16, 17].

Besides the objective measurements, some subjective measurements are also used in the literature for measurement subjects' preference and their reading experience. Some questionnaires were designed towards the presented conditions.

3 Reading Chinese Versus Reading English

Most previous studies used English as the experimental text for reading. English belongs to the alphabetic system, and it is different from Chinese which belongs to the logographic system. The differences between Chinese and English result in limitations of applying conclusion derived from studies on reading English on displays, and the special features of reading Chinese can provide us some fundamental guidelines for designing a Chinese e-Reader.

3.1 Spatial Complexity

Words in English are com-posed of roman letters. These letters consists only a small number of strokes. Hence, the spatial complexity of them is relatively low. Meanwhile the spatial complexity of these letter are relatively uniform, and can be easily distinguished as a stimulus set in which it contains a set of style features. Similar to roman letters, Chinese characters are composed of a number of strokes as

well. However, the number of strokes varies greatly among different characters, from 1 up to 32 [18]. Therefore, the spatial complexity is relatively higher than Roman letters.

3.2 Font Style

Besides the spatial complexity caused by the great number of strokes, font style is another factor deciding the appearance of the language on a display. English and other western languages are composed of alphanumeric letters in one dimension. The presence and absence of a limited subset of features can create different font styles in English.

In contrast to English, Chinese characters displayed in a two dimensional manner, and they are composed of radicals with or without stems [19]. Only an alphabetic letter is meaningless in a complete English sentence. However, in Chinese, radicals are usually derived from simple Chinese character in order to indicate the attributes or partial meaning of the character, while the remaining part of the character, so-called stems are used to indicate the pronunciation or some other attributes of the character, which means a Chinese character might convey much more meaning than an English word.

3.3 Segmentation of Chinese Words

Words are regarded as the basic meaningful element unit of a language. In English, different words are separated by providing spaces in-between to assist readers to segment them. However, in Chinese, it is totally a contradictory situation: there are no spaces between the words to segment different meaningful parts [20].

3.4 Eye Movement

Besides linguistic differences between English and Chinese, different behaviors in eye movement provide additional evidence for designing Chinese reading environment. The effective vision region covers 1 character to the left fixation to 2-3 characters to the right of fixation when reading Chinese from left to right, while the region covers 3-4 letters to the left fixation to about 14-15 letters to the right of fixation, which is larger than that in reading Chinese. Furthermore, the average gaze range for reading Chinese is about 2.6 characters and 7-8 letters for reading English.

4 Key Influencing Factors

In this section, related factors which have been taken into account in previous studies are collected from previously published papers. Google scholar was used to find related articles published in this area. “Reading”, “Chinese”, “legibility”, “readability”, “electronic paper”, and “e-Book reader” are used as keywords for searching related articles, and only paper with high relevance are collected for this review. Several important papers were selected according to their relevance. Related factors (or variables), reading tasks, reading performance measurements, and displays used in the experiment are listed in Table 1.

Table 1. Different influencing factors for reading Chinese

Ref	Related factors	Reading task	Reading performance	Display
[3]	Display medium Light source, ambient illumination polarity, font styles	A series of target search task	Searching performance Visual fatigue	Ch-Cl display, E-ink display, and conventional paper
[6]	4 resolution displays, 6 character sizes	1. Visual searching task; 2. Reading task: 24 text excerpts	Reading speed, Searching speed, Subjective evaluation	Display of mobile phone
[14]	Book type, gender	Ten nouvelettes	Reading speed, Reading accuracy, Eye fatigue	Electronic paper display
[21]	Font type, character size, column setting, line spacing, display polarity	16 simple passages	Reading effectiveness	15-in color CRT display
[22]	Leading speed, presentation mode	Static Chinese character search task ; A leading-display Information reading task	Static search score, Comprehension	Sony Ericsson P910i mobile phone
[23]	Screen type, character size, text/background color combination, whole body motion	Search for and identify the specific buttons and Chinese characters	Searching time NMCB, Visual fatigue	17-in LCD and CRT
[24]	Display screen type, Chinese typography, text/background combination, speed, jump-length	72 paragraphs with about 120 words	Proportion of errors	CRT, LCD displays
[16]	Light source, display medium, ambient illumination, character size	A series of letter-search task	Searching performance visual fatigue	VGA e-Reader, E-ink reader
[25]	Surface treatment, illumination level, radius of curvature	A series of letter-search task	Searching performance visual fatigue	simulated electronic paper
[26]	Display type, light source, ambient illumination, interline spacing, character size	A series of letter-search task	Searching performance visual fatigue	Ch-Cl display, E-ink display

From Table 1, different factors were investigated in different experiment for different purposes. These factors can be classified by following two different approaches according to their task dependency and hardware dependency. According to the hardware dependency, those factors can be further divided into two groups: hardware-related factors and software-related factors. In addition, if considering the task dependency, those software-related factors can be further divided into different subgroups according to different task types.

4.1 Hardware and Software Related Factors

Hardware-related factors are the factors determined by the producer of the display, while software-related factors are the factors determined by the software developer.

