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An Eye Tracking Study of Line Spacing Effects on Reading Simplified Chinese

Project Report

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Abstract

This paper presents an eye tracking study of how interlinear line spacing affects simplified Chinese reading. In a within-subjects design, we collected data from 35 subjects reading articles formatted in a variety of seven conditions of line spacing. Total reading time, number of fixations, average fixation duration, average saccade length and regression rate were computed. For the smallest line spacing, average saccade length and regression rate were significantly shorter compared to other conditions. However, there were no significant differences across seven conditions in terms of total reading time, number of fixations as well as average fixation duration.

Keywords

Eye tracking, typography, line spacing, Chinese reading.

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1. Introduction

The tale of written word processing starts in our gaze when the capable eyes move around the page constantly and help our brain effortlessly give us access to its meaning and pronunciation. We "scan" text with the most sensitive part of our vision, like a robot with two discerning cameras scooping up the printed information. But unlike these stylized mechanical androids, the process of human reading is far from simple and hosts a sophisticated set of decoding operations whose effectiveness would involuntarily be influenced by even subtle ergonomic issues, such as font type, font size, column numbers, character spacing, typographic layouts, to name but a few (Dyson, 2004). From the standpoint of legibility[1] and readability[2], typographic issues have been studied by ergonomists, advertisers and psychologists for over hundreds of years, focusing previously on printed papers and now gradually, with the rapid expansion of eye tracking technology and electronic texts, moving to address online presentation on digital screens. Although there have been a considerable number of studies devoted to investigating how various typographical and font variables influence reading behaviors in terms of eye movement patterns, empirical researches examining how interlinear spacing affects the efficiency of reading in simplified Chinese are as it were far fewer (e.g. Chan and Lee 2005).

Myriads past studies on Chinese reading have worked on determining the best combination of typographic factors in terms of lexical issues to present text both on pages or digital screens for optimal reading. For example, among the great variety of font types available for traditional Chinese text presentation, researches investigating the subjective preference for divergent typefaces showed that Ming and Kai were the most frequently used and Kai was aesthrtically more pleasing to readers than Ming (Shieh et al, 1997; Chang, 2005). In terms of character size, the optimal range of readable Chinese character was thought to be 0.3-2.3° visual angle, with a maximum reading rate at 0.5° predicted by an inverted-U cubic model (Xu & Jordan, 2009). Taking this line of argumentation one step further, following studies in this perspective argued forcefully that reading was faster with 0.68° character size than 1° (Yen, Tsai, Chen, Lin, & Chen, 2011), and faster with 0.7° than 0.4°, 1.4° and 2.1° (Shu, Zhou, Yan, & Kliegl, 2011), thus putting forward a possible hypothesis that a more precise optimal range of character size was something between 0.4° and 1° visual angle. Much similarly, variables like character spacing, orthographic coding etc. posed no exception coming into scholars' notice and have received sufficient academic consideration (e.g. Bai et al., 2008; Yen et al., 2011).

So over the past few decades, in most psycholinguistic experiments the researchers were principally interested in properties of characters and it has pervaded almost all linguistic subdisciplines that the difficulty to encode lexical issues would lead to a poor reading performance, in most cases appearing to be a deceleration in reading speed, and concomitantly to an extension of eye fixations, contraction of saccade length, and increase of regression rate (Rayner & Pollatsek, 1987; Rayner, Pollatsek, Ashby, & Clifton, 2012; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006). This consensual view seemed to lead readers to broadly assume that as long as font type, font size, and length of line were at all reasonable, reading would proceed

[1] Legibility：Legibility generally refers to how easy an item in a text, for example, a single letter or a limited string of letters, could be identified (Yen et al, 2011).

[2] Readability：Readability refers to how easy it is to comprehend a text structure with a higher complexity, for example, lines or pages of text (Yen et al, 2011)

quite normally because lexical processing of the words in the text drove the eyes (Morrison & Inhoff, 1981; Rayner & Pollatsek, 1987). Because of this general view, until recently, the number of studies dealing with the effect of line spacing in Chinese reading still has been quite sparse.

The present study therefore aims to examine how a different type of typographical variable, the spacing between lines, influences reading and seeks to shed further light on the optimal range of line spacing in terms of a better reading efficiency. For the sake of determining what impact will be created and how reading is processed in varied line conditions in greater detail, one of the best ways of investigation is an alliance of traditional readability task and the matured eye tracking technique, which is particularly informative and overt for detecting real time reading processes.

The structure of this report is organized as follows. Research background is briefly reviewed in this chapter. Section 2 begins by introducing theoretical and empirical information, including line spacing effects, written Chinese processing as well as eye tracking in methodological discussion. Section 3 then illustrates the experimental design and present data analysis in regard of different eye movement measures, the results of which are discussed and integrated with previous findings in the latter part of this section. Finally, summaries and conclusions concerning the findings and possible directions for future studies are illustrated in the last section.

2. Theoretical and Empirical Background

Instead of going straight to introduce the experimental details, it is worth being familiar with the effects of line spacing on character legibility and text readability. Also, unique visual properties of Chinese characters relative to the logographic writing system as well as spacing setting will be briefly reviewed below, followed by an overview of the eye tracking methodology used in the present studies.

2.1 Line Spacing Effects and Properties of Chinese Characters

Thanks to many ergonomic studies which have been conducted to develop design guidelines for presenting alphanumeric characters, the issue of line spacing was not never received any insights from foreign academia. As early as 1960s, it has been generally accepted that in English printed materials intended specially for native adults, an addition of two or three points of extra space vertically between two adjacent lines created a positive contribution to text readability and legibility (Ganayim and Ibrahim, 2013). Then Paterson and Tinker (1965) reported a series of studies involving silent reading of English-speaking adults and proclaimed that there was a strong association between line spacing as well as reading rate. If the line spacing was greater than the point size of the type, it would significantly confer an advantage with some setting of type size and line lengths. Thereupon they advised that in English reading, for optimal sizes of type, an interlinear spacing of 1 to 4 points was conducive to promote reading efficiency. Kolers et al (1981) then compared single and double spacing for electronic reading on computer screens, and obtained a result which supported the double-line-spacing advantage and declared that double-line-spacing was marginally superior to single spacing. Kruk and Muter (1984) in quick succession found a larger and more remarkable effect than that presented by Kolers et al (1981), indicating that double spacing became the overmatch in competition in the case that double line spacing decreased lateral masking, reduced fixation count and leaded to more accurate return sweep during reading. The American National Standard for Human Factors Engineering of Visual Display Terminal Workstation (1988) also suggested that in cases where legibility is important, a minimum of two stroke widths or 15 percent of character height shall be used for spacing between lines of text. After the proclamation of this industrial criterion, many studies included line spacing as one of selected typographic variables to estimate its interaction with other layout features (e.g. line length, column numbers, etc.) and worked on determining the best configuration of typographical factors to present text both on pages or digital screens for optimal reading (e.g. Mills and Weldon 1987, Muter 1996, Boyarskiet al.1998, Bernardet al.2002, 2003, Dyson 2004).

However, research achievements or design guidelines for presenting English alphabets cannot be applied directly to Chinese characters since the written system of English is to a large degree divergent from that of Chinese (Cai, Chi and You, 2001). English belongs to an alphabetic system in which words are composed of left-to-right alphanumeric letters in one dimension (Gibson, 1971). In contrast, as a script which has been for a long time particularly famous for being different, written Chinese is universally considered to be a logographic language comprised of characters, which are in turn composed of radicals with straight line or poly line strokes in a two-dimensional fashion. The logographic writing system in Chinese uses characters as the writing unit and each character is a visual-spatial item, which though differs in their visual and linguistic complexity, admits of no exception occupied a fixed amount of space in print, inequivalent to the English letter in this respect. Different characters, though vary greatly in complexity in terms of the number of strokes, conform to a roughly square frame which is not usually linked to one another (Yen et al, 2011). And no matter how complex a character is, it must be confined into this constant, box-shaped and equal-sized rectangular region. This kind of visual structure of Chinese characters makes them appear as integrated, isolated visual objects, such that they can be coded as a pyramid of bundles of semantic and phonetic features (Tsai and McConkie 2003; Dehaene, 2009, p98). Figure 1 demonstrates the squareness of Chinese characters both in traditional style and simplified format[3]. Chinese readers, unlike those alphabetical system users, have adapted themselves to the constraints of Chinese writing and grew a hierarchy of detectors turned to the internal structures of Chinese characters.

