Dividing lines at the word boundary position helps reading in Chinese

Xingshan Li, Wenchan Zhao & Alexander Pollatsek

Psychonomic Bulletin & Review

ISSN 1069-9384
Volume 19
Number 5

Psychon Bull Rev (2012) 19:929-934
DOI 10.3758/s13423-012-0270-6

Psychon Bull Rev (2012) 19:929–934
DOI 10.3758/s13423-012-0270-6

BRIEF REPORT

Dividing lines at the word boundary position helps reading in Chinese

Xingshan Li · Wenchan Zhao · Alexander Pollatsek

Published online: 22 May 2012

Abstract Unlike in English, the Chinese printing and writing systems usually do not respect a word boundary when they split lines; thus, characters belonging to a word can be on two different lines. In this study, we examined whether dividing a word across two lines interferes with Chinese reading and found that reading times were shorter when characters belonging to a word were on a single line rather than on adjacent lines. Eye movement data indicated that gaze durations in a region around the word boundary were longer and fixations were closer to the beginnings and ends of the lines when words were split across lines. These results suggest that words are processed as a whole in Chinese reading, so that word boundaries should be respected when deciding how to split lines in the Chinese writing system. They also suggest that the length of return sweeps in reading can be cognitively guided.

Keywords Chinese reading · Line arrangement · Word processing

In English and other alphabetic writing systems, a word is not usually split across lines. If it is, a hyphen indicates that the word has been split, but the preferred typographical system is that, if a word is too long to fit at the end of a line, it will be printed at the beginning of the next line. In contrast, the Chinese printing and writing system usually does not do this. Although the current Chinese writing system is similar to the English writing system in that the characters go from left to right on a line and the lines run from the top to the bottom of the page, there is a key difference. Chinese characters are usually printed within same-sized spaces, and the right sides of the lines are aligned, so that each line has an equal number of characters, except for the first and last lines of a paragraph. (The first line in a paragraph is indented.)

Not only are word boundaries at the end of a line ignored in printed material, they are ignored in hand-written material. To confirm this, we counted the numbers of lines in which a multiple-character word was shown in one line or across two lines in the essays of a zoology class of 30 students. Among the 768 lines that had a multiple-character word (or part of a multiple-character word) at the line end, 63 % of the words were written on one line, and 37 % were written across lines. This suggests that Chinese writers do not always keep characters belonging to a word on the same line of text.

In English and in most alphabetic writing systems, the concept of a word is highlighted by the writing system, in that words are delimited by spaces. Linguistically, it isn't quite that simple, as some compound words are written with a space between the morphemes and some without, and usually there is no principled difference for the distinction (e.g., *basketball* vs. *tennis ball*). One possible reason that the English and other alphabetic writing systems do not split a word across two lines is that English readers process the letters belonging to a word as a whole (Reicher, 1969; Wheeler, 1970). Hence, presenting a word on two lines

X. Li (✉)
Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences,
Beijing, China
e-mail: lixs@psych.ac.cn

W. Zhao
China Agricultural University,
Beijing, China

A. Pollatsek
Department of Psychology, University of Massachusetts,
Amherst, MA, USA
e-mail: pollatsek@psych.umass.edu

prevents readers from processing the word as a unit, so that reading is slowed down. Hence, a word is usually printed on a single line to facilitate word recognition in English reading.

The Chinese writing system has some reasons for not dividing lines at word boundary positions. First, Chinese characters are so-called "square characters," and people apparently like the text to be arranged neatly. Second, because there are no spaces between words in natural reading, people might think that placing the line boundary between the characters has no effect on reading. Third, Chinese writers may simply attempt to fill each line with as many characters as possible. Taking these concepts together, it is not unreasonable that people would employ the choice to make each line have an equal number of characters, so that the text looks neater.

Words are also not as well defined in Chinese as in English. One important reason is the fact mentioned above, that there are no spaces between words. Chinese readers do not always agree with each other on where word boundaries are (Hoosain, 1991). (However, English readers may also disagree whether spaced compound words are one word or two.) These factors have made *some* Chinese linguists believe that words may not be so important in the Chinese grammar system, and as a result, they argue that characters are the basic unit in Chinese reading (Xu, 2005). However, it is widely accepted that words are important in Chinese reading and that they are the basic meaningful unit in the Chinese reading system (Huang & Liao, 1991).