In the literature, different display medium has been investigated for reading Chinese, such as mobile phones, small leading displays, electronic papers, LCD, and CRT displays. Although some of them (CRT) are far different from display medium in e-Readers, there are still some information useful for designing an e-Reader. From the investigation, it is observed that some variables are totally determined by the technical specifications of a display, such as, display resolution, refresh rate, color performance, lighting mechanism, and so on.

Some conclusions have been drawn in previous studies concerning the effects of display types. In [26], it was found that searching accuracy of electrophoretic electronic ink display was greater than chlorestic liquid crystal display; in [6], significant differences were found relative to resolution for text reading tasks, and the combination of resolution character size was found influencing the target searching speed significantly.

Besides hardware dependent factors, there are still lots of factors determined by the configuration of software. Those software-related factors can be easily adjusted according to display specifications, and these factors include: font type, character size, text/background color combination, column setting, inter-line spacing, jump length, leading speed, polarity, etc. These factors can be set as default values for configuring the software in order to provide an easy configuration and nice reading experience.

4.2 Task Dependent Factors

In previous studies, different tasks were carried out to evaluate different aspects of an eReader configuration. Generally, the tasks can be classified into searching task and text reading task. The target searching task asks the user to locate the specific character or word on the screen rapidly and accurately, while the reading task gave different reading questions or assignments to the user to evaluate their comprehension after reading the text from the display.

As discussed in the literature, legibility is relatively more important for the quick browsing task (searching task), while readability is relatively more important for understanding the meaning of the text. However, currently, it was declared in [6] that both factors were not able to be distinguished simultaneously. In this section, related factors are summarized according to the conclusions drawn from previous high relevant studies. The summery is shown in Table 2.

Table 2. Task dependency of different factors investigated in the literature

Task types & Measurements	Font type	Character size	Text/background color combination	Column setting	Interline spacing	Jump length	Leading speed	polarity	Ref
Reading speed	x	x		x	x			x	[21]
Reading Comprehension		x							[21]
			x			x			[24]
		x					x		[22]
Searching speed		x							[6]
		x							[16]
		x						x	[3]
		x			x				[26]
Searching accuracy		x							[16]
		x			x				[26]
Legibility	x	x							[19]

From Table 2, it is observed that different measurements are influenced by different factors. Sometimes, the combination of different factors could also affect the reading performance in a reading task [6]. And obviously, for reading tasks and searching tasks, different type setting parameters can generate different influences. Therefore, the findings from the literature demonstrate certain guidelines for designing the user interface for an eBook reader. For different tasks, those software-related factors should be carefully designed according to different tasks.

4.3 Research Limitations

At first, traditional Chinese was used in most of the previous studies for evaluating the Chinese reading performance. However, simplified Chinese has deployed its application in mainland China with a population about 1.4 billion. In comparison to traditional Chinese characters, simplified Chinese characters are converted from traditional Chinese characters, and have less number of strokes, especially for some very complex characters. The simplification decreases the spatial complexity of traditional Chinese, and it might have some potential influence on the readability and legibility of Chinese languages.

Secondly, until now, the legibility of only three types of font styles (Ming, Kai, Li) has been evaluated in [19] for traditional Chinese, since those three types are the earliest developed in Chinese calligraphy. Besides those three types of font styles, there are more than dozens of different font styles used for computer display. The other types of font style should be selected further to evaluate their readability and legibility for different reading tasks.

Thirdly, for paper-like displays, only target searching tasks have been carried out for assessing effects from a limited number of variables, such as character size, display type, interline spacing [3, 16, 25-29]. The other type setting factors have not been involved in any experiment evaluation for intensive text reading tasks.

Forth, the standardization of reading content is still missing for evaluating the reading performance. It is believed that different reading content might locate at different difficulty levels for the reading comprehension. In different studies, different reading contents were used for reading performance of the subjects. However, if those reading contents or experiments can not be standardized or normalized, the conclusion from different research studies might be contradictory. Therefore, how to set up a standard experiment procedure with a standardized reading task might be interesting for the further research.

5 Design Suggestions for Chinese e-Readers

After reviewing previous researches on reading Chinese on different displays, we would like to propose several suggestions for designing e-Readers for Chinese readers.

- Classification of design variables. It is admitted that there are lots of factors influencing the final reading performance of the reader. Those design variables should be classified according to their nature. Since the hardware system (display) has already determined lots of hardware related parameters. Much more attention

needs to be paid on other software-related factors. In addition, task dependency should be considered while designing the reading interface.

- Default configuration. Default configuration is necessary for an e-Reader to display the text in a default manner. The default manner should satisfy the common users for intensive reading tasks. The default configuration for reading Chinese on e-Readers is one of possible research directions in the future.
- Free type setting appearance. Although font types and character size might influence the reading performance statistically, each individual user might have his or her reading preference. To respect the individual preference, a free type setting appearance is strongly recommended to allow users to set up their individual e-Readers according to their own preference.

6 Conclusion

E-Book readers, they are mainly used for intensive text reading tasks. In this paper, a comprehensive review was carried out on previous research work on reading Chinese on different displays, since there are only a few papers about reading performance on e-Readers. The factors engaged in previous research are classified and discussed according to their hardware dependency and task dependency. Limitations in previous research and further suggestions were also presented in this paper for guiding the design of e-Reader for Chinese users.

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