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Joint effect of insertion of spaces and word length in saccade target selection in Chinese reading

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The present study examined how insertion of spaces before and after a word affects saccade target selection in Chinese reading. We found that inserting spaces in Chinese text changes the eye movement behaviour of Chinese readers. They are less likely to fixate on the character near the space and will try their best to process the entire word with less fixation when a space is inserted after a word, making the final characters in a long word less likely to be fixated on. However, we did not find evidence that they target their eyes at the word centre when a space is inserted before or after a word. These results enhance our understanding of the mechanisms of eye movement control in Chinese reading.

In English reading, readers target a preferred viewing location (PVL) that is halfway between the beginning and the middle of a word when they move their eyes (Rayner, 1979). English readers can do so because of the presence of interword spaces that provide visual cues for word segmentation, thereby helping target selection in reading. In contrast, there are no spaces between words in Chinese reading. Hence, it is unclear how Chinese readers accomplish target selection when they move their eyes during reading.

When studying saccade target selection in reading, researchers usually draw an initial landing position distribution curve on a specific region of interest (ROI), which is called the PVL curve. The PVL curve peaks halfway between the beginning and the middle of a word in English reading, indicating that English readers target the word centre when they plan their eye movements. On the other hand, some eye movement studies in Chinese reading have reported flat PVL curves (Tsai & McConkie, 2003; Yang & McConkie, 1999), which do not support a word-based saccade target selection strategy.

Yan, Kliegl, Richter, Nuthmann and Shu (2010) explored the landing positions in two-, three- or four-character long words in Chinese reading and found that PVL curves peak at the beginning of words. They divided the data into two parts based on the number of fixations on a word: the PVL curves peak at the beginning of a word in cases with two or more fixations, and at the word centre for single fixations. Based on these findings, they proposed that Chinese readers target their eyes at the word centre when they can segment the word with parafoveal vision, and at the beginning of a word when they cannot do so. However, Li, Liu and Rayner (2011) presented simulation results showing that even a simple model that assumes that saccades travel at constant distances could generate the same kind of initial fixation distributions observed by Yan et al. (2010). Li et al. (2011) therefore suggested that the results of the study conducted by Yan et al. (2010) do not necessarily support the view that Chinese readers target their eyes at the word centre when they can segment a word with parafoveal vision and at the beginning of a word when they cannot do that.

In order to further test whether Chinese readers target their eyes at word centres, Li et al. (2011) designed an experiment in which either a two- or a four-character word was embedded in the same sentence frame. They analysed a four-character ROI that contained the target word, as well as two characters following the target word in the two-character word condition, and the whole target word in the four-character word condition. If Chinese readers have a tendency to target at the word centre, then the peak of the PVL curve in the four-character word condition should be further to the right compared with that in the two-character word condition. However, their analysis yielded PVL curves that were almost identical for the two conditions. Hence, no evidence was found to support the view that Chinese readers target their eyes to word centre during reading.

Previous studies have shown that interword spaces are very important for eye movement guidance in English reading and that eye movement behaviour changes when spaces are removed (Morris, Rayner & Pollatsek, 1990; Perea & Acha, 2009; Rayner, Fischer & Pollatsek, 1998). Recent studies have shown that inserting spaces between words affects eye movements during target selection in Chinese reading as well (Bai et al., 2011, 2012; Liu & Li, in press; Zang, Liang, Bai, Yan & Liversedge, in press). Zang et al. (in press) examined how interword spaces influence the eye movement behaviour of both adults and children by inserting spaces between words. They found that initial fixations tended to land near the word centre more in the spaced condition than in the unspaced condition, suggesting that inserting spaces between words does affect target selection in Chinese reading.

Previous studies have shown that inserting a space before or after a word affects word processing differently. Liu and Li (in press) examined whether facilitation of word processing occurs when spaces are added in Chinese reading. No facilitation of word processing was observed when a space was inserted before a word. However, when a space was inserted after a word, both the duration and number of fixations decreased, suggesting that word processing was facilitated under this condition. Furthermore, they found that the inserted spaces also affected the initial landing position on words. Specifically, initial fixations occurred further into the words and away from the space in both the space-before and space-after conditions compared with the unspaced condition.

The observation that inserting a space before or after a word affects eye movements differently is not totally surprising. In fact, this was predicted by a Chinese word segmentation and recognition model proposed by Li, Rayner and Cave (2009). This model adopts some of the assumptions of the interactive activation model (McClelland & Rumelhart, 1981; Taft, Zhu & Peng, 1999), and assumes that Chinese word recognition involves multiple levels of processing, namely a visual perception level, a character recognition level and a word segmentation and recognition level. Word segmentation and recognition is an interactive process. The model assumes that characters are processed in parallel at the character recognition level, while words are recognised serially. When some characters are partially activated, they feed forward to activate words at the word processing level. The activated words compete with each other until a single word finally wins the competition and it is recognised. When a word is recognised, it is also segmented from the rest of the sentence.