倉個們倫偉長門閂閃閆閉開閲閎閏
仓个们伦伟长门闩闪闫闭开阅闳闰

Figure 1. Examples of squareness of Chinese characters (upper for traditional, lower for simplified).

Chinese characters have unique structures compared to western characters and the pattern of structures can be roughly categorized into 10 types: single-radical, left-right, up-down, up-right, up-left, left-down, up-left-down, left-up- right, left-down-right, and enclosure (Dai, Lui and Xiao, 2007). No matter which pattern a character belongs to, it is indisputably confined into the constant,

[3] It should be pointed out that Chinese characters consist of two versions, one is simplified and another is traditional characters. Traditional Chinese characters exhibit a higher level of complexity than simplified characters since the former are often comprised of many strokes. So in order to promote literacy development, a "Scheme for Simplifying Chinese Characters" was enacted by the Chinese government in 1956, specifying that for the sake of pervasive learning, Chinese characters should be changed to be visually simpler. Nowadays simplified Chinese characters are used throughout mainland China, whilst traditional Chinese characters are mainly exploited in Hong Kong and Taiwan (Liversedge, Gilchrist and Everling, 2011).

box-shaped and equal-sized rectangular region (see Figure 2). In other word, characters are separated by spaces of an equal size, either horizontally or vertically. In this sense, the concept of "character area" and "stroke density" are developed as special descriptive measures for comparing Chinese characters, in which character area refers to the area of the rectangle that circumscribes the character and the stroke density refers to the ratio of the total area of the strokes to the character area (You, Cai and Chen, 1997; Cai et al, 2001).

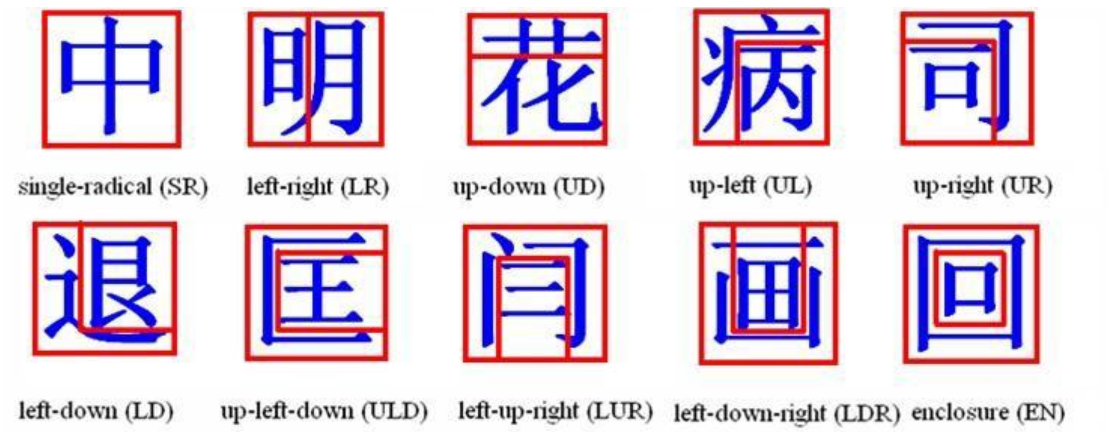

Figure 2. 10 types of Chinese character structures (single-radical, left-right, up-down, up-left, up-right, left-down, up-left-down, left-up-right, left-down-right and enclosure).

Since it is noted that each Chinese character conforms to a square character area and is not usually linked to one another, many studies covering a large scope of varieties set about evaluating the effects of spacing between two neighboring characters (e.g. Bai et al., 2008; 梁 菲菲 & 白學軍, 2010; 陳家興 &蔡介立, 2016) but lose sight of the effects of distance within two contiguous lines. Up to now, an ancient study about line spacing tested with Chinese characters on printed pages showed that line spacing with 0.5 and 1 time character height engendered no difference to reading speed (Chuang, 1982), but the results have been refuted by three subsequent researches. Modernly, Chan and Lee (2005) in order to estimate whether font type, character size, column setting, line spacing and display polarity would interactively affect objective performance measures and the subjective preferences in traditional Chinese reading, have tested these five factors with line spacing containing two levels: single and double line spacing. The results presented an overwhelming positive effect of double line spacing in terms of reading speed and personal preferences. Before long, Chan (2014) again tested effects of line spacing on proofreading performance and scrolling of traditional Chinese text. He compared single, one and a half (1.5), and double spacing and found that single spacing resulted in the fastest proofreading time whereas double spacing contributed to the highest typo detecting rate. Cheng (2015) studied the effects of spacing in reading simplified Chinese for elderly people, and the analyses revealed that under the wider line spacing condition (double spacing), the elderly read faster than in condition of narrow line spacing (one and a half spacing).

To sum up, though the above mentioned three experiments on line spacing have explored the effects of line space with divergent purpose and in terms of different audiences, inadequacy still exits. The first problem is that they did not have a rigorous definition of the dimensions for single or double space. Chen (2005 & 2014) defined line spacing as the distance of the empty space between two adjacent horizontal lines of texts (bottom of the upper line to the top of the following line) but Cheng (2015) in his study stipulated that line spacing referred to the distance between two underside base lines of characters (bottom of the upper line to the bottom of the following line). In this aspects their results could not be integrated together to provide an overall reference of effects of line space. On the basis of these considerations, for our discussion, it is of necessity to differentiate two varied standards of line spacing and specify one definition for stimuli setting. While it is a trivial matter to calculate the distance that fits between two lines of text, it is far less trivial to determine how to optimize the variables for the purpose of reading efficiency. Another problem is that, the existing reports on line spacing covered a small range in which only single, one and a half, and double spacing were tested. More conditions worth consideration and need to be included in order to find out an optimal range of line spacing. And lastly, to understand the detailed structure of how human process written text, recent researches have turned to eye movement tracking as a valuable analysis tool and took full advantage of this effective indicator of human visual information processing and cognition. The data analysis of Chen' two studies simply relied on behavioral reading speed and subjective preference, neither of which took the advantage of eye tracking technique to explore detailed reading performance of normal adults. So in this paper, it would appear to be of paramount importance to test the potential effect of line spacing by analyzing eye movement patterns to investigate how it influences online reading. With eye tracking technology, a camera records where a subject's eye is fixating and maps these gaze points to the text to immediately follow the subject's reading behavior.

So for the pursuit of a comprehensive understanding about the study design, the application of eye tracking technology will be discussed as below before the experiment introduction, followed by its mechanism and an overview of the eye movement measures adopted in the present study.

2.2 The Eye Tracking Methodology

The study of eye movements pre-dates the debut of eye tracking technology by almost 100 years. As far back as the second half of the 19th century, by a reliance on naked-eye observation, the French ophthalmologist Louis Émile Javal used a mirror to observe eye movement in silent reading and firstly reported that eyes do not move continuously along a line of text but make short rapid movements intermingled with frequent stops, which he coined the term "saccade" for such kind of succession of discontinuous individual movements (Rayner, Juhase and Pollatsek, 2005). From the late 19th to the mid-20th century, early tracking equipment gradually came out to assist manually unaided observation. The first precise and non-invasive eye tracking technique was not developed until 1901 by Dodge and Cline, using light reflected from the cornea (Jacob and Karn, 2003). Shortly after this, Judd, McAllister and Steel in 1905 upgraded the initial one which could only record horizontal eye position via applying motion picture photography to record the temporal aspects of eye movements in two dimensions. Additional advances in eye tracking system which have allowed measurements to be more accurate and more easily obtained were made after that in various ways during the beginning period of the 20th century, and since its widespread use at that time, the technology of eye tracking from now has gained a wide acceptance and developed into a standard tool in a wide variety of disciplines, including psychology, cognitive science, human-computer interaction, marketing research, medical research, to name but a few. More recently, innovations in eye tracking technology have enabled a reduce of the need to constrain participants' head and body movements, which makes it possible to record fixation behaviour during more interactive and world-situated language use (Land, 2007). As regard to reading-based studies, eye tracking technology is notably capable of providing multi-dimensional information and a high temporal resolution for the examination of online language processing, thus specific applications of eye tracking in psycholinguistics have been highly promising for many years and are believed to be one of the best current approaches to discover immediate signs of word recognition (Sereno and Rayner, 2003).

This section gives an introduction to eye tracking technology and also addresses some eye movement measurements which are highly related to reading performance, for the sake of facilitating the discussion of data analysis in the later section.

2.2.1 Eye Tracking in Chinese Reading

Eye movements have been extensively examined as an effective indicator of human visual information processing and cognition. Reading, as a complex cognitive process of decoding symbols to construct or derive meaning, has been drawn its mysterious curtains via the key technique—eye tracking. The eye tracking technology has revealed that reading is performed as a series of eye fixations with frequent saccades between them. Human beings do not appear to fixate on every word in a text, but instead fixate on some words while apparently filling in the missing information using context according to some linguistic regularities (Rayner, Juhase and Pollatsek, 2005).

To our knowledge, the history of the earliest eye movement study investigating Chinese reading retrospects to the early 1920s, when Miles and Shen used photographic equipment to record readers' eye movements in the silent reading of Chinese text presented both vertically and horizontally (Liversedge, Gilchrist and Everling, 2011). Later on, more and more researches which endeavored to delve into the recesses of Chinese written language comprehension flourished and important aspects of eye movement behaviour during Chinese reading have gradually been established. One part of studies focused on the influence of intrinsic characteristics of Chinese orthography on eye movements during reading, e.g. character complexity, word frequency, predictability as well as spacing. For instance, as regard to character complexity, Just and Carpenter (1980) recorded the eye movements of native Chinese readers and found that they spent more time on characters which contained more strokes and each additional stroke occupied reliably 4.6 millisecond of gaze duration. Yang and McConkie (1999) manipulated the complexity of its constituent characters in a two-character word and reported that both the complexity of characters and words influenced reading because more complex words took longer time to identify and contained a higher property of receiving a refixation. Much more recently, G. Yan et al. (2011) examined the role of stroke encoding in Chinese character identification by different proportions of stroke removal either from the beginning or from the end of the character construction sequence. Reading times, fixation counts and regression rates all showed that Chinese characters with 15 percent of stroke removal were as easy to understand as completed ones, which reflected some redundancy related to stroke complexity within simplified Chinese characters. Apart from visual complexity, character or word frequency of occurrence is another issues extensively studied in Chinese reading. One representative is Chen et al (2003)'s investigation which reported a robust effect of word frequency on fixation times on a target word and found that fixation was longer at low frequency words than high frequency words (see also G.Yan et al., 2006). Rayner et al. (2005) found a robust predictability effect and declared that fixation time was also greatly influenced by how predictable a word is. Another critical issue which received multiple attention with the development of eye tracking technology is Chinese word boundary. Unlike alphabetic system in which words are perceptually salient because of spaces between them, Chinese text does not contain such salient visual cues thus is not as immediately apparent as is the case in spaced scripts such as English. Bai et al. (2008), under the help of an eye tracker with high spatial and temporal accuracy, examined how inserting spaces between words influenced reading and found that word spaced text neither facilitated reading nor interfered with reading since subjects read word spaced text as quickly as normal unspaced text. Another part of studies focused on information extraction during reading. Inhoff and Liu (1998) made their first successful attempt in examining readers' perceptual span during reading of Chinese sentences. The results revealed that perceptual span during Chinese reading was asymmetric and appeared to be smaller than in English: extended one character to the left of the fixated character and up to three characters to its right. Besides the perceptual span, subsequent researches also investigated the parafoveal preview effect and the acquisition of parafoveal word information in Chinese, for example, the experiments of Tsai et al.(2003) about time course of phonological and orthographic processing in the parafovea discovered an early and rapid parafoveal phonological activation at both character and radical levels. M.Yan et al. (2009) manipulated preview characters which were either identical, unrelated, or semantically related to the targets, and found a significant preview advantage from orthographically and semantically related characters on first fixation and gaze durations, which suggested that to some extent, useful semantic information could be obtained from the parafovea during Chinese reading. Eye tracking technology also helps to record developmental trends during Chinese reading. Chen et al. (2003) conducted a comparative study between second-, fourth-, sixth-grade children as well as the undergraduate students, and found that as reading skill increases with age, saccade lengths and perceptual span increase, while fixation durations, the number of fixations, and regressions decrease. Among all these substantial number of work investigating Chinese reading in virtue of eye tracking, basic patterns of eye movements in Chinese reading have exposed many striking differences between Chinese and English, and in this aspect leave inspiration as well as enlightenment for subsequent researches.

Great advances in both eye tracking technology and language processing theory create a closer link between numerical eye tracking data and actual cognitive processes underlying reading, thus many different eye movement research paradigms were used with a high frequency, for example, moving window paradigm, moving mask paradigm, boundary paradigm, fast priming paradigm, disappearing text paradigm and visual - world paradigm.

The classic gaze-contingent moving window paradigm was designed by McConkie and Rayner in 1975 for the sake of determining the size of perceptual span (Liversedge, Gilchrist and Everling, 2011; Rayner, 1998). In this technique, an illusion of text is created on a screen via the passage being perturbed outside a predefined window region around the point of fixation. This window area moves in synchrony with eye movements so that wherever the reader fixates, the device can be programmed to become legible only within the window while outside of the defined area the text is disrupted in some way, such as masked by strings of X or replaced with scrambled letters (see Figure 3). Subjects can move their eyes as they please, but the amount of viewing information on each fixation is experimenter-controlled. So whenever and wherever the eyes move, a new area of text is exposed while the region previously visible is disrupted as the computer refreshed the display discreetly. The size of window can be defined in terms of letter spaces, word boundaries or any controlled prerequisite according to the experiment aims. By varying the size of the window systematically, the assumption is that when the window is as large as the region from which the reader can normally obtain information, there is no significant difference between reading in that situation and natural reading. Successfully, McConkie and Rayner (1975) using this device made a remarkable discovery that as long as enough letters were presented left and right of fixation, participants failed to notice the manipulation and detect the trick, believing that they were looking at a perfectly normal page of text (see also Rayner, 1998; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). Their experiment thus proves that human being consciously extract and process a limited subset of visual inputs at a time. So by means of this technique, the effective visual field can be determined via observing under which condition of exact window size reading performance is identical to the normal text reading. So subsequent researches have determined that skilled readers of alphabetic writing systems like English obtain useful information from an asymmetric perceptual span extending roughly 3－4 character spaces to the left of fixation and 14－15 character spaces to the right (e.g. McConkie and Rayner, 1975; Rayner and Bertera, 1979; Rayner, 1998, 2009), and that of Chinese reading extended one character to the left of the fixation and up to three characters to its right (e.g. Inhoff and Liu, 1998).

(a) Research on eye movements during Chinese reading is reviewed. [normal sentence]

(b) Research on eye xxxxxxxxxs xxxxx xxxxxx xxxxxx xx xxxxxxx. [the 1st fixation]
*

(c) xxxxxx xx xxx movements during xxxxxxx xxxxxxxxx xx xxxx. [the 2nd fixation]
*

(d) xxxxxx xx xxx xxxxxxxxx xxxxx Chinese reading xx xxxxxxxxx. [the 3rd fixation]
*

Figure 3. An example of the moving window paradigm. The first line shows a normal line of text. The following lines show an example of three successive fixations with a window of 16 letter space. The fixation location is marked by an asterisk.