Moreover, many studies have suggested that Chinese words have psychological reality and might be able to affect reading in Chinese. First, Cheng (1981) found that, similar to the word superiority effect in English, Chinese characters were identified more accurately in a word than in a string of characters that did not constitute a word. Second, Li and Pollatsek (2011) found that processing at the word level can feed back to low-level judgments, such as where a character is. Third, some eye movement measures in Chinese reading, such as fixation time and saccade length, are affected by word properties such as word frequency (Yan, Tian, Bai, & Rayner, 2006), predictability (Rayner, Li, Juhasz, & Yan, 2005), and length (Li, Liu, & Rayner, 2011). Fourth, a recent study (Li, Gu, Liu, & Rayner, 2012) has provided evidence that interrupting Chinese readers from simultaneously viewing two characters belonging to a word slows down their reading, as compared with when they can see both characters simultaneously. In that study, they used a novel variation of the moving-window paradigm in which the sentences contained only two-character words. The key comparison was between two conditions that each had two-character windows of normal text. In the word-window condition, the window contained the word that was being fixated, whereas in the nonword-window condition, the window contained adjacent characters from two words. As compared to the word-window condition, in the nonword-window condition, (1) reading times were longer, (2) the mean fixation duration was longer, (3) saccade lengths were shorter, and (4) there were more regressions. Hence, there was some cost when both characters belonging to a word were not shown simultaneously. In normal Chinese text, when the characters belonging to a word are shown in different lines, Chinese readers also can not process the characters belonging to a word simultaneously.

All of the above studies show that words are units of processing in Chinese and that processing the component characters simultaneously is facilitative, and thus these studies suggest that some cost in reading is involved when the characters belonging to a Chinese word are shown on two different lines. However, those studies employed either single words or a reading task that used unnatural displays. Hence, most of the studies provided only indirect evidence for word-based processing in reading. In this study, we examined whether viewing the component characters of a word is facilitative in normal Chinese reading by comparing two conditions in which the same passages of text were arranged differently. In one condition, the characters of the last word in a line were shown on the same line, and in the other condition, they were shown on two different lines. We examined overall reading times, as well as various eye movement measures, to try to diagnose any differences in reading times that would be observed in reading rates. In addition, to understand how general was any effect due to splitting words across lines, the difficulty of the text was manipulated. One possibility was that the effect of the line arrangement manipulation would have an effect only when the text conditions were more difficult (and readers really did have to process all of the words), but would have little or no effect when the text was easy, and the words could often be guessed from context.

Method

Participants

A group of 33 native Chinese speakers, who were students from universities in Beijing near the Institute of Psychology, Chinese Academy of Sciences, were paid to participate in the experiment. Their average age was 22.5 years old. All of them had normal or corrected-to-normal vision, and all were naive with regard to the purpose of the experiment.

Apparatus

Eye movements were recorded by an SR EyeLink 2000 eyetracker, which has a resolution of approximately 30′ of arc. Participants read the paragraphs (which were printed horizontally, from left to right) on a 21-in. CRT monitor (SONY Multiscan G520) connected to a DELL PC. The eyetracking system sampled at a rate of 2000 Hz and provided eye movement data for further analysis via another PC. The participants rested their heads on a chinrest to minimize head movements during the experimental trials. Viewing was binocular, but eye movement data were collected only from the right eye. The participants were seated 58 cm from the video monitor. The refresh rate of the CRT monitor was 150 Hz, and the resolution was 1,024 × 768. The participants pressed a button on a buttonbox (Microsoft SideWinder Game Pad) to answer comprehension questions that appeared periodically throughout the experiment.