The model assumes that the processes of recognition and segmentation of a word cannot be distinguished from each other. This suggests that word n is segmented once it is recognised, and at the same time, both the right boundary of word n and the left boundary of word n + 1 will be clear. Therefore, the model predicts that insertion of a space before word n + 1 can provide readers with clear left boundary information. However, since the left boundary of word n + 1 is automatically marked after recognising word n, this information is not helpful for the segmentation of word n + 1. In addition, adding a space would obstruct the parafoveal preview of word n + 1 when compared with the unspaced condition. For this reason, there is no facilitation in the processing of word n + 1 when a space is inserted before it. In contrast, when a space is inserted after word n, the explicit right boundary clues combined with the clear left boundary information offered by the segmentation of word n – 1 may help readers segment the word n out of the rest of the sentence before recognising it.

In the present study, we explore how insertion of a space either before or after a word affects eye movement guidance in Chinese reading. We inserted a space either before a target word (space-before condition) or after a target word (space-after condition), or did not insert a space at all (unspaced condition). We also manipulated the length of the target word. The target word was either a two-character or a four-character word, which was embedded within the same sentence frame. Previous studies have shown that word length influences eye movement in reading (Just & Carpenter, 1980; Rayner, Sereno & Raney, 1996). Importantly, the peaks of PVL curves shift right as word length increases (McConkie, Kerr, Reddix & Zola, 1988; Rayner, 1979). We explored the effect of word length and its interaction with space location in eye guidance during Chinese reading.

Previous studies found no evidence to support the view that Chinese readers target their eyes on the word centre (Li et al., 2011). Therefore, the question of whether inserting a space before or after a word makes Chinese readers target their eyes at word centre remains unanswered. The model proposed by Li et al. (2009) posits that word segmentation and word recognition are parts of a unified process. Since inserting a space before a word does not provide any information about the right boundary of the word, we did not expect Chinese readers to target their eyes at the word centre. Inserting a space to the right of a word may provide some information about the right side of the word boundary, especially when the eyes are close to the inserted space. Hence, inserting a space after a word might make Chinese readers more likely to fixate on the centre of a word. If this is the case, the initial landing position should differ between the two conditions for different word lengths.

Moreover, we further explored whether inserting a space after a word would affect eye movement behaviour once the target word is fixated and how it would interact with word length. Wei, Li and Pollatsek (in press) suggested that Chinese readers process as many characters as possible during each fixation, and the target of the next saccade is programmed to be somewhere beyond the processed characters. Characters that belong to a word are usually processed as a unit in Chinese reading (Li, Gu, Liu & Rayner, in press). Hence, characters that belong to a single word are easier to process than the same number of characters that belong to multiple words (Li et al., 2009). Once the first character that belongs to a long word is fixated, more characters can be processed. Therefore, the final characters of a long word should be less likely to be fixated. Li et al. (2011) found a trend like this, but the effect was not significant. Inserting a space after a word gives readers some information about word boundary and helps readers with word segmentation, so that readers could focus attention on the fixated word. Indeed, Li and Liu (in press) showed that inserting a space after a word facilitates processing of the fixated word, enabling quick processing of the word. Hence, insertion of a space after a word makes the final characters of a long word less likely to be fixated than the initial characters of a long word or the characters of a short word. We tested this prediction in the present study.

Additionally, we sought to confirm the findings of previous studies that Chinese readers target their eyes further away from space (Li et al., 2011; Zang et al., in press). The perceptual span in Chinese reading is one character to the left of the fixation point and two or three characters to the right of the fixation point (Inhoff & Liu, 1998). As a result, Chinese readers do not need to fixate at the neighbouring character of the space to efficiently perceive the word. Hence, we expected the landing position to be further away from the space than in the unspaced condition.

Methods

Participants

Forty-eight participants (27 women and 21 men) were recruited from universities in Beijing that are near the Institute of Psychology, Chinese Academy of Sciences. The participants, who were paid to participate in this experiment, had normal or corrected-to-normal vision. Their ages ranged from 19 to 27 years (M = 22.3 years).

Apparatus

Eye movements were recorded using an EyeLink 1000 eye tracker (SR Research Ltd, Mississauga, Ontario, Canada). Participants were instructed to read sentences (which were presented horizontally from left to right on a single line) on a 19-inch CRT monitor (resolution: 1,024 × 768 pixels; refresh rate: 100 Hz) connected to a Dell PC (Dell Inc.). A chinrest was utilised to minimise head movement during the experiment. Viewing was binocular, but only the right eye was monitored. Participants were seated 58 cm away from the monitor, at this distance one character subtended a visual angle of approximately 0.6°.

Material and design

Eighty-four experimental sentence frames and 20 practical sentences were selected from Li et al. (2011). A two-character word and a four-character word were embedded into each sentence frame. All the two-character target words in the two-character condition were carefully selected such that they did not make up a four-character word with the following two characters. In the four-character condition, neither the first two characters nor the last two characters constituted a word by themselves. The character complexity, measured by the mean number of strokes of characters, was not significantly different across the two-character condition (M = 7.98, SD = 2.44) and the four-character condition (M = 7.53, SD = 1.86). As in English, word frequency is highly correlated with word length. The frequencies of longer words are usually lower than those of shorter words. Hence, we could not control word frequencies in these two conditions well. The word frequency of the target word in the two-character condition (M = 64.23, SD = 123.43) was higher than that of the four-character condition (M = 1.57, SD = 1.36). In one-third of the trials, a space was inserted before the target word (space-before condition); in another one-third of the trials, a space was inserted after the target word (space-after condition); and there was no space in the sentence in the remaining one-third of the trials (unspaced condition). Hence, this experiment was a 2 (word length) × 3 (spacing condition: space-before, space-after and unspaced conditions) design, and there were 14 sentences for each condition. Each participant was allowed to read one version of each sentence frame only once. The sentences were randomly presented, with the 20 practice sentences presented at the beginning of the experiment.