The second paradigm is moving mask paradigm (also named foveal mask paradigm) developed by Rayner and Bertera in 1979 with the aim of determining the extent to which readers can obtain enough information outside foveal. (Rayner, 1998; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). It contains a high degree of similarity with the moving window technique, with the exception that the text is perturbed within the predefined region around the point of fixation while other information is presented normally beyond the mask region. So wherever the reader looks, a mask obscures the text around fixation (see Figure 4). The moving mask paradigm together with the moving window paradigm create an allowance for researchers to compare the importance of foveal and parafoveal vision in reading. It has been proved that reading performance suffers more severely when the fovea is perturbed compare with that when the parafovea vision is obliterated, and information necessary for semantic identification is obtained from the foveal and near parafoveal region, whereas other gross information is obtained from the parafovea (Rayner, 1998).

(a) Research on eye movements during Chinese reading is reviewed. [normal sentence]

(b) xxxxxxx xx xxx movements during Chinese reading is reviewed. [the 1st fixation]

*

(c) Research on eye xxxxxxxxx xxxxxx Chinese reading is reviewed. [the 2nd fixation]

*

(d) Research on eye movements during xxxxxxx xxxxxx is reviewed. [the 3rd fixation]

*

Figure 4. An example of the moving mask paradigm. The first line shows a normal line of text. The following lines show an example of three successive fixations with a mask of 16 letter space. The fixation location is marked by an asterisk. As in the moving window paradigm, the mask moves in synchrony with the eye movements.

Rayner in 1975 also invented another gaze-contingent technique named the boundary paradigm, created to test the parafoveal preview effect in terms of what kind of information can be extracted from a word before it is fixated (Rayner, 1998; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). In the boundary paradigm, an invisible boundary is just to the left of a single critical target word which is initially replaced by another word or by a nonword. When the reader's saccade crosses over the covert prespecified location, the initially displayed stimulus is always replaced immediately by the correct version of the target word without reader's notice (see Figure 5). If the initially presented stimuli contains some denominators with the target, gaze duration on the target word will be shortened. So the assumption by using this paradigm is that if a reader obtains information from the preview, any inconsistency between what is processed on the prior fixation and what is available on the fixation after crossing the boundary is registered in the fixation time on the target word (Rayner, 1998; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). By means of this paradigm, it has been revealed that parafoveal preview effect can help readers obtain orthographic and phonological codes from the parafovea about letter position (Rayner, 1998).

(a) Research on eye movements during | Chinese reading is reviewed. [normal sentence]

(b) Research on eye movements during | chess reading is reviewed. [prechange]

*

(c) Research on eye movements during | Chinese reading is reviewed. [postchange]

*

Figure 5. An example of the boundary paradigm. The first line shows a normal line of text and the second line shows a line of text prior to a display change. As soon as reader's eye movements crosses the transparent boundary (here indicated by the string "|"), an initially presented word (chess) is replaced by the target word (Chinese). The subtle change occurs during the saccade so that the reader is not aware of the modification. The fixation location is marked by an asterisk.

In a similar way, the fast priming paradigm also takes the advantage of covert boundary just to the left of the target word to examined the priming time of orthographic, semantic, and phonological factors (Rayner, 1998; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). Exactly as the boundary paradigm, a target location in the text is initially occupied by a random string of letters. However, when the reader's saccade crosses the boundary location during reading, near-threshold primes are flashed briefly (30-40 milliseconds) in a target location prior to the onset of a target word, inequivalent to the boundary paradigm in this respect (see Figure 6).

(a) Research on eye movements during | Chinese reading is reviewed. [prechange]
*

(b) Research on eye movements during | chess reading is reviewed. [prime]
*

(c) Research on eye movements during | Chinese reading is reviewed. [postchange]
*

Figure 6. An example of the fast priming paradigm. The first line shows a line of text prior to a display change with the fixation location marked by an asterisk. As soon as reader's eye movements crosses the transparent boundary (here indicated by the string "|"), the prime word (chess) is presented for a brief experimental controlled duration, and is in turn replaced by the target word (Chinese) for the remainder of the trial. Reader does not notice the presence of the prime word if its exposure is shorter than 50ms.

The fifth technique is disappearing text paradigm. This novel paradigm was developed by Rayner and his colleagues in 2003 in order to further determine what controls when the eyes move in reading (Rayner, 1998; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). It is a gaze-contingent change method with covert boundaries placed between all the words within the sentence. Whenever reader's fixation strides over a boundary, the newly fixated word disappears after a specified delay while the previously fixated word reappears, guaranteeing that the word currently fixated by the reader is the only one word missing from the sentence at any moment (see Figure 7). The prespecified delay between the first fixation and the disappearance of word restricted reader's opportunity to visually encode the word. Under this paradigm, researchers found that skilled readers are able to read and understand sentences normally when presented as disappearing text with the word being presented for 60 milliseconds for English (e.g. Rayner et al., 2003) and 80 milliseconds for Chinese (闫国利等 , 2007) from fixation onset. Even when the word is no longer visible, reader's mental processing determine when they would move their eyes onto the next word in the sentence, which provides clear support for cognitive control models of eye movements in reading (Liversedge, Gilchrist and Everling, 2011; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010).

(a) Research on eye movements during Chinese reading is reviewed. [prechange]

*

(b) movements during Chinese reading is reviewed. [postchange]

*

(c) Research on eye movements during Chinese reading is reviewed. [prechange]

*

(d) Research on eye Chinese reading is reviewed. [postchange]

*

Figure 7. An example of the disappearing text paradigm. Four lines demonstrate an example of two successive fixation with fixation location marked by an asterisk. As soon as reader's fixation strides over a transparent boundary, the newly fixated word disappears after a specified delay while the previously fixated word reappears.

The last popular methodology is visual-world paradigm firstly used by Cooper in 1974 (闫国利, 巫金根, 胡晏雯, & 白学军, 2010). Cooper pointed out that when interlocutors are simultaneously exposed to spoken language and a visual filed containing entities which are semantically corresponded with informative items of the speech, their sights will be spontaneously enticed to those objects according to what they heard. So he developed visual-world paradigm by using fixations in a pre-defined visual context as online indicators of how sentences are interpreted during auditory comprehension. In this paradigm, a sentence is presented auditorily with a visual scene in which different entities are depicted. Among these entities, eye movement patterns are affected by certain properties of the linguistic input and typically, listeners' fixation was drawn to objects that were mentioned or were in some way associated with the context. The proportion of fixations to the depicted elements which is related to the meaning of sentence provides an index of the strength of the link between the visual world entity and the language processing (Liversedge, Gilchrist and Everling, 2011; 闫国利, 巫金根, 胡晏雯, & 白学军, 2010). The advantage of this paradigm is that it provides information about how language users integrate linguistic information with visual information derived from the real environment, therefore it is well suited to study the way people produce and understand utterances about objects and events they see (闫国利, 巫金根, 胡晏雯, & 白学军, 2010).

2.2.2. Eye Movement Measures

Although eye movements have been examined for a long time via myriads studies with readability tasks and considerable collected data have demonstrated that eye movements are intimately related to the moment-to-moment cognitive processing activities of readers, it has only been in the last few decades that their measurement has led to important discoveries about psychological processes which occur during such tasks as reading, visual search, scene perception, etc. (Rayner, 1998). Before moving to a further discussion of experiment design, it is obliged to briefly note the different processing measures typically used in the research we discuss. Eye movement valuables in total can be categorized into global measures as well as time-based local measures. The former mainly contains saccade size, fixation duration, number of regressions, and the latter includes first fixation duration[4], single fixation duration[5], gaze duration[6] and go-past time[7]. In the present study, whole page of test materials was determined as interest periods with no specific interest areas, so global measures were chosen to be recorded and those tested in the present study are explained in detail as below:

(1) Total reading time per passage: Just as its name implies, total reading time per passage refers to the whole time demand for processing an article. A number of studies have revealed that reading speed varied based on an individual's profession, but on a broader spectrum, a native English adult read about 382 words per minute on average with a satisfying comprehension rate (70%-80%) (Rayner, 1998), and similarly, the index for Chinese reader was 386 words per minute, the equivalent of 580 characters per minute (Sun and Feng, 1999).

