Assessing effects of viewing distance on normal Chinese reading: Some methodological and theoretical implications

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Viewing distance determines a range of factors affecting reading performance. Previous studies of Chinese-character reading have shown considerable disagreement and inconsistency in their choice of viewing distances, however, with obvious implications for research in this area. The present study aimed to resolve this issue by determining the optimal viewing distance for studies of normal Chinese reading. Stimuli were pages of text that were composed of a standard Chinese typeface (Song) that was presented in a standard size (10.5 pt). Forty reading distances were used, ranging from 2.5 to 100.0 cm. Distances within the range of 7.5–55.0 cm produced faster reading rates than did the distances at either end of the continuum, and a regression model showed that 35 cm was the optimal viewing distance. These findings indicate an optimal range of retinal image sizes between 2.0° and 0.3° per character. The implications of these findings for understanding the processes that are involved in Chinese reading and for the appropriate presentation of Chinese stimuli in experiments are discussed.

Viewing distance is an important factor in the determination of reading performance. For example, variations in viewing distance can result in changes in visual acuity and in the extent of visual fatigue. For stimuli of a known physical size, moreover, viewing distance determines the size of the retinal image, which affects reading in at least two important ways. First, retinal-image size affects the spatial-frequency content that is available to the reader, and this can have a considerable effect on reading performance. Using English text, for example, Legge, Rubin, Pelli, and Schleske (1985) pointed out that reduced spatial-frequency content can cause a loss of visual information and thus impair performance on visual tasks (see also Majaj, Liang, Martelli, Berger, & Pelli, 2003; Majaj, Pelli, Kurshan, & Palomares, 2002). More recently, Patching and Jordan (2005) found that identification accuracy for English words was different for band-pass-filtered words that were centered at various frequencies between 1.1 and 13.7 cpd. Second, retinal-image size may interfere with normal patterns of eye movements. For example, studies of eye movements during reading of English text found that the lengths of forward saccades (in characters) were effectively shorter when the retinal-image size was increased to five times the size of normal text (Courier 10 pt) and larger (Mohammed & Dickinson, 2000). Also using English text, Morrison and Rayner (1981) reported that saccade size (in character spaces) did not differ significantly at three viewing distances (36, 53, and 71 cm). They noted, however, that fixation duration increased as viewing distance increased. O'Regan (1983) observed that reading time for English text was unaffected by six

viewing distances, from 25 to 75 cm. Character size was not reported, however, so the precise interpretation of these findings is unclear. In a more recent study, Shieh and Lee (2007) investigated participants' subjective preferences for viewing distances and found that the preferred viewing range was between 358 and 623 mm. This finding provides no indication of the effect of viewing distance on reading performance, however, and it was obtained using Chinese readers of English.

The situation has been no clearer in studies using Chinese text. Indeed, a thorough investigation of the literature reveals no studies in which viewing distance was manipulated to assess its effects on normal Chinese reading. Over the years, moreover, many researchers have made arbitrary decisions about the size of the stimuli that they used in experiments and the viewing distance at which these stimuli were presented. These decisions have resulted in the use of a wide range (30–200 cm) of viewing distances (see Table 1) and, therefore, in stimuli subtending a wide range of retinal sizes. This variability underscores the importance of identifying the viewing distance at which standard Chinese text is processed most efficiently, both for a more informed approach to the use of Chinese stimuli in experiments and for the development of an accurate theoretical understanding of the processes underlying Chinese reading.

Accordingly, the purpose of the present study was to assess the effects of viewing distance at which passages of normal, standard-size Chinese text were read and thus help establish the optimal range of retinal-image sizes for normal Chinese text presentation.¹ A widely adopted, standard Chinese typeface (Song, 10.5 pt) was used, and

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Table 1
Visual Angles, Viewing Distances, and Stimulus Widths That Have Been Reported in the Literature

	Visual Angle (deg)	Viewing Distance (cm)	Stimulus Width (cm)
Hoosain & Shiu, 1989	0.4	100	0.7*
Chan & Lee, 2005	0.45	45	0.35
	0.63	45	0.5
Hsiao & Shillcock, 2005; Hsiao, Shillcock, & Lavidor, 2006	0.62	92	1
Yeh & Li, 2002	0.69	115	1.4*
Tsai, Lee, Tzeng, Hung, & Yen, 2004	0.9	70	1.1*
Inhoff & Liu, 1998; Liu, Inhoff, Ye, & Wu, 2002	0.9	65	1*
Zhang & Peng, 1983	1	35	0.6*
Perfetti & Zhang, 1991, 1995	1	30	0.52*
Lee, Tsai, Huang, Hung, & Tzeng, 2006	1	60	1.05*
Hsiao, Shillcock, & Lee, 2007	1.03	100	1.8
Tan & Perfetti, 1997	1.03*	50	0.9
Chen & Tang, 1998	1.2	60	1.3*
Yeh & Li, 2004	1.2	55	1.15*
Tan & Perfetti, 1999	1.2	50	1.05
Yan, Tian, Bai, & Rayner, 2006	1.22	75	1.6*
Coney, 1998	1.27*	45	1
Fang, 2003	1.3	NR	NR
Tan, Hoosain, & Peng, 1995	1.34	150	3.5*
Valdes-Sosa et al., 1993	1.43	80	4
Bai & Shen, 1995	1.46	165	4.2
Zhang et al., 2004	1.5	NR	NR
Shimoyama, Nakajima, Ito, & Shibata, 1997	1.6	200	5.6*
Kuo et al., 2001	2–3	194	6.8–10.1*
Kuo et al., 2003; Kuo et al., 2004; Lee et al., 2004	2.3	194	7.8*
Hinojosa, Martín-Loeches, Gómez-Jarabo, & Rubia, 2000	3	65	3.4*
Dong et al., 2005	3 ± 1	NR	NR
Tse & Cavanagh, 2000	4	57	4*
Huang, Cai, & Chen, 2004	10–11**	50	8.8–9.7*
Lin & Shieh, 2006	NR	55	NR

Note—NR, not reported. *Not reported, but estimated on the basis of the other parameters that were provided in the original study. **Concluded by Huang et al. (2004) to be the optimal visual angle.

an extensive range of viewing distances was selected, with extremes that were selected to provide a range of reading performances and with small intervals in order to enable a sensitive assessment of the effects of changing distance on reading performance within these extremes. Specifically, the experiment used 40 viewing distances between 2.5 and 100 cm, with each neighboring distance differing by 2.5 cm. Effects of viewing distance were assessed by recording the rate at which passages were read at each distance. The prediction was straightforward: If viewing distance has an effect on Chinese reading, different reading rates should be observed at different viewing distances. Indeed, if Chinese reading is highly sensitive to viewing distance, even small changes in distance should affect reading performance.

METHOD

Participants

Twenty participants (age, 21–26 years) took part in a single session. All were native speakers of Chinese, reported normal or corrected-to-normal vision, and were screened for minimum binocular acuity of 3/3 or better using a Bailey–Lovie eye chart.

Stimuli

Forty-two passages of text were selected from stories that were published in the most recent issues of *Globe Times*, a popular Chinese daily newspaper. The passages were all traveling notes describing interesting stories and experiences outside China and

thus provided an engaging text. Each passage contained approximately 648 Chinese characters in four paragraphs, and each was presented in its entirety in a single-screen display. All passages had their starting character in the same position: the top-left corner of the screen.

Visual Conditions

Each passage of text was shown as it would appear in a normal printed Chinese format. Song (also known as SimSun) is a common typeface in mainland China, and for many years it has been the default typeface for simplified Chinese in Windows and Microsoft Office products. Formal Chinese publications such as books and newspapers use Song presented at 10.5 pt as the standard for printed text (Zhu, Li, Wu, & Zhu, 2005). These two parameters were thus employed in the present study to reproduce the typical layout of printed Chinese texts, so that each single character occupied approximately 0.30 cm (horizontally and vertically), 28 characters were shown in each line (allowing for punctuation), and interlinear spacing was 0.25 cm. All characters were presented in black on a white background. Background luminance was 99 cd/m², and stimulus luminance was 6 cd/m². Each passage of text occupied a screen area measuring approximately 10.5 cm horizontally by 15.0 cm vertically.

Apparatus

All passages were presented on a Samsung SyncMaster 753s monitor that was set to a resolution of 1,280 × 1,024 pixels and a frame rate of 60 Hz. A Cambridge Research Systems VSG 2/5 card was used to control stimulus presentations and to record reaction times via a Cambridge Research Systems CT3 response box. Participants remained seated in a constant location, and the location of the monitor was adjusted appropriately for each viewing distance that was used in the experiment. Participants were seated in a normally illuminated

room, and a chinrest was used to ensure accurate viewing distance throughout the experiment.

Design

Forty-two passages were used in the experiment. Two passages were designed to be used as practice stimuli, and the remaining 40 passages were used as experimental stimuli. Each participant was shown a different experimental passage at each of 40 distances ranging from 2.5 to 100 cm. The order in which distances were used was counterbalanced across participants using a Latin square design.

Procedure

For each trial, the monitor was adjusted to the appropriate viewing distance (along the 2.5- to 100.0-cm continuum). Each trial started with a fixation dot in the top-left corner of a blank screen, denoting where the initial character of the passage would appear. Participants were instructed to fixate the dot and to press a button on the response box when they were ready to read the passage. This buttonpress initiated the presentation of the passage and started the timer. Participants read through each passage of text once, silently, from top left to bottom right, as they normally would do when reading Chinese text.² After reading the final character of each passage, participants pressed the button again. This immediately removed the passage from the screen and stopped the timer. Prior to the presentation of the experimental passages, participants were given two practice passages in order to familiarize themselves with the experimental procedure and with the appearance of the text. To ensure that passages were read for meaning, five questions were asked after each passage, each addressing a key point in that passage. The criterion of a minimum of 60% correct was used for each set of five questions in order to ensure that participants were reading carefully enough to comprehend the passage.³ All 20 participants matched or exceeded this accuracy

criterion for every passage. Mean accuracy for each of the 40 distances was above 90%.

RESULTS

Reading rate was defined as the number of characters that were read per minute. Mean reading rates for the 40 viewing distances are shown in Figure 1. A one-way ANOVA, with Greenhouse–Geisser correction to provide a more conservative analysis, showed a main effect of distance [$F(9.30, 176.65) = 6.96, p < .001, \eta_p^2 = .27$]. Bonferroni post hoc t tests were conducted between all pairs of distances and these revealed a pattern of performance that is best described in terms of six ranges: 2.5, 5.0, 7.5–55.0, 57.5–70.0, 72.5–90.0, and 92.5–100.0 cm. There were six main findings across these different ranges: (1) Reading rates did not differ significantly across distances within the same range. (2) Reading rates at 2.5 cm did not differ from reading rates at any distance within the 92.5- to 100.0-cm range. (3) Reading rates at 5 cm did not differ from reading rates at either 2.5 cm or at any distance within the 92.5- to 100.0-cm range. (4) Reading rates at any distance within the 7.5- to 55.0-cm range were faster than at 2.5 cm and at any distance within the 92.5- to 100.0-cm range (all $ps < .05$). (5) Reading rates at distances within the 57.5- to 70.0-cm range showed evidence of decreasing toward the levels of performance that were observed at the extremities (2.5 and 92.5–100.0 cm). In particular, performance at 57.5, 67.5, and 70.0 cm did

Figure 1. Mean reading rates in characters per minute (cpm) at the 40 distances that were used in the experiment, and the regression curve of the means. The gray area corresponds to the critical range of 7.5–55.0 cm under the regression curve. All mean reading rates at distances within this area (range mean = 477 cpm) were significantly faster than those at 2.5 cm and those at 92.5–100.0 cm (range mean = 358 cpm). The dotted line shows the maximum mean reading rate of 494 cpm at a viewing distance of approximately 35 cm.

not differ from performances at 2.5 cm or at any distance within the 92.5- to 100.0-cm range. (6) Reading rates from any distance within the 72.5- to 90.0-cm range did not differ from reading rates at 2.5 cm or at any distance within the 92.5- to 100.0-cm range.

Following these analyses, a cubic model (third-order polynomial) was fit to the data (see Figure 1).⁴ The model also revealed that a maximum mean reading rate of 494 characters per minute (cpm) occurred at approximately 35.0 cm, corresponding to an optimal visual angle (horizontal and vertical) of 0.5° for each character.

DISCUSSION

The purpose of the present study was to assess the effects of viewing distance at which passages of normal, standard-size Chinese text were read and thus help establish the optimal range of retinal-image sizes for experiments investigating the reading of normal Chinese characters. The motivation for this research was heightened by the large variety of viewing distances and stimulus sizes that have been used previously in the literature to study Chinese character reading. To provide a precise assessment of the effects of viewing distance, an extensive range of viewing distances was used, with extremes that were selected to produce a range of reading performances and with small intervals within these extremes to enable a sensitive assessment of the effects of distance on reading performance. The results revealed a pattern of performance that is best described in terms of ranges, and we defined the optimal range as a continuous range within which each single distance produced faster reading rates than those that were produced at the extreme distances that were used in the study (2.5 cm, 92.5–100.0 cm). Our findings indicated that 7.5–55.0 cm was the optimal viewing-distance range (mean reading rate = 477 cpm) for normal Chinese reading, and regression analysis suggested a maximum mean reading rate of 494 cpm at approximately 35.0 cm, corresponding to a retinal character size of 0.5°.

These findings offer a number of insights into the processes underlying efficient Chinese reading. First, 7.5–55.0 cm is a range in which certain key spatial frequencies may be available. A substantial body of psychophysical evidence indicates that the human visual system operates in the spatial-frequency domain, responding to visual patterns on the basis of their spatial-frequency content. Sensitivity to various spatial frequencies is known to vary systematically (see, e.g., Campbell & Robson, 1968; Graham, 1989). Also, the human visual system is, in general, most sensitive to spatial frequencies in the range of 2–6 cpd, and more contrast is needed for detection of lower and higher spatial frequencies. In line with this research, there have been many investigations into the role of spatial frequency in reading (at least for English text and letters; Majaj et al., 2003; Majaj et al., 2002; Patching & Jordan, 2005). Legge et al. (1985) found that maximum reading rates were achieved for characters (letters) subtending between 2.0° and 0.3°. In the present experiment, similarly, characters in a typical Chinese typeface (Song, 10.5 pt) that were presented within the optimal range of 7.5–55.0 cm subtended between 2.3° and

0.3°, which resembles the Legge et al. finding. Within this optimal range, moreover, spatial frequencies corresponding to overall character extent were between approximately 0.2 and 1.6 cpd, and these are low spatial frequencies to which the magnocellular pathway is most sensitive (Legge, 1978; Merigan, Byrne, & Maunsell, 1991; Skottun, 2000); and spatial frequencies corresponding to stroke width were between approximately 2.2 and 16.1 cpd. Consequently, the optimal reading performance that was observed within this distance range suggests that visual information that is extracted within a range of 3.3-octave spatial-frequency bands with center frequencies of between 0.7 and 5.1 cpd is particularly useful for the reading of Chinese characters. Indeed, the indication from the regression analysis is that spatial frequencies of 1 and 10 cpd correspond to overall character extent and stroke width, respectively, which suggests more specifically that these spatial frequencies might be particularly valuable for readers of Chinese. The center frequency of this band, 3.2 cpd, resembles the peak of the spatial-contrast-sensitivity function of human vision (Campbell & Robson, 1968), suggesting that this pattern of reading performance has its foundations in the visibility of information in Chinese characters. Nevertheless, the range of viewing distances at which performance was optimal suggests that efficient reading of Chinese text can be achieved using a range of scales of information, and that the use of this information is somewhat flexible; however, the impaired performances that we observed for distances that were outside this optimal range indicate the limits of this flexibility.

Second, distances within the optimal range of 7.5–55.0 cm may be better suited to producing the eye-movement patterns that are essential in everyday Chinese reading. Morrison and Rayner (1981) noted that fixation duration increased slightly as viewing distance increased from 36 to 53 to 71 cm, and they suggested that this was probably because characters may be less discriminable at greater distances, resulting in longer fixations. The distances above the optimal range in our experiment (especially those of 92.5 cm and above) are thus likely to have produced substantial difficulty in character discrimination, which in turn induced longer fixation durations and therefore induced significantly slower reading rates. At the shorter distances in the experiment—those below the optimal range (2.5 cm and 5 cm)—characters subtended larger retinal-image sizes, with the result that more characters fell in the less sensitive parafovea and peripheral areas of vision, consequentially reducing the effective perceptual span, which may have contributed to the impairment in reading performance that we observed. In addition, readers experience different aspects of visual fatigue that is induced by adaptive changes in the resting states of accommodation and convergence in near vision (Owens & Wolf-Kelly, 1987); thus, the extremely short viewing distances of 2.5 and 5 cm that were used in our experiment may have exacerbated this situation. It is interesting to note that the optimal viewing distance of 7.5–55.0 cm that we observed in the experiment is also the range in which, given the length of human arms, material can be held comfortably in the hands for reading.

The finding that 7.5–55.0 cm is the optimal distance range in normal Chinese reading suggests that distances within this range are appropriate for normal Chinese text presentation in experiments. It should be noted, however, that the optimal viewing distance range that we observed was based on the use of Chinese text stimuli in standard print size (0.3 cm horizontally and vertically). If a display in an experiment does not have a resolution that is high enough to present Chinese characters accurately in standard print size, the retinal character sizes (2.3–0.3°) corresponding to those distances that are within the optimal distance range can be achieved by using distances that are greater than 55.0 cm. Nevertheless, caution should be taken when distances that are substantially outside the optimal range—especially those of 92.5 cm and larger—are considered as the viewing distance in an experiment that is designed to investigate normal Chinese reading. This is because the perception of Chinese characters at shorter distances is part of natural reading, and the processes that are involved may be disrupted when the viewing distance is considerably different from the viewing distances that are encountered in everyday reading. Indeed, abnormal viewing distances (e.g., 165, 194, and 200 cm; see Table 1) may bring their own confounding influences. As described by Leibowitz (1971), the initiation of oculomotor movements for focusing on stimuli is coupled with a subjective expectation that this action will be accompanied by a change in the size of the retinal image. The influence that this expectation has on the perception of size was demonstrated by Leibowitz and Moore (1966), who showed that different viewing distances altered the perceived extent of a stimulus, even though the stimulus in their experiment always occupied the same visual angle (1°).

In summary, the present study found that viewing distance has a substantial effect on performance in normal Chinese reading, and that when presenting Chinese characters in a common standard typeface, distances of 7.5–55.0 cm were an optimal range, one that produced the highest reading rates. This finding has implications for our understanding of the processes that are involved in normal Chinese reading and for the presentation of Chinese stimuli in experiments that are designed to study these processes. By presenting stimuli in experiments that are guided by the viewing distances and associated retinal-image sizes that were identified in the present study, experimenters can reveal more precisely the processes that are involved in Chinese character reading.

AUTHOR NOTE

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NOTES

1. Another technique for varying retinal-image size is to change the physical size of stimuli. Manipulating viewing distance rather than physical stimulus size provides a number of advantages for studying Chinese reading, however. For example, even graphical displays with the highest resolution cannot provide resolution that is adequate for smaller image sizes, which can create confounds in the construction of the visual image. In addition, although standard print sizes exist in Chinese, standard viewing distances do not. Consequently, using changes in physical image size to manipulate retinal-image size would require an arbitrary assumption about which single viewing distance to use, one that is based on little previous research (see Table 1). Selecting a standard size of print and varying the distance at which it is viewed, therefore, will provide information about the effectiveness of different retinal-image sizes for reading Chinese without these confounding assumptions about unknown components of the reading process.
2. It should be noted that modern Chinese text is normally printed in horizontal lines of characters and is read from top left to bottom right.
3. The regression analysis was conducted on the group averaged data. The details of the regression model ($R^2 = .838$), including coefficients, standard errors, and 95% confidence intervals (CI) are as follows: constant = 408.689 ($SE = 13.06$, $CI = 382.2$ to 435.2); $b_1 = 5.408$ ($SE = 1.09$, $CI = 3.196$ to 7.621); $b_2 = -0.0988$ ($SE = 0.0246$, $CI = -0.1486$ to -0.049); $b_3 = 0.0004$ ($SE = 0.0002$, $CI = 7.862E-5$ to 0.0007).
4. The generally greater variability in reading performance at the shorter end of the distance continuum is explained by the greater proportional change in distance that was produced by each 2.5-cm increment.

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