Procedure

Before the experiment, participants were given instructions and a brief introduction of the eye tracker. The eye tracker was calibrated and validated at the beginning of the experiment, and participants performed this procedure by looking at a white dot randomly presented in the middle of the screen. The calibration error was smaller than 0.5° of the visual angle. Afterwards, each participant read 20 practice sentences, followed by 84 experimental sentences. Each participant was tested individually, and calibration was conducted when necessary during the experiment. Participants were instructed to read the sentences silently for comprehension, and 30% of the sentences were followed by comprehension questions. Drift correction was conducted at the beginning of each trial, and participants had to fixate on a white square (1° × 1° in size) located at the first character of the sentence before the sentence was shown. Participants had to press a button on the bottom box to start the next trial. The experiment lasted about 30 minutes.

Results

Accuracy

Mean accuracy for the comprehension questions was 92%. When all accuracy data were analysed by repeated-measure analysis of variance (ANOVA) with spacing conditions and word length as within-participant factors, no main effect or interaction effect was found to be significant, *F*s < 1. These results suggest that the participants could indeed understand the sentences equally well.

Eye movement measures on target word

An eye blink usually lasts about 200–250 ms during reading (Volkmann, Riggs & Moore, 1980) and readers cannot gain any useful information during this period due to visual suppression (Manning, Riggs & Komenda, 1983). To minimise the interference on fixation durations caused by eye blinks, trials due to a track loss or with more than three eye blinks were excluded from the analyses, resulting in 8% of the trials being excluded. Furthermore, 1.3% of fixations were also excluded from analyses because they were shorter than 80 ms or longer than 1,000 ms. We calculated the first fixation duration and gaze duration on the target word to examine the effects of inserting a space before or after a word. The data are shown in Table 1. Eye movement measures were subjected to a series of repeated-measure ANOVA with spacing conditions and target word length as within-participant factors, using participants (F_1) and items (F_2) as random variables.

For the first fixation duration, there was a main effect of spacing type, $F_1(2,94) = 6.61$, $p = .002$, $\eta_p^2 = .12$, MSE = 5,843; $F_2(2,166) = 6.78$, $p = .001$, $\eta_p^2 = .07$, MSE = 10,447. First fixation durations for the space-after condition ($M = 256$ ms, $SE = 5$ ms) were significantly shorter than those for the unspaced condition ($M = 266$ ms, $SE = 6$ ms; $F_1(1,47) = 4.65$,

Table 1. Eye movement measures on target words in different spacing conditions.

	Space before		No space		Space after	
	2-character	4-character	2-character	4-character	2-character	4-character
First fixation duration	269(6)	273(6)	267(7)	265(6)	253(7)	258(6)
Gaze duration	299(9)	391(14)	293(9)	397(14)	278(9)	361(14)

Notes: First fixation durations and gaze duration are measured in milliseconds. Standard deviations are reported in parentheses.

$p < .05$, $\eta_p^2 = .09$, MSE = 10,643; $F_2(1,83) = 4.14$, $p < .05$, $\eta_p^2 = .05$, MSE = 12,869) or the space-before condition ($M = 271$ ms, $SE = 6$ ms; $F_1(1,47) = 17.53$, $p < .001$, $\eta_p^2 = .27$, MSE = 22,285; $F_2(1,83) = 14.51$, $p < .001$, $\eta_p^2 = .15$, MSE = 41,613). First fixation durations for the unspaced condition ($M = 266$ ms, $SE = 6$ ms) were also numerically shorter than those for the space-before condition ($M = 271$ ms, $SE = 6$ ms). However, this difference was not significant, $F_1(1,47) = 1.22$, $p > .10$; $F_2(1,83) = 2.51$, $p > .10$. Moreover, the main effect of target word length and the interaction between spacing type and word length was not significant, Fs < 1.