Materials and design

We used 12 paragraphs for the experimental trials and two additional paragraphs for practice. We attempted to manipulate the difficulty of the passages a priori: Among the 12 experimental trials, four were children's stories (easy), four were stories from a brief introduction to American history (medium), and another four were taken from the Chinese translation of Hendrik Willem van Loon's *The Story of America* (difficult).[1] The difficult and medium paragraphs contained subject matter that was likely to be unknown to Chinese readers, in an attempt to reduce the impact of the different background knowledge of the participants. The lengths of the paragraphs were not significantly different across difficulty levels: all were approximately 160 characters long (with a minimum of 152 and a maximum of 171) and consisted of ten or eleven lines.

Among the 112 lines in all of these paragraphs, 97 lines that ended with all or part of a two-character word were selected as experimental lines, and the character positions of the last words in these lines were manipulated. In the *divided-word* condition, the last word in a line was always shown on two separate lines, with one of the characters at the end of one line and the other character at the beginning of the next. In the *word boundary* condition, the target word was always shown at the end of a line, and no word was shown crossing two lines. Hence, the text was left justified but not right justified. The numbers of lines were identical in the two boundary conditions (both were 10.33 lines, with an *SD* of 0.49 lines), and the numbers of characters per line were equal for the two conditions (both were 15.60, with an *SD* of 0.40). The paragraphs in these two line-arrangement conditions were counterbalanced across conditions, but the order of the presentation was randomized for each participant. There were equal numbers of trials in each condition, and each paragraph was shown in the divided-word condition for half of the participants, and in the word boundary condition for the other participants, using a counterbalanced design. Each paragraph was shown on the same screen. Custom-made software based on the UMass Eyetracking software was used to present the two conditions.

[1] Although the texts were chosen a priori to have three levels of difficulty, ratings from an independent set of participants suggested that the primary difference in difficulty was found between the easy/medium texts and the difficult ones. This difference was enough to serve our purpose, to show that the boundary manipulation effect generalized across different levels of text difficulty. As we will show later, the boundary effect was relatively similar for all three levels of difficulty, despite the much longer reading times for the difficult passages.

Procedure

When the participants arrived for the experiment, they were given the instructions for the experiment and a description of the apparatus. The eyetracker was calibrated at the beginning of the experiment, and the calibration was validated as needed. For calibration and validation, the participants looked at a dot that was presented at each of 3 × 3 locations on the display in a random order. The maximum error of the calibration was 0.5°. Each participant read two paragraphs for practice and the 12 experimental paragraphs in a different random order. The participants were told to read silently and that they would periodically be asked to answer questions about the sentences. These questions were asked after half of the 12 paragraphs that were read. The characters were shown in the Song font with a font size of 16. Each character extended about 0.6° × 0.6° square, and the distance between lines was about 0.9°.

Each trial started with a fixation box (1° × 1°) that was located where the first character of the paragraph would appear. After the participant had successfully fixated on the box, the entire paragraph appeared on the screen. After reading a paragraph, the participant pressed a response button on a button box, which led either to presentation of the comprehension question or the start of the next trial.

Data analysis

Fixations longer than 1,000 ms or shorter than 80 ms were disregarded in the analyses. A 2 (condition) × 3 (difficulty level) analysis of variance (ANOVA) or *t* test was carried out on each of the sets of data, using participants (*F* or *t*) as random effects.

Results and discussion

Accuracy

Three participants were removed from the analyses because their accuracy on the comprehension questions was close to 50 %. For the other participants, the accuracies in the word boundary condition, $M = 97$ %, $SE = 2$ %, and the divided-word boundary condition, $M = 93$ %, $SE = 2$ %, were not significantly different, $t(29) = 1.14$, $p > .20$. Accuracy was high in both conditions, indicating that participants could understand the reading material in these novel display conditions, although there was a hint that comprehension was slightly sacrificed in the divided-word condition.

Reading time

Reading times were significantly longer in the divided-word condition than in the word boundary condition (30.39 vs. 28.29 s), $F(1, 29) = 6.39$, $MSE = 3.09 \times 10^7$, $p < .05$, $\eta_p^2 = .18$ (see Table 1). There was also a large main effect of difficulty level, $F(2, 58) = 99.84$, $MSE = 4.82 \times 10^7$, $p < .001$, $\eta_p^2 = .78$. The reading times in the easy, medium, and difficult conditions were 23.72, 24.63, and 39.67 s, respectively. The interaction between the two factors was not close to significant ($F < 1$). Because of the large variability in reading times from paragraph to paragraph, we wanted to assess what fraction of the participants found an overall advantage in the word boundary condition over the divided-word condition. In fact, the effect was quite consistent (averaged over difficulty levels of the text): Among the 30 participants, 24 had shorter reading times in the word boundary condition, which was significantly above chance, $t(29) = 3.52$, $p < .005$.