(2) Number of fixations: Number of fixations indicates the total number of valid fixations to read a passage. During the process of reading, the eyes continuously make jerky movements, and between this small steps eyes remain relatively still during fixations about 200-300 milliseconds (Rayner, 1998). It has been proved that readers who made fewer eye fixations read faster because they took in more words with each fixation. And the number of words readers could process in an eye fixation largely depended on their vision span, vocabulary and familiarity with what they were reading.

(3) Average fixation duration: Average fixation duration refers to the mean duration in milliseconds of all selected fixations. During reading, the average fixation duration has been proven about 225-250 milliseconds in English ((Rayner, 1998, 2009 for a review) and amounted to 257 milliseconds in Chinese (Sun and Feng, 1999). As would be expected, fixation duration is modulated by text difficulty: fixation durations increase as the text becomes more difficult, here in the present study we would like to see weather line space is another critical determinant of fixation duration.

(4) Average saccade length: Average number of characters between two valid fixations. Our eyes are in constant motion when we read because of the need to bring words into the most sensitive part of our vision. Instead of travelling continuously across the page, the eyes move in jerky saccades which varied in absolute size but are approximately constant when measured in numbers of letters. Previous researches have demonstrated that skilled readers move their eyes during reading on the average of every quarter of a second, and the distance in each saccade is between 1 and 20 characters with the average being 7–9 characters in English (Rayner, 1998) and 2.6 character spaces with a range from 2.0 - 3.0 characters, equivalent to 1.7 words in Chinese (Sun and Feng, 1999). As the brief movement of our eyes which bring poorly-resolved peripheral input onto the foveal part of our retinas, saccade is a major component of reading since it forms the basis of early visual letter-extraction processes and higher-level lexical, syntactic, and semantic processes (Liversedge, Gilchrist, & Everling, 2011). Although O'Regan (1980) argued that saccade length is critically determined by properties of characters, the question that whether line space would affect saccade length is still worth consideration.

(5) Regression Rate: One important characteristic of eye movements while reading is that eyes mainly move forward along the lines of text, but sometimes they return to previous regions of text (Liversedge, Gilchrist, & Everling, 2011). About 10-15% of the time skilled readers move their eyes back to previously read material in the text and about 70 % of the regressive saccades are

4 first fixation duration: the duration of the first fixation on a word independent of the total number of fixations.

5 single fixation duration: cases when only a single fixation is made on a word.

6 gaze duration: the sum of all fixations on a word prior to moving to another word.

7 go-past time: the time from when a word is first fixated until the reader moves forward in the text; this measure includes regressions back to earlier words as well as the time on the word itself.

mainly small-amplitude inter-word regressions, which bring the eyes to the immediately prior word, but in some instances, particularly when a text or a sentence comprehension difficulty is experienced they are longer saccades (e.g. Frazier and Rayner, 1982). It follows that the regression is strongly influenced by the difficulty of the text since such eye movements are often made in order for readers to undertake processing associated with the computation of a coherent representation of the discourse (Rayner, Foorman, et al, 2001). So through analyzing the number of regressions, the present study could answer the question that whether inappropriate line spacing is a catalyzer for comprehension failures.[8]

2.2.3 Mechanism

By comparison to methodologies in virtue of photographic technique, current commercially available eye tracking systems are greatly in the ascendant in terms of high sampling frequency, precision as well as accuracy via taking advantages of video images to exactly determine the gaze point of the eye by "corneal-reflection/pupil-center" method (Goldberg & Wichansky, 2002; as cited in Ball & Poole 2006: 211).

These video-based eye trackers are mounted either exactly on the subject's head or remotely, on a desktop in front of the participant, and according to it, eye trackers can be categorized into three types. The most common one is the static eye tracker, which puts both the infrared illumination and eye video camera on the table in front of subjects. It has two sub-types respectively named tower-mounted eye tracking and remote eye tracker. Tower-mounted eye tracker is capable of closely contacting with subjects via restraining their head movements and viewing then with distance, while remote eye tracker has nothing to do with head attachment. The second popular set up named head-mounted eye tracker, by which both illumination and camera are put exactly on the subject's head through a cap, helmet or a pair of glasses. The last one equipment is a combination of head tracker and head-mounted eye tracker, under which the position of head in space can additionally be included into calculation and data analysis (Holmqvist et al, 2011, p51). These different types of trackers allow researchers to choose equipment freely according to their specific needs, for example tower-mounted eye tracker is popularly used in gaze contingent reading research while head-mounted eye tracker should be exploited if a study aims to trace the eye movements of a soccer player during games.

The ability of modern eye tracking systems to track participants' eyes is fairly reliable than with systems of the recent past, and at the same time they are incredibly easy to operate. Taking the system adopted in the present study as an example, below shows a straightforward subject setup process. Its configuration simply includes one host PC, one display PC, one tower mount and one mount camera. The first step in an eye-tracking session is to set up the participant and eye tracker, so that the intended eye image appears in the center of the global view of the camera image via appropriate adjustment. When the camera image of the eye is clear, the pupil threshold can be

[8] All of the above parameters of Chinese reading refers to conditions when readers reading Chinese text with horizontal layouts, rather than vertical text. It should be noted that written Chinese can be arranged either horizontally as in alphabetic language (e.g. English), or vertically from top to bottom within a column. Although horizontal Chinese text is more prevalent at present in mainland China, vertical Chinese text still can be seen in certain regions (e.g. Hong Kong, Taiwan) or on some occasions like calligraphies, drawings, or paintings. For vertical Chinese text, reading performance was poles apart from that of horizontal text: mean fixation duration was longer (approximately 290 ms) than horizontal Chinese text (approximately 260 ms), average saccade length (approximately 1.2 characters) was only about half that for horizontal Chinese text (approximately 2.6 characters), and reading rate was slower (approximately 260 characters per minute, 170 equivalent words per minute) than horizontal Chinese text (approximately 580 characters per minute, 390 equivalent words per minute) (Liversedge, Gilchrist and Everling, 2011).

automatically set by pressing the “Auto Threshold” button when the camera image is selected. Have the subject look at the corners of the monitor, and accordingly adjust the pupil threshold by using the pupil threshold adjustment buttons if the pupil image has problems. The preceding step is a nine-point calibration, in which nine targets are displayed for the subject to fixate. Then a validation should be run immediately after the calibration, by which the accuracy of the system in predicting gaze position from pupil position is scored. After the system is set up and calibrated successfully, pressing the “output” button from the Camera Setup screen to start the experiment and the gaze position will be monitor and record in real time. Through these convenient operations, eye tracking analysis easily reveals how the eye moves during the reading process when eyes read an individual line of text in discrete chunks by making a series of fixations and saccades.

3. Experiment

3.1 Design

The primary objective of this study is to critically evaluate the effects of line spacing on Chinese reading performance, covering a large scope of line spacing derived from two divergent definitions in accordance with the consideration presented in section 2.1:1. the distance from top of a line to top of the following line; 2. the distance in between bottom of a line and top of the following line. As the exclusive within-participants independent variable in this experiment, line spacing here was defined as the distance of the empty space between two adjacent horizontal lines of texts and was manipulated by changing the distance in between bottom of a line and top of the following line. Seven levels of line space were involved: 17%, 75%, 133%, 200%, 300%, 400%, 500% of character size.

The reason why 17%, 75% and 133% interline spacing were selected is that these three conditions are corresponded to single-, 1.5- and double space respectively in many popular editors, like Microsoft Word, NotePad, as regards to the second definition of line space. And as a comparison, the counterpart of single and 1.5 spaced defined in the first definition fell in the scope of 75% to 133%. The greater spacing like 300%, 400%, 500% of character size were tested to fill the blank of existing research field.

All seven conditions of line spacing were assigned to 35 running tests according to a Latin square, with 5 passages in each condition. And each participant was required to perform all of the seven experimental conditions in which different layouts and passages were read and comprehended in a random order. An example of the text in the seven line spacing conditions is shown in Figure 8. The total reading time, number of fixations, average fixation duration, average saccade length, as well as regression rate were measured via eye tracker. Comprehension was assessed by a true-or-false test, which afforded an objective measure and allowed a comprehensible coverage of passage contents.

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Figure 8. Examples of experimental materials in seven conditions. Due to the ongoing advances in picture editors, we can easily change the line space when necessary.

3.2 Participants

37 native Chinese-speaking students (17 males and 20 females) at City University of Hong Kong were invited to participate in this experiment. They were all self-reported right handers, qualified simplified Chinese character readers, with normal or corrected-to-normal vision in both eyes, and none had a history of psychiatric, neurological or cognitive disorders. As college students, all participants were assumed to be understanding generally at satisfactory levels in terms of reading practice. They were all naïve to the experiment purpose and would receive HK

$90 as remuneration upon successful completion.

3.3 Materials

A total of 45 unrelated Chinese prose passages, having no rare words, no technical terms and no names of unusual instruments, were randomly selected from *Southern Weekly* with a wide range including 7 key sections: news, current political situation, economy, environment, biography, culture, and comment. The difficulty level of these passages was rated prior to the experiment by a focus group of ten subjects of the same education background as those tested in the study. In this pilot offline study, subjects answered a perception of text readability questionnaire, which consisted of a forced-choice, 5-point Likert scale, with statements 1 = "Not at all" and 5 = "Completely" as anchors. The questionnaire items included "The text was easy to read" and "The topic was familiar". Afterwards, 35 passages of similar difficulty which did not indicate any significant difference ($F(34, 246)=.874$, $P=.734$) based on norming results were selected and made for experimental stimuli. Including punctuation marks, the word counts of the 35 articles were between 479 and 520 (M=497, SD=11.77). All participants received the same informative passages but with a different layout according to one of conditions of interline spacing. Every passage was compiled in a format of 22pt Simsum font, 100 greyscale (pure black text color with white background), normal 0 character spacing, divided into four pages with four lines of text within each one, and presented vertically centered on the computer screen. To continue reading onto the next page, participants were told to press a button. In constructing the comprehension questions, care was taken to ensure that a subject could not readily respond without careful reading of the content. The assignment of passages and the serial order of the seven reading conditions were counterbalanced between subjects via use of Latin square. The dependent variables included five eye movement indicators: total reading time, number of fixations, average fixation duration, average saccade length, as well as regression rate.

3.4 Apparatus

Testing materials were presented on an 18-inch Viewsonic CRT screen with a pixel resolution of 1024*768 at 85 Hz refreshing rate. The monitor was placed on a table of 730 mm height and was 640 mm from participants' eyes. At this viewing distance, each character subtended a visual angle of 0.70°.Eye movements were recorded with an SR Research Eyelink 1000 eye tracker sampling at 1000 Hz and tracked both the pupil and corneal reflection. With subject's head movements minimized through the use of a chin rest, their eye movements were recorded only from the right eye, although viewing was binocular. An adjustable chair was used to ensure that each subject's line of regard was roughly perpendicular to and at the center of the screen. Application software was developed for generating stimuli and exporting data to statistical software for further analysis.

3.5 Procedure

Each participant was individually tested in a quiet room with dimmed lighting. They were initially seated at a distance of approximately 64cm from the computer screen with an eye-camera positioned in front of them and adjusted for optimal tracking. Participants were than assigned randomly to equal number of passages in each experimental condition according to the Latin square counterbalancing and instructed to read the passages silently at an unconstrained way and try their best to understanding their meanings in preparation for comprehension tasks in the wake. Each stimulus would be shown after a drift correction and a specific button press on a game pad by subjects. Once they pressed the button again, the passage would be removed and then a true-or-false question related to the content was presented subsequently on the screen and needed to be attempted based on immediate comprehension. After finishing, another randomly ordered passage display was afterwards initiated by the subject. In order to avoid mental or visual fatigue, a 5-min rest was given to participants after reading five passages. The whole experiment took around 90 minutes including calibration, reading and appropriate intervals. Before the real experiment began, subjects were instructed to familiarize themselves with the passage format and experimental setup by attending a 10-min practice session. Camera setup and a standard 9- point grid calibration were conducted before every condition and whenever necessary.

3.6 Results

The eye movement data from two participants were excluded from the analysis due to a too low accuracy of answering comprehension questions (<80%). In total, 35 participants were included in final analysis with a mean comprehension accuracy of 96%, indicating that the participants comprehended the reading materials adequately. Fixations which fell outside the upper and lower 40% pixels of the height of the passages were treated as invalid fixations and thus discarded. The differences between the seven conditions of line space were tested with one-way repeated measures ANOVA, in which the total reading time, number of fixations, average fixation duration, average saccade length, as well as regression rate were conducted with the factor of interlinear space.

ANOVA performed on the total reading time yielded no statistically significant effect of interline spacing, $F(4.406, 154.226) = .691$, $p = .613$ (Figure 9), but by means of the overall speed metric, the double space was the fastest and read 6% quicker than the slowest condition (133% spacing, 1.5 line spacing in Microsoft Word).

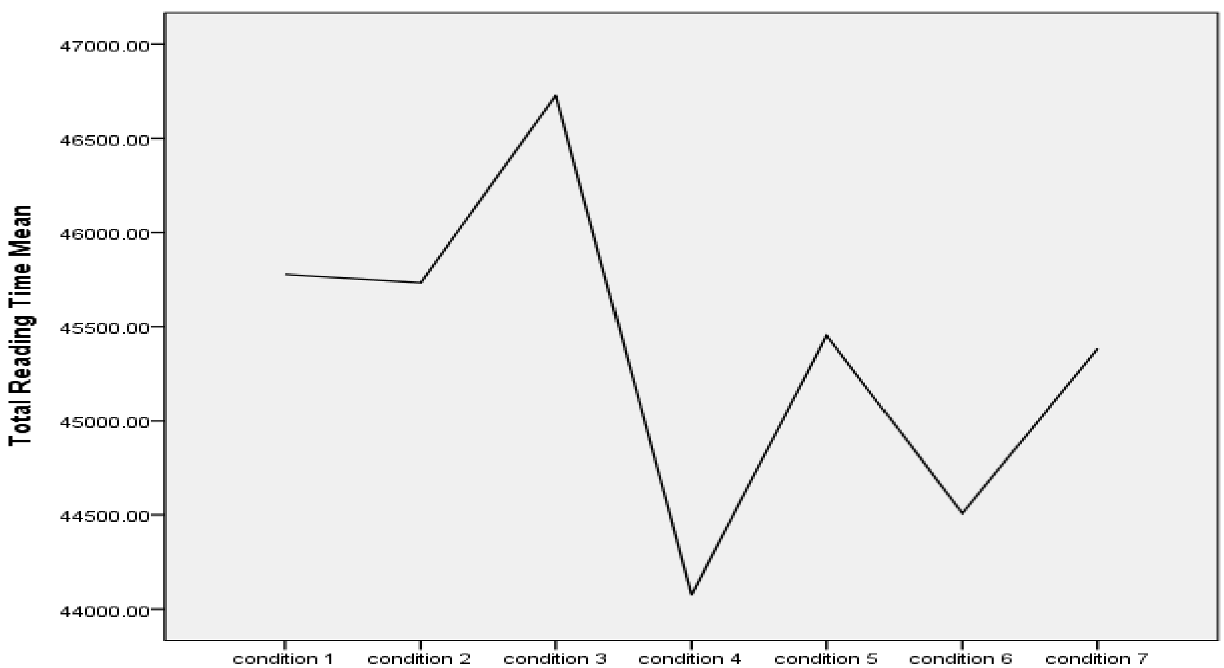

Figure 9. Total reading time (ms) per passage as a function of interline spacing in 7 conditions.

Similar to the total reading time, ANOVA performed on the number of fixations yielded no statistically significant effect of interline spacing, $F(4.212, 143.224)=.822$, $p=.518$ (Figure 10), but the double spacing produced the fewest fixation count, which was 4% fewer than the poorest condition. (133% space, 1.5 line space in Microsoft Word).

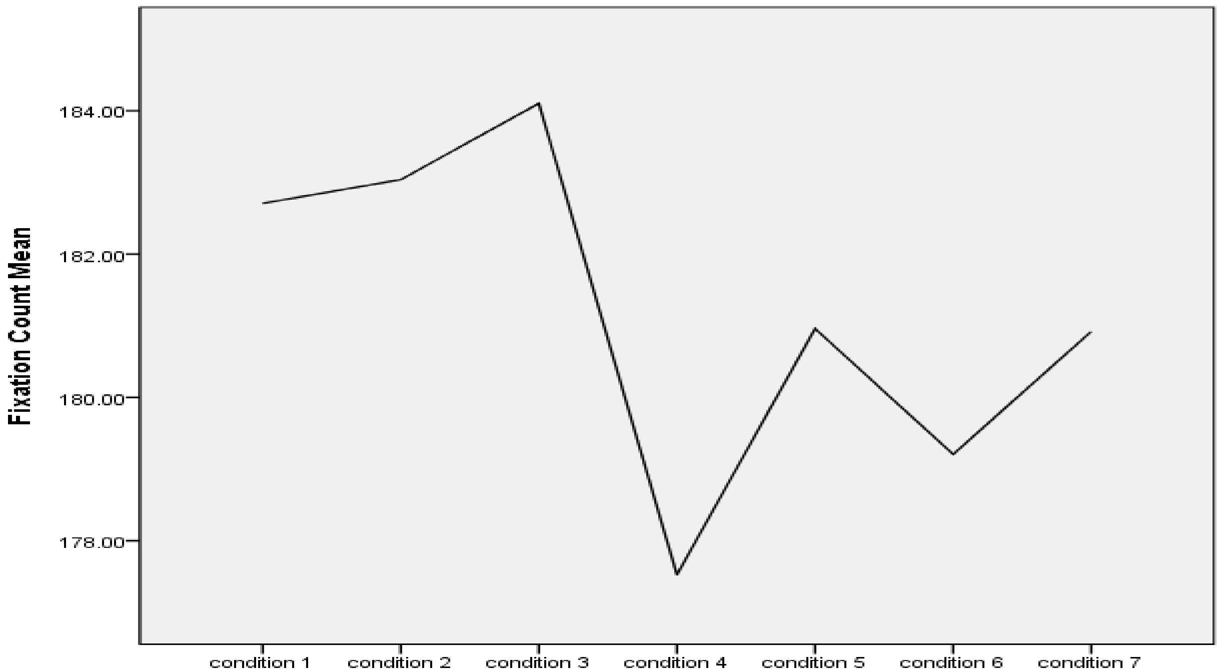

Figure 10. Numbers of fixation as a function of interline spacing in 7 conditions.

ANOVA performed on the average fixation duration yielded no statistically significant effect of interline spacing, $F(4.347, 147.794)=1.783$, $p=.130$ (Figure 11). The condition of double spacing and quadruple spacing (400% of character size) tolerably engender the same time span of fixation duration.

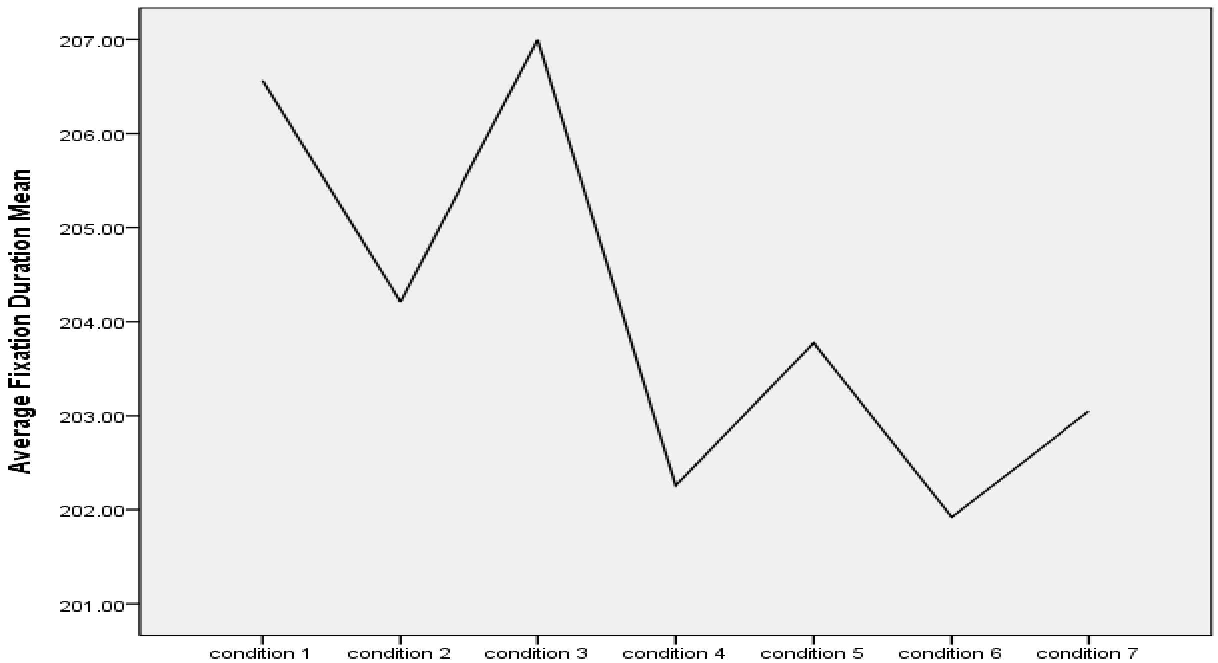

Figure 11. Average fixation duration (ms) as a function of interline spacing in 7 conditions.

Analyses of average saccade length and regression rate showed approximately similar patterns. The average saccade length of individual participants ranged from 4.046 visual angle to 4.444 visual angle, with an overall mean of 4.271. ANOVA was performed on the average saccade length, $F(4.312, 144.699) = 15.180$, $p<.001$ (Figure 12), which revealed that saccade length became longer with the increase of line space. For regression rate, a significant main effect showed that the regression rate was much more lower for 17% line space (M = 0.197) compared with other six conditions, $F(4.219, 143.906) = 56.772$, $p<.001$ (Figure 13), indicating that with larger line space, participants were more likely to look back to previously read content than with smaller line space.

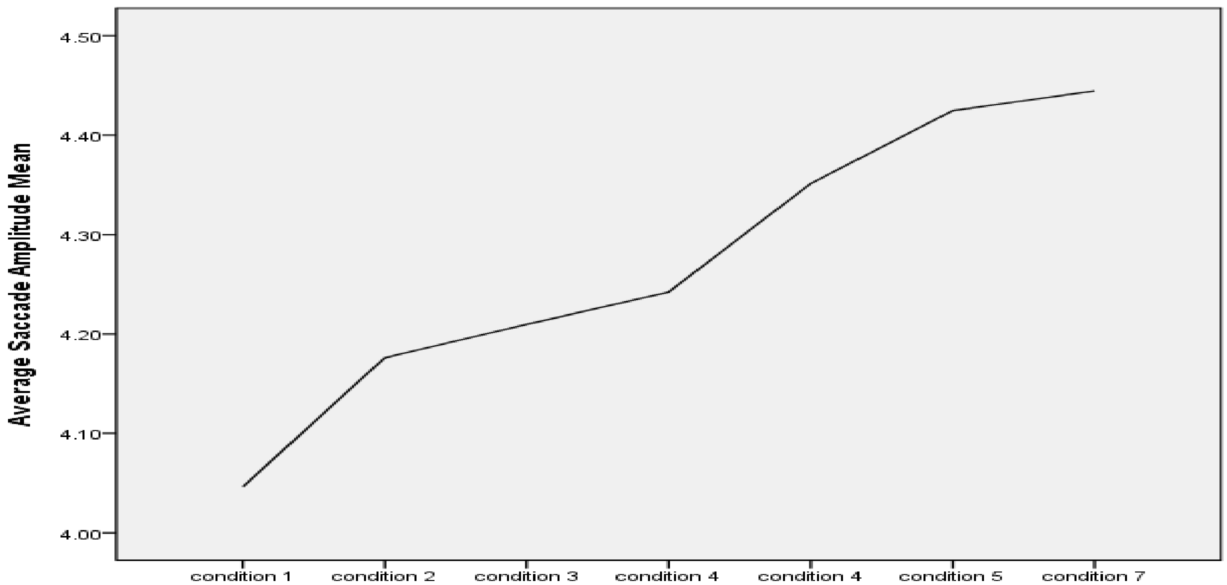

Figure 12. Average saccade length in visual angle (°) as a function of interline spacing in 7 conditions.

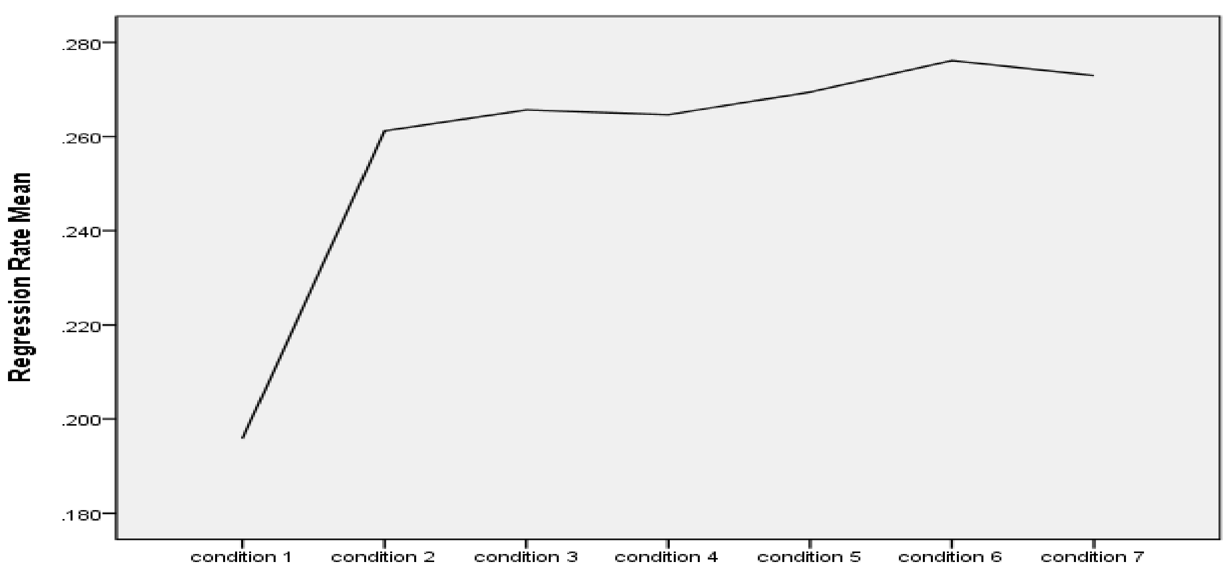

Figure 13. Average regression rate as a function of interline spacing in 7 conditions.

4. Discussion

In this paper, we investigated how the typographical issues of line spacing impact reading performance when reading simplified Chinese. Seven conditions of line spacing were compared and the results did not reveal any significant differences in reading time, number of fixations, as well as average fixation duration, indicating that readers were able to process all the passages well regardless of the divergent line spacing conditions, and adding interline spacing between two adjacent lines does not facilitate or destruct reading speed. From a practical standpoint, the lack of effect of interline spacing on reading speed render an allowance for displaying more text information within a finite given area.

These findings are in agreement with Chuang (1982) in which no speed differences were revealed when reading printed Chinese text with interline spacing of 0.5 and 1 times character height, but dissimilar to those of previous studies in which the reading speed of participants did significantly differ as a function of line spacing (Chan and Lee, 2005; Chan et al, 2014; Cheng, 2015). In terms of Chan and Lee's study (2005) which advocated that double line spacing was significantly better than single line spacing, we argue that the reason why our results were not concordant with theirs is that we adopt a normal reading in the experiment but Chan and Lee adopted a slow reading in their study. It has been proved that reading rate of normal adult Chinese reader who read Chinese texts was 580 characters per minute, equivalent of 9.7 characters per second (Sun and Feng, 1999; Liversedge, Gilchrist and Everling, 2011). However, the average reading time reported in Chan and Lee' s study (2005) was 215 characters per minute for single line spacing and 210 characters per minute for double line spacing, which were approximately twice over the given average reading speed of Chinese readers (580 characters per minute). So the inconformity in results may attribute to different reading model performed in two studies. For Chan's another study (Chan et al, 2014) conducted with the purpose of investigating how line space influence proofreading performance, we also argue that compared with normal reading, task based reading relies much more on typographic setting. And lastly, the inconformity of our study and Cheng's study (2015) was not surprised since the participants of Cheng's study were elder people. For the aging groups, it is quite logical to recommend written texts in large and scattered print as a compensation of their presbyopic symptoms when their visual acuity is diminished.

It should be noted that compared with the above mentioned studies which all successfully found evidence for large-space advantages, although there was no significant main effect on time difference between the seven conditions, as seen in Figure 9, double line spacing was for the most part superior than other conditions.

The effect of line spacing on the perceptions of average saccade length and regression rate, did however, engender significant differences indicating that additional interline spacing between two adjacent lines though makes no influence on reading speed, does destruct comprehension achievements in Chinese texts. As mentioned in section 2.3 that the regressive saccades are to a large extent catelized by the difficulty of the text since such eye movements are often made in order for readers to undertake processing associated with the computation of a coherent representation of the discourse (Rayner, Foorman, et al, 2001), so the results here demonstrated that written text formatted with 17% line spacing seemed to be easier to read and produced a better comprehension achievement than other larger line spacing conditions. At the first blush, the results may run counter to the well-known lateral masking effect or crowding effect which refers to that the likelihood of correctly identifying a letter is lower when the letter is surrounded, or “flanked” by other characters than when it is presented in isolation (Jo, 2000; Pelli et al., 2007). Since character formatted with 17% line spacing contains the closest touch with its circumambient context among all the seven line spacing conditions, it should contribute to a large regression rate in line with the crowding effect. The fact, however, are quite the opposite. We argue that the reasons behind the opposite results are that, on the one hand, 17% line spacing was not so narrow that the identification of a letter would be grievously influenced by its adjacent neighbors. Prudent to the American National Standard for Human Factors Engineering of Visual Display Terminal Workstation (1988) which suggested that a minimum of 15% character height shall be used for spacing between lines of text that in cases where legibility is important, the 17% line spacing in our study abided by it thus can guarantee an appropriate quality of legibility and avoid visual crowding. On the another hand, we consider 17% line spacing was suitable for skilled readers to cover the previously read lines within their perceptual span when fixate at current line, so they could keep much more contextual information in mind at one time when they process the immediately received information. On the contrary, when between line spacing became larger, previously obtained information could not be active constantly to support instant language processing, so readers had to look back to search for compensation. In this way, larger line spacing renders more regressive saccades. As for average saccade length, we consider that the fact saccade became longer in wake of increase of line spacing is not unexpected or surprised because wide line spacing renders a large return sweep which bring the eyes from the end of current line to the beginning of next line. Therefore it should be kept in mind from a practical standpoint that the large return sweep is an inevitable prey as line spacing increase to avoid crowded information.

5. Conclusion

Generally speaking, results here show that total reading time, number of fixations and average fixation duration do not vary with the line spacing, but average saccade length and regression rate clearly present an overwhelming positive effect of the smallest line space condition (117%). Since the uniformity tendency of total reading time, number of fixations and average fixation duration makes the outcome of this study incapable of defining the optimal range of line space, the follow-up study which has been designed to probe much more narrow line spacing to get a whole new future to venture.

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