Gaze duration had a similar pattern. There was a main effect of spacing type, $F_1(2,94) = 5.49$, $p = .006$, $\eta_p^2 = .11$, MSE = 20,263; $F_2(2,166) = 8.25$, $p < .001$, $\eta_p^2 = .09$, MSE = 38,978. Gaze durations in the space-after condition ($M = 319$ ms, $SE = 11$ ms) were significantly shorter than in the space-before condition ($M = 345$ ms, $SE = 10$ ms, $F_1(1,47) = 7.39$, $p = .009$, $\eta_p^2 = .14$, MSE = 61,157; $F_2(1,83) = 13.07$, $p = .001$, $\eta_p^2 = .14$, MSE = 120,859) or the unspaced condition ($M = 345$ ms, $SE = 10$ ms, $F_1(1,47) = 6.79$, $p < .05$, $\eta_p^2 = .13$, MSE = 60,416; $F_2(1,83) = 12.31$, $p = .001$, $\eta_p^2 = .13$, MSE = 112,878). No difference was obtained for the gaze duration in the space-before condition ($M = 345$ ms, $SE = 10$ ms) and that in the unspaced condition ($M = 345$ ms, $SE = 10$ ms, Fs < 1). Gaze durations in the two-character condition ($M = 289$ ms, $SE = 7$ ms) were significantly shorter than those in the four-character condition ($M = 383$ ms, $SE = 12$ ms, $F_1(1,47) = 139.18$, $p < .001$, $\eta_p^2 = .75$, MSE = 622,197; $F_2(1,83) = 114.05$, $p < .001$, $\eta_p^2 = .58$, MSE = 986,305). Interaction between the two factors was not significant, $F_1(2,94) = 1.19$, $p > .10$; $F_2(2,166) = 1.97$, $p > .10$.

In summary, the results of the present study generally replicate the findings of a previous study (Liu & Li, in press) showing that the insertion of a space after a word facilitates the processing of the word, but the insertion of a space before a word did not facilitate the processing of the word.

Initial landing position on a four-character ROI

To explore whether insertion of spaces causes Chinese readers to have a tendency to look at the centre of a word, we drew a PVL curve on a four-character ROI in all conditions (Figure 1). If Chinese readers target their eyes at the centre of words, the PVL curve for the four-character condition should shift to the right compared to the curve for the two-character condition. For the unspaced and the space-before conditions, the four-character ROI was aligned to the beginning of the target words; thus, the ROI was composed of a two-character target word and the following two characters for the two-character condition. For the space-after condition, the ROI was aligned to the right side of the target word and the ROI included a two-character target word and the preceding two characters for the

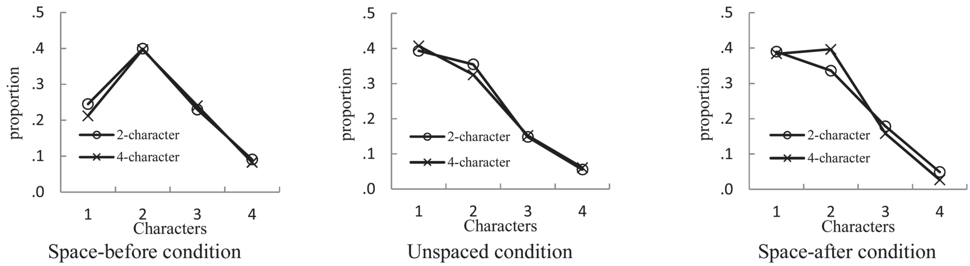

Figure 1. Proportions of initial fixations on different character positions.

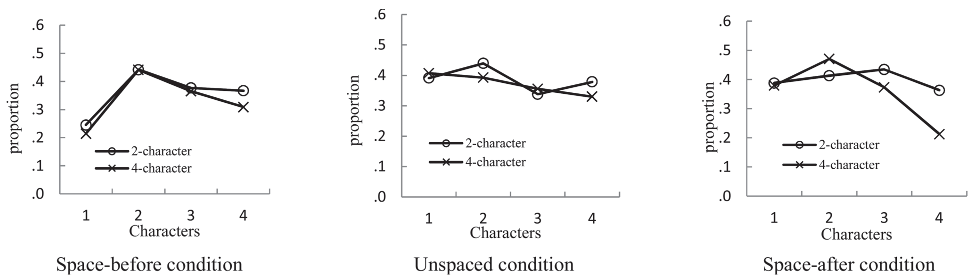

Figure 2. Proportions of all forward fixations at different character positions on a four-character ROI.

two-character condition. The proportions of the initial landing position of the different characters on a four-character ROI were subjected to a 3 (spacing type: space-before condition, unspaced condition or space-after condition) × 2 (word length: two-character condition or four-character condition) × 3 (character position: first character, second character or third character) repeated-measures ANOVA with participants (F_1) and items (F_2) as random variables. Our major interest was to examine whether inserting a space either before or after a word makes Chinese readers target their eyes at the centre of a word. Hence, we also carried out a 2 (word length: two-character condition or four-character condition) × 3 (character position: first character, second character or third character) repeated-measures ANOVA for each spacing condition to examine how word length affects landing position in different spacing conditions. Note that only three characters were analysed even though we show four characters in Figure 2. This was done since the proportions at the four positions added up to one, indicating that they are not independent.

The proportions of the initial landing position were affected by spacing type $F_1(2,94) = 7.30$, $p < .001$, $\eta_p^2 = .13$, MSE = 0.03; $F_2(2,166) = 13.82$, $p < .001$, $\eta_p^2 = .14$, MSE = 0.05 and character position, $F_1(2,94) = 39.16$, $p < .001$, $\eta_p^2 = .45$, MSE = 3.25; $F_2(2,166) = 121.25$, $p < .001$, $\eta_p^2 = .59$, MSE = 4.99. Planned contrasts revealed that the proportions of initial fixations in the space-after condition ($M = .31$, $SE = .004$) were significantly higher than those in the space-before condition ($M = .29$, $SE = .007$, $F_1(1,47) = 9.28$, $p = .004$, $\eta_p^2 = .17$, MSE = 0.04; $F_2(1,83) = 26.48$, $p < .001$, $\eta_p^2 = .24$, MSE = 0.07) and also higher than that in the unspaced condition ($M = .30$, $SE = .005$, $F_1(1,47) = 7.78$, $p = .008$, $\eta_p^2 = .14$, MSE = 0.01; $F_2(1,83) = 8.13$, $p = .005$, $\eta_p^2 = .09$, MSE = 0.02). In addition, the proportions of initial fixations in the unspaced condition ($M = .30$, $SE = .005$) were also higher than those in the space-before condition ($M = .29$, $SE = .007$). However, the difference was significant in the item analysis, $F_2(1,83) = 6.27$, $p < .05$, $\eta_p^2 = .07$, MSE = 0.02 and marginally significant in the subject analysis, $F_1(1,47) = 3.87$, $p = .06$, $\eta_p^2 = .08$, MSE = 0.01. Since the proportions of fixation in the four positions add up to 1 for each condition, the difference between these conditions was likely to be caused by the fixation probability difference in the fourth condition. For the space-after condition, the final character of the target word was less likely to be fixated, so the fixation probabilities in the other three character positions were higher than that of the unspaced condition. The initial landing positions were less likely to fall on the third character position ($M = .18$, $SE = .01$) than the first character ($M = .34$, $SE = .02$, $F_1(1,47) = 33.76$, $p < .001$, $\eta_p^2 = .42$, MSE = 2.23; $F_2(1,83) = 115.01$, $p < .001$, $\eta_p^2 = .58$, MSE = 4.06) or the second character position ($M = .37$, $SE = .01$, $F_1(1,47) = 75.24$, $p < .001$, $\eta_p^2 = .62$, MSE = 3.25; $F_2(1,83) = 255.53$, $p < .001$, $\eta_p^2 = .76$, MSE = 5.77). In addition, the proportions of initial fixations on the second character position ($M = .37$, $SE = .01$) were also higher than in the first character position ($M = .34$, $SE = .02$) and the difference reached significance only in the item analysis, $F_2(1,83) = 6.17$, $p < .05$, $\eta_p^2 = .07$, MSE = 0.15, not in the subject analysis, $F_1(1,47) = 2.90$, $p = .10$. Since character position was involved in the interaction, we will discuss these differences later.

More importantly, a significant interaction between spacing type and character position was also observed, $F_1(4,188) = 20.99$, $p < .001$, $\eta_p^2 = .31$, MSE = 0.64; $F_2(4,332) = 27.85$, $p < .001$, $\eta_p^2 = .25$, MSE = 0.99. In the space-before condition, the proportion of initial fixations on the second character was higher ($M = .40$, $SE = .02$) than those of fixations on the first character position ($M = .23$, $SE = .02$, $F_1(1,47) = 35.39$, $p < .001$, $\eta_p^2 = .43$, MSE = 1.37; $F_2(1,83) = 83.03$, $p < .001$, $\eta_p^2 = .50$, MSE = 2.45) and the third character position ($M = .23$, $SE = .02$, $F_1(1,47) = 21.10$, $p < .001$, $\eta_p^2 = .31$, MSE = 1.28; $F_2(1,83) = 59.53$, $p < .001$, $\eta_p^2 = .42$, MSE = 2.27). In addition, no difference was observed between the proportions of initial fixations on the first character ($M = .23$, $SE = .02$) and the third character ($M = .23$, $SE = .02$, Fs < 1). These results suggest that Chinese readers avoid fixating on the first character when a space is inserted before a word.

In the unspaced condition, the initial landing fixations were more likely to fall on the first character ($M = .40$, $SE = .02$) of the ROI than on the second character position ($M = .34$, $SE = .02$; $F_1(1,47) = 4.89$, $p < .05$, $\eta_p^2 = .09$, MSE = 0.17; $F_2(1,83) = 5.77$, $p < .05$, $\eta_p^2 = .07$, MSE = 0.29) or the third character position ($M = .15$, $SE = .01$, $F_1(1,47) = 55.61$, $p < .001$, $\eta_p^2 = .54$, MSE = 2.92; $F_2(1,83) = 149.89$, $p < .001$, $\eta_p^2 = .64$, MSE = 5.25), and the probability of fixations falling on the second character ($M = .34$, $SE = .02$) was also higher than that of falling on the third character ($M = .15$, $SE = .01$, $F_1(1,47) = 58.07$, $p < .001$, $\eta_p^2 = .55$, MSE = 1.69; $F_2(1,83) = 96.94$, $p < .001$, $\eta_p^2 = .54$, MSE = 3.07). These results confirmed findings from previous studies (Li et al., 2011; Yan et al., 2010), which showed that PVL curves peak at the word beginning in natural sentence reading.

In the space-after condition, the PVL curves were similar to those in the unspaced condition. The proportion of initial fixation peaked at the beginning of a word, and decreased linearly from left to right. The proportions of fixations on the first ($M = .38$, $SE = .02$) and the second characters ($M = .37$, $SE = .02$) were not significantly different (Fs < 1), and the second character ($M = .37$, $SE = .02$) was fixated more often than the third character ($M = .17$, $SE = .01$, $F_1(1,47) = 73.71$, $p < .001$, $\eta_p^2 = .61$, MSE = 1.93; $F_2(1,83) = 92.03$, $p < .001$, $\eta_p^2 = .53$, MSE = 3.36). The interaction between word length and character position was not significant (Fs < 1). These results suggest that inserting a space after a word does not affect the initial fixation distribution of the two word length conditions differently.

The two PVL curves for the two-character and the four-character conditions were almost identical to those of the three spacing conditions. These results did not provide evidence to support the view that initial landing position was affected by word length in any of the spacing conditions.

Mean landing position on a four-character ROI

In order to get a general picture of how insertion of space affects saccade target selection, mean landing positions under different conditions were calculated based on a four-character ROI. If Chinese readers target their eyes at word centre, the value of mean landing position should be larger for the four-character condition than the two-character condition. The mean landing position data were subjected to a 3 (spacing type: space-before condition, unspaced condition or space-after condition) × 2 (word length: two-character condition or four-character condition) repeated-measures ANOVA with participants (F_1) and items (F_2) as random variables.

The main effect of spacing type was significant, $F_1(2,94) = 30.88$, $p < .001$, $\eta_p^2 = .39$, MSE = 2.92; $F_2(2,166) = 52.69$, $p < .001$, $\eta_p^2 = .39$, MSE = 5.25. Planned contrast showed that the mean landing position in the space-before condition ($M = 1.10$, $SE = 0.05$) was significantly longer than that in the unspaced condition ($M = 0.77$, $SE = 0.04$, $F_1(1,47) = 42.99$, $p < .001$, $\eta_p^2 = .48$, MSE = 9.19; $F_2(1,83) = 88.33$, $p < .001$, $\eta_p^2 = .52$, MSE = 15.96) and the space-after condition ($M = 0.78$, $SE = 0.03$, $F_1(1,47) = 40.52$, $p < .001$, $\eta_p^2 = .46$, MSE = 8.31; $F_2(1,83) = 71.99$, $p < .001$, $\eta_p^2 = .46$, MSE = 15.55). The mean landing positions were not different across the unspaced condition ($M = 0.77$, $SE = 0.04$) and the space-after condition ($M = 0.78$, $SE = 0.03$, $F_1(1,31) = 1.57$, $p > .10$; $F_2(1,83) < 1$). No other main effect or interaction was significant (*F*s < 1). It is important to note that neither the effect of word length nor the interaction between word length and other factors reached statistical significance, providing no evidence that Chinese readers target at word centre when spaces are inserted either before or after a word. These results are consistent with existing findings (Zang et al., in press).

To explore how likely the null effect we observed is to be reliable, we conducted Bayesian *t*-tests for mean landing position for different word lengths using a Bayes factor calculation (Rouder, Speckman, Sun, Morey & Iverson, 2009) for each spacing condition. Our results revealed that the null hypothesis of no word length effect on landing position was 8.1, 6.3 and 7.4 times more likely to be true than the alternative hypothesis of a word-length effect for the space-before condition, unspaced condition and space-after conditions, respectively. These results show that the probability that word length does not affect landing position is very high, and suggest that Chinese readers do not target at the centre of a word in any of the three spacing conditions.

Forward saccade landing positions

When we calculated the PVL curve, only initial fixations on a word were included. Hence, only the fixations that occurred as a result of saccades launched from the characters to the left of that ROI were counted, but refixations on the ROI were not. As a result, all of the forward fixations were counted when calculating the number of fixations for the first character, but only a proportion of the fixations (fixations resulting from long saccades) were counted for the other characters. Thus, the proportion of included fixations decreased from left to right. To make the analysis more comparable for all of the characters in the ROI, we analysed all of the forward fixations on a four-character ROI (including intraword refixations).

This measure is very important to explore whether the final character is fixated on or not when a space is inserted after a word. The proportions of forward fixations on different characters were subjected to 3 (spacing type) × 2 (word length) × 4 (character position) repeated-measures ANOVA with participants (F_1) and items (F_2) as random variables.

All three factors affect forward fixation probability, as suggested by the significant main effects of spacing type, $F_1(2,94) = 13.26$, $p < .001$, $\eta_p^2 = .22$, MSE = 0.15; $F_2(2,166) = 15.25$, $p = .001$, $\eta_p^2 = .16$, MSE = 0.27, word length, $F_1(1,47) = 34.85$, $p < .001$, $\eta_p^2 = .43$, MSE = 0.21; $F_2(1,83) = 23.31$, $p = .001$, $\eta_p^2 = .22$, MSE = 0.38 and character position, $F_1(3,141) = 20.56$, $p < .001$, $\eta_p^2 = .30$, MSE = 0.67; $F_2(3,249) = 33.07$, $p < .001$, $\eta_p^2 = .29$, MSE = 1.18.

In addition, the interaction between spacing type and character position was also significant, $F_1(6,282) = 11.40$, $p < .001$, $\eta_p^2 = .19$, MSE = 0.30; $F_2(6,498) = 16.36$, $p < .001$, $\eta_p^2 = .17$, MSE = 0.69. Furthermore, word length also significantly interacted with character position, $F_1(3,141) = 5.91$, $p = .001$, $\eta_p^2 = .11$, MSE = 0.12; $F_2(3,249) = 4.75$, $p = .003$, $\eta_p^2 = .05$, MSE = 0.20. Since all of the main effects and the two-way interactions are involved in the three-way interaction, we did not explore these main effects and two-way interactions in further detail.

Moreover, the interaction among the three factors was significant, $F_1(6,282) = 2.89$, $p = .009$, $\eta_p^2 = .06$, MSE = 0.06; $F_2(6,498) = 2.87$, $p = .009$, $\eta_p^2 = .03$, MSE = 0.122. The PVL curves in Figure 2 are different across the three spacing conditions. To better understand how word length and character position affect the forward landing position in different spacing conditions, three 2 (word length) × 4 (character position) repeated-measures ANOVA for both participants (F_1) and items (F_2) were conducted, with one ANOVA for each spacing condition.

In the space-before condition, the proportion of fixations was slightly higher in the two-character condition (*M* = .36, *SE* = .01) than in the four-character condition (*M* = .33, *SE* = .01, $F_1(1,47) = 7.92$, $p = .007$, $\eta_p^2 = .14$, MSE = 0.06; $F_2(1,83) = 12.12$, $p = .001$, $\eta_p^2 = .13$, MSE = 0.13). This suggests that two words in the four-character ROI (in the two-character condition) need longer time to process than one word in the same region (in the four-character condition), which is consistent with the findings of a previous study (Li et al., 2009). The PVL curves were inverted-U shaped, with a peak at the second character position. This effect was confirmed by the result that the main effect of character position was also significant, $F_1(3,141) = 24.98$, $p < .001$, $\eta_p^2 = .35$, MSE = 0.75; $F_2(3,249) = 39.56$, $p < .001$, $\eta_p^2 = .32$, MSE = 1.34. The proportion of forward fixations on the second character (*M* = .44, *SE* = .03) was significantly higher than of those on the first character (*M* = .23, *SE* = .02, $F_1(1,47) = 68.60$, $p < .001$, $\eta_p^2 = .59$, MSE = 4.34; $F_2(1,83) = 156.50$, $p < .001$, $\eta_p^2 = .65$, MSE = 7.74), third character (*M* = .37, *SE* = .01, $F_1(1,47) = 5.72$, $p < .05$, $\eta_p^2 = .11$, MSE = 0.47; $F_2(1,83) = 10.95$, $p < .001$, $\eta_p^2 = .12$, MSE = 0.89) or fourth character (*M* = .34, *SE* = .02, $F_1(1,47) = 16.16$, $p < .001$, $\eta_p^2 = .26$, MSE = 1.04; $F_2(1,83) = 38.31$, $p < .001$, $\eta_p^2 = .32$, MSE = 1.87). No interaction was found (*F*s < 1). These results suggest that Chinese readers do not fixate on the first character when a space is inserted before a word.

In the unspaced condition, the fixation proportion varied among the different character positions, as indicated by a reliable main effect of character position, $F_1(3,141) = 3.71$, $p < .05$, $\eta_p^2 = .07$, MSE = 0.11; $F_2(3,249) = 5.40$, $p < .001$, $\eta_p^2 = .06$, MSE = 0.19. The second character was more likely to be fixated on (*M* = .42, *SE* = .02) than the third character (*M* = .35, *SE* = .02, $F_1(1,47) = 7.11$, $p < .05$, $\eta_p^2 = .13$, MSE = 0.46; $F_2(1,83) = 9.52$, $p = .003$, $\eta_p^2 = .10$, MSE = 0.84) or the fourth character (*M* = .35, *SE* = .02, $F_1(1,47) = 5.22$,

$p < .05$, $\eta_p^2 = .10$, MSE = 0.37; $F_2(1,83) = 9.16$, $p = .003$, $\eta_p^2 = .09$, MSE = 0.65). The main effect of word length was not significant, $F_1(1,47) = 2.08$, $p > .10$; $F_2(1,83) = 2.57$, $p > .10$, and the interaction between the two factors did not reach significance, $F_1(3,141) = 1.75$, $p > .10$; $F_2(3,249) = 1.70$, $p > .10$.

In the space-after condition, the fixation probability was affected by word length and character position, as indicated by a significant main effect of word length, $F_1(1,47) = 20.64$, $p < .001$, $\eta_p^2 = .31$, MSE = 0.16; $F_2(1,83) = 14.35$, $p < .001$, $\eta_p^2 = .15$, MSE = 0.27 and character position, $F_1(3,141) = 15.87$, $p < .001$, $\eta_p^2 = .25$, MSE = 0.42; $F_2(3,249) = 22.70$, $p < .001$, $\eta_p^2 = .22$, MSE = 0.87. The proportion of forward fixations was significantly higher in the two-character condition (*M* = .40, *SE* = .01) than in the four-character condition (*M* = .36, *SE* = .01). Forward fixations were less likely to fall on the fourth character (*M* = .29, *SE* = .02) than on the first character (*M* = .38, *SE* = .02, $F_1(1,47) = 21.12$, $p < .001$, $\eta_p^2 = .31$, MSE = 0.88; $F_2(1,83) = 29.49$, $p < .001$, $\eta_p^2 = .26$, MSE = 1.82), second character (*M* = .44, *SE* = .02, $F_1(1,47) = 34.49$, $p < .001$, $\eta_p^2 = .42$, MSE = 2.29; $F_2(1,83) = 71.41$, $p < .001$, $\eta_p^2 = .46$, MSE = 4.19) or third character (*M* = .40, *SE* = .02, $F_1(1,47) = 31.88$, $p < .001$, $\eta_p^2 = .40$, MSE = 1.29; $F_2(1,83) = 28.59$, $p < .001$, $\eta_p^2 = .26$, MSE = 2.29).

More importantly, the interaction between word length and character position was also significant, $F_1(3,141) = 9.12$, $p < .001$, $\eta_p^2 = .16$, MSE = 0.21; $F_2(3,249) = 8.25$, $p < .001$, $\eta_p^2 = .09$, MSE = 0.36. Fewer fixations were made on the fourth character (*M* = .21, *SE* = .02) than on the other three characters (*M*s = .38, .47, .37, *SE*s = .02, .02, .02 for the first, second and third characters, respectively) in the four-character condition, $F_1(3,141) = 23.79$, $p < .001$, $\eta_p^2 = .34$, MSE = 0.64; $F_2(3,249) = 27.94$, $p < .001$, $\eta_p^2 = .25$, MSE = 1.11. In contrast, the differences in the number of fixations on those characters were not significant under the two-character condition, $F_1(3,141) = 1.99$, $p > .10$; $F_2(3,249) = 2.27$, $p = .09$. These results suggest that Chinese readers avoid looking at the final character when a space is inserted after a word. Moreover, our results indicate that word length affects fixation probability, which suggests that word processing affects saccade target selection. It is noteworthy that the interaction between word length and character position did not reach significance in the unspaced condition, which indicates that the effect must be caused by the space inserted after a word.

General discussion

In the present study, we examined how insertion of a space in Chinese text interacts with word length and jointly affects saccade target selection. Insertion of spaces in a text may provide information about word boundaries to Chinese readers. One might expect that Chinese readers are more likely to target at the centre of a word in some of these conditions. However, we found no evidence that Chinese readers targeted their eyes at the word centre even when spaces were inserted before or after a word. Additionally, word length did not affect the initial landing position in any of the three spacing conditions.

Bayesian *t*-tests showed that the null hypothesis of no word length effect on landing position was more likely to be true than the alternative hypothesis of a word-length effect. This is not very surprising given that there are no spaces between words in Chinese texts. The model of Chinese word segmentation and recognition proposed by Li et al. (2009) assumes that Chinese word segmentation and recognition may be a unified process and neither happens earlier than the other. Chinese readers do not know word boundary before recognising it, thus it is hard for them to target on the word centre. Inserting a space before a word does not help Chinese readers do that. As noted by Li et al. (2011), inserting a space after a word does not provide useful information about the right side of the word boundary. This is consistent with our finding that Chinese readers do not target the word centre even when a space is inserted before or after a word.

However, when all forward saccades were considered in our analysis, word length was found to have an effect on fixation probabilities on the target characters. Specifically, for the space-after word condition, the characters before the inserted space were less likely to be fixated on when the word was long than when it was short. One possible reason for this may be that when Chinese readers fixate on the first or second characters of a four-character ROI, they try their best to process as many characters as possible, then saccade somewhere beyond these processed characters. Since characters that belong to a word are processed as a whole (Li et al., in press) and the final characters of a long word are predictable given the first characters of the same word, Chinese readers are more likely to process more characters in the four-character condition than in the two-character condition. This may explain our result that the final characters before the inserted spaces were less likely to be fixated on in the four-character condition than in the two-character condition. It is noteworthy that the effect was significant in the space-after condition, but not in the unspaced condition or space-before condition. This may be due to the fact that the space inserted after a word provides right boundary information of the target word and facilitates processing of that word (Liu & Li, in press).

These results also generally replicate the findings of Liu and Li (in press), which showed that inserting a space before or after a word makes the readers' eyes avoid targeting the characters close to the space. We also found that inserting a space after a word facilitates the processing of that word. Chinese readers are less likely to fixate on the character near the space in the space-before and space-after conditions. This may be attributed to a number of factors. For the space-before condition, Chinese readers may have recognised the first character after the space with parafoveal vision, so they do not need to fixate on it. A second and more likely reason may be that Chinese readers adopt an efficient reading strategy (Deruaz, Whatham, Mermoud & Safran, 2002). Since the perceptual span of Chinese readers is one character to the left of the fixation and two or three characters to the right of the fixation, Chinese readers might fixate on the second character so that they can process as many characters as possible with a single fixation.

In summary, insertion of spaces in Chinese text affects eye movements of Chinese readers. They are less likely to fixate on the character near the space and will try their best to process the entire word with less fixation when a space is inserted after a word, making the final characters in a long word less likely to be fixated on. However, they do not target their eyes to the word centre when a space is inserted before or after a word. These results enhance our understanding of the control of eye movement in Chinese reading.

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