Global eye movement measures

We first analyzed the text to see whether the boundary manipulation affected global measures of eye movements. In fact, it affected the number of fixations per passage, $F(1, 29) = 4.75$, $p < .05$, $\eta_p^2 = .14$, $MSE = 384$, but not the mean fixation duration, $F < 1$ (see Table 1). In contrast, the passage difficulty manipulation influenced both measures, $F(2, 58) = 106.50$, $MSE = 498$, $p < .001$, $\eta_p^2 = .79$, and $F(2, 58) = 35.80$, $MSE = 70.64$, $p < .001$, $\eta_p^2 = .55$, respectively. In both cases, the interaction was not close to significant, Fs < 1. The lack of an effect of the boundary manipulation on mean fixation durations suggests that the boundary manipulation was not causing a global change in how the readers were going through the texts.

Local reading time measures

Obviously, the global reading times contain a lot of variability unrelated to the word boundary manipulation. However, because individual fixations at the beginnings and ends of lines usually also are quite variable, we thought that the best level of analysis was to define a region of interest (ROI) that contained the target word (word$_n$) and the words before and after it (word$_{n-1}$ and word$_{n+1}$). Gaze duration (or first-pass time) on the region was a natural measure. This is the sum of the fixation durations on the region between when the reader entered it from the left until the reader left it in either direction. The values in Table 1 are averaged over all of the ROIs in a condition in which there was a boundary manipulation (i.e., there was no boundary manipulation on some lines). There was a large and significant gaze duration difference on the ROI between the word boundary and divided-word conditions (401 vs. 452 ms), $F(1, 29) = 10.20$, $MSE = 11{,}803$, $p < .005$, $\eta_p^2 = .26$. There was also a main effect of difficulty, $F(2, 58) = 9.77$, $MSE = 5{,}105$, $p < .001$, $\eta_p^2 = .25$, but the interaction was not close to significant, $F < 1$ (see Table 1). There was some concern that this region was too large. However, when it was defined to be only the target word and the following character, the gaze duration effect was quite similar (246 vs. 306 ms), $F(1, 29) = 24.34$, $MSE = 6{,}737$, $p < .001$, $\eta_p^2 = .46$.

Another measure of local processing in a region is total time, which is the gaze duration measure defined above plus the duration of any fixations when the reader regresses back to the ROI. There was an even greater effect of the boundary manipulation on total time in the ROI (667 ms in the word boundary condition vs. 779 ms in the divided-word condition), $F(1, 29) = 20.79$, $MSE = 27{,}132$, $p < .001$, $\eta_p^2 = .42$. We also found a main effect of difficulty, $F(2, 58) = 73.89$, $MSE = 23{,}977$, $p < .001$, $\eta_p^2 = .72$. Although the interaction was not significant, $F(2, 58) = 1.33$, $p > .1$, there was an indication that the word boundary effect on total time was less in the easy condition (see Table 1).

The number of fixations in the ROI was also greater in the divided-word condition (2.69 fixations) than in the word boundary condition (2.39 fixations), $F(1, 29) = 10.62$, $MSE = 0.37$, $p < .005$, $\eta_p^2 = .27$. We also found a main effect of difficulty, $F(2, 58) = 105.91$, $MSE = 0.27$, $p < .001$, $\eta_p^2 = .79$, but the interaction was not significant, $F < 1$.

First and last landing position on a line

Since the words in the ROI were in different locations in the two boundary conditions, and because readers usually do not look at the very end of a line nor the very beginning of a line, we did not think it was of much interest to compare individual fixation durations in the ROI. Instead, we examined the landing positions of the last fixation of a line and the first fixation on the following line in the first reading pass, regardless of whether they were on the last word or the first word. The location of the last fixation was indexed from the end of the line; if the last fixation was on the last character, this was scored as a "1," if it was on the next-to-last character, this was scored as a "2," and so forth. The last landing position was significantly closer to the end of the line in the divided-word condition than in the word boundary condition (1.98 vs. 2.22 characters), $F(1, 29) = 14.38$, $MSE = 0.17$, $p < .001$, $\eta_p^2 = .33$. No other effects were significant (ps > .10).

The landing position of the first fixation on a line was scored analogously to the procedure above, with a fixation landing on the first character scored as a "1," and the pattern

Table 1 Reading measures

	Passage Difficulty					
	Easy		Middle		Difficult	
	Divided	Boundary	Divided	Boundary	Divided	Boundary
Reading time (s)	24.44 (1.58)	22.99 (1.43)	25.93 (1.53)	23.34 (1.49)	40.79 (2.75)	38.55 (2.44)
Number of fixations per passage	89.90 (5.28)	85.30 (4.80)	93.40 (4.95)	84.18 (4.92)	142.32 (8.34)	137.02 (8.10)
Mean fixation duration per passage (ms)	228 (5)	229 (5)	234 (4)	233 (5)	243 (4)	239 (5)
Gaze duration on ROI[a] (ms)	429 (28)	382 (19)	446 (21)	383 (18)	482 (25)	436 (21)
Total time on ROI[a] (ms)	635 (50)	576 (35)	703 (44)	582 (33)	998 (56)	842 (53)
Number of fixations on ROI[a]	2.18 (0.15)	2.07 (0.11)	2.34 (0.15)	1.97 (0.11)	3.55 (0.20)	3.14 (0.26)
Landing position of last fixation on a line (characters)	2.00 (0.08)	2.18 (0.08)	1.99 (0.08)	2.32 (0.07)	1.96 (0.09)	2.15 (0.11)
Landing position of first fixation on a line (characters)	2.56 (0.11)	2.63 (0.11)	2.46 (0.10)	2.69 (0.11)	2.38 (0.11)	2.66 (0.10)

The numbers in the parentheses are standard errors

[a] See the text for a definition of the ROIs

was similar to the above. Here, the first fixation was closer to the beginning of a line in the divided-word condition (2.47 vs. 2.66 characters), $F(1, 29) = 12.63$, $MSE = 0.13$, $p < .001$, $\eta_p^2 = .30$, and no other effects were significant (ps>.1). We think it plausible that these landing phenomena explain why there were about five more fixations per passage in the divided-word condition.

General discussion

We found that passage reading times were longer if a Chinese word was shown across different lines than if it was shown on the same line. Further analyses indicated that a large fraction of the effect could be explained by the processing times in the narrow ROI containing the target word. In particular, almost half of the 2 s difference in passage reading times between the divided-word and word boundary conditions could be explained by the total time in the ROIs (110 ms difference per ROI times about eight ROIs per passage). Moreover, there was virtually no general slowdown in fixation durations due to the boundary manipulation, again suggesting that the effects of the word boundary manipulation were localized.

The results of the present study are consistent with those of the Li et al. (2012) moving-window study discussed earlier, which demonstrated that reading speed was slowed down if participants could not view the characters belonging to a word simultaneously. It is not clear, however, what the most important mechanism for this slowdown is. One possibility is that having to store the first part of the word in some sort of short-term memory buffer exerts a penalty. A second possibility is that seeing the entire word at the end of the line in the parafovea in the word boundary condition would be an important contributor to the better performance in the word boundary condition. In future studies, we will obviously have to explore the efficacy of preserving words at the beginnings as well as at the ends of lines. The third is that seeing only the first part of a two-word compound caused people to misparse the compound and treat the first character as a one-character word. Further studies will be needed in which the linguistic properties of the words will be varied.

As we indicated earlier, we did not closely examine individual fixation times on the words in the ROIs, especially because comparing individual fixation times on the target word would be close to meaningless. However, an interesting finding emerged from examining the fixation locations—particularly, those of the last fixation on one line and the first fixation on the subsequent line. That is, the last fixation on the line in the divided-word condition was closer to the end of the line, and the first fixation at the beginning of the line was closer to the beginning. This is probably a contributor to why gaze durations were longer in the ROI for the divided-word condition. It also suggests that—some of the time when a divided word was encountered—the reader realized that the rest of the word (perhaps a single character) was at the beginning of the next line, and thus that an eye movement needed to be directed quite close to the beginning of the next line in order to encode it. What we think makes this finding particularly interesting is that we know of no prior experiment that has demonstrated that this kind of higher word-level information directs return sweeps in reading.

The results of the present study also clearly show that the difficulty of Chinese reading affects eye movements in Chinese reading. The number of fixations and the average fixation durations increased with the difficulty levels of the reading material, indicating that eye movement control is directly influenced by the contents of the texts being read, which is consistent with reading in English and in other alphabetic languages (e.g., Jacobson & Dodwell, 1979; Rayner & Pollatsek, 1989). What is also of interest, however, is that the difficulty of the passage did not interact with the text arrangement manipulation. This indicates that the text arrangement manipulation only affected relatively low-level word identification processes, and that the disruption of these word identification processes has limited interaction with the difficulty of the text.

The data of the present study also suggest that the arrangement of Chinese reading might need reconsideration. As indicated above, it appears that a major motivation for having equal numbers of characters per line in standard Chinese printing (and even writing) is so that the texts look neat—and specifically, so that the right ends of the lines are aligned. However, two obvious ways can be used to avoid splitting words between lines. The first is what was done in the present study, which is analogous to left justification; however, then the right sides of the lines are not aligned, and some neatness is sacrificed. However, if something analogous to full justification in alphabetic languages were employed, in which the sizes of the spaces between characters were varied so that both the left and right sides of the lines would still be aligned, the outcome might be deemed to be sufficiently neat. One obstacle to employing either of these methods previously has been that they would have been technically close to impossible. But now, with word processing tools, it would be very easy to implement either of these formats in Chinese printing, and in the Chinese writing system more generally.

Author note This research was supported by the Opening Project of State Key Laboratory of Digital Publishing Technology, the Knowledge Innovation Program of the Chinese Academy of Sciences (KSCX2-YW-BR-6), and by a grant from the Natural Science Foundation of China (31070904). We thank Pingping Liu for her help when preparing the stimuli and programming the experiment. We also thank Sarah White and Albrecht Inhoff for their helpful comments on an earlier version of the manuscript.

References

Cheng, C. M. (1981). Perception of Chinese characters. *Acta Psychologica Taiwanica*, *23*, 137–153.

Hoosain, R. (1991). *Psycholinguistic implications for linguistic relativity: A case study of Chinese*. Hillsdale, NJ: Erlbaum.

Huang, B. R., & Liao, X. D. (1991). *Modern Chinese*. Beijing, China: Higher Eduction Press.

Jacobson, J. Z., & Dodwell, P. C. (1979). Saccadic eye-movements during reading. *Brain and Language*, *8*, 303–314.

Li, X. S., Gu, J. J., Liu, P. P., & Rayner, K. (2012). *The psychological reality of words in Chinese reading: Evidence from eye movements*. Manuscript submitted for publication.

Li, X. S., Liu, P. P., & Rayner, K. (2011). Eye movement guidance in Chinese reading: Is there a preferred viewing location? *Vision Research*, *51*, 1146–1156.

Li, X. S., & Pollatsek, A. (2011). Word knowledge influences character perception. *Psychonomic Bulletin & Review*, *5*, 833–839.

Rayner, K., Li, X. S., Juhasz, B., & Yan, G. (2005). The effect of word predictability on the eye movements of Chinese readers. *Psychonomic Bulletin & Review*, *12*, 1089–1093.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice Hall.

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology*, *81*, 275–280.

Wheeler, D. D. (1970). Processes in word recognition. *Cognitive Psychology*, *1*, 59–85.

Xu, T. Q. (2005). Character as the basic structural unit and liguistic studies. *Language Teaching and Linguistic Studies*, 1–11.

Yan, G. L., Tian, H. J., Bai, X. J., & Rayner, K. (2006). The effect of word and character frequency on the eye movements of Chinese readers. *British Journal of Psychology*, *97*, 159–268.