Psychon Bull Rev (2015) 22:524–530
DOI 10.3758/s13423-014-0693-3

BRIEF REPORT

Saccade target selection in Chinese reading

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Abstract In Chinese reading, there are no spaces to mark the word boundaries, so Chinese readers cannot target their saccades to the center of a word. In this study, we investigated how Chinese readers decide where to move their eyes during reading. To do so, we introduced a variant of the boundary paradigm in which only the target stimulus remained on the screen, displayed at the saccade landing site, after the participant's eyes crossed an invisible boundary. We found that when the saccade target was a word, reaction times in a lexical decision task were shorter when the saccade landing position was closer to the end of that word. These results are consistent with the predictions of a processing-based strategy to determine where to move the eyes. Specifically, this hypothesis assumes that Chinese readers estimate how much information is processed in parafoveal vision and saccade to a location that will carry novel information.

Keywords Eye movement · Saccade target selection · Chinese reading

In English reading, readers usually target their saccades to a preferred viewing location (PVL), which is usually slightly to the left of the center of a word (Rayner, 1979). The PVL is close to a position called the *optimal viewing position* (OVP), which is at the center of a word. At the OVP, word recognition efficiency is at its highest (Liu & Li, 2013; O'Regan & Jacobs, 1992; O'Regan, Lévy-Schoen, Pynte, & Brugaillère 1984; Vitu, O'Regan, & Mittau 1990). It has been argued that English readers learn to adopt an optimized saccade target selection strategy to improve their reading performance (McConkie, Kerr, Reddix, & Zola 1988; Reichle, Rayner, & Pollatsek 1999). English readers can do so because the spaces between words mark the word boundaries, and they therefore can perceive word boundaries in parafoveal vision. However, in a writing system such as Chinese, no spaces between words mark the word boundaries. How Chinese readers decide where to move their eyes during reading is thus an interesting question that needs further research.

In English reading, evidence for the existence of the PVL is supported by the PVL curve, which denotes the initial eye movement landing position distribution on different letters of a target word. The PVL curves usually peak near the center of a word, and the peak of the curves shifts right when word length increases (Rayner, 1979). By contrast, no consistent results have been found regarding whether a PVL exists in Chinese reading. Some studies have shown that PVL curves are flat, suggesting that Chinese readers do not target any specific position within a word (Tsai & McConkie, 2003; Yang & McConkie, 1999). However, other studies have shown that the PVL peaks at the word beginning (Yan, Kliegl, Richter, Nuthmann, & Shu 2010; Zang, Liang, Bai, Yan, & Liversedge 2013).

Yan et al. (2010) divided eye movement data from Chinese readers into two parts based on how many times the word was fixated (only one fixation or multiple fixations), and they plotted PVL curves separately for these two situations. They found that the PVL curves peaked at the word beginning when there was more than one fixation on the word, but peaked near the word center when there was only one fixation on the word. On the basis of these results, they argued that Chinese readers target

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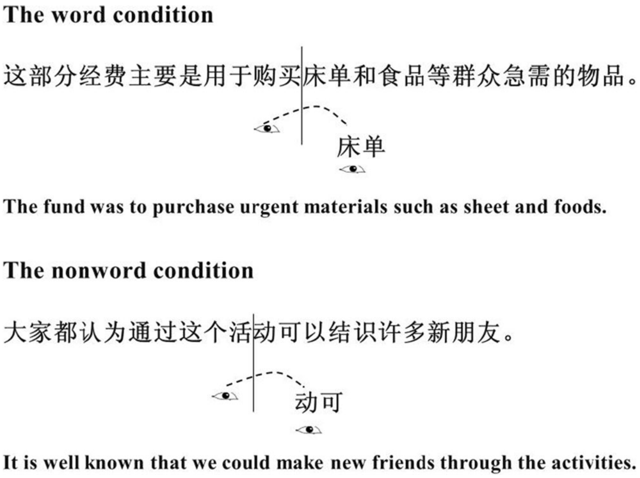
the word center when they can segment the word in parafoveal vision, but target the word beginning (which is the next character to the right of the currently fixated word) when they can not. However, Li, Liu, and Rayner (2011) argued that these findings do not necessarily support their claims. Given that words are processed more efficiently if the eyes fixate at the center of the word, it may be that when Chinese readers fixate on the word center by chance, they do not need another fixation on the same word. However, when they fixate on the word beginning, they may need another fixation on the same word. To further support this view, they conducted a simulation that assumed that Chinese readers saccade a constant distance (with variance). They found that the PVL curves peaked at the word beginning, similar to Yan et al.'s results. When their simulated data were divided into two parts using the same method used by Yan et al., they found that the PVL curves peaked at the word center when there was only one fixation on that word, and at the word beginning when there was more than one fixation. Although this simulation did not make any assumption that the eyes move to any specific position within a word, they still found results similar to those of Yan et al. These simulation results show that the results observed by Yan et al. do not necessarily support the view that Chinese readers target any specific position within a word during Chinese reading.

Other recent studies did not find evidence of a PVL in Chinese reading (Li, Bicknell, Liu, Wei, & Rayner 2014; Li et al., 2011; Tsai & McConkie, 2003; Yang & McConkie, 1999). Li et al. (2011) manipulated the length of the target word to examine how word length affects saccade target selection strategies in Chinese reading. The target words were either two or four characters long, and they were embedded in the same sentence frame. If the PVL was at the word center, the PVL curves should shift right for long as compared with short words. However, the PVL curves were almost identical in these two conditions, providing no evidence to support the view that Chinese readers target the word center. A corpus analysis on eye movement data also did not show any evidence for the existence of a PVL in Chinese reading (Li et al., 2014). Li et al. (2014) analyzed fixation probabilities on each character of words in sentences and found that the fixation probability was not affected by the position of the character within a word. That Chinese readers do not adopt a word-based target selection strategy is not peculiar. No spaces exist between words, so Chinese readers cannot rely on low-level visual cues to segment words in parafoveal vision. Therefore, Chinese readers cannot target any specific position within a word when they plan their next eye movement.

Other studies have also suggested that Chinese readers do not adopt a constant-distance strategy. First, high-predictable words in a sentence are skipped more often than low-predictable words (Li et al., 2014; Rayner, Li, Juhasz, & Yan 2005). This finding is contrary to the predictions of the constant-distance strategy. Second, Wei, Li, and Pollatsek (2013) found that saccades that leave a high-frequency word are longer than those that leave a low-frequency word. This finding suggests that saccade length is not constant, but is affected by the processing difficulty of the fixated word. Third, Li et al.'s (2014) corpus analysis showed that saccade length is affected by many factors, including the frequency and length of the fixated word, as well as the character frequency and character complexity of the characters to the right of fixation. If Chinese readers do not use a word-based strategy or a constant strategy, how do they know where to look during reading? Wei et al. (2013) proposed a processing-based strategy. According to this strategy, Chinese readers process as much information as possible on a given fixation and then saccade somewhere beyond that position. This processing-based strategy could explain the data observed by Wei et al. When the currently fixated word is easy to process, Chinese readers have more cognitive resources to process characters to its right. Therefore, more information carried by the characters to the right of fixation would be processed in the parafovea, and the saccade length would be longer after leaving a high-frequency word.

The processing-based view is consistent with some findings in English reading that indicate that the size of perceptual span is affected by the lexical processing difficulty of the currently fixated word (Henderson & Ferreira, 1990; Inhoff & Liu, 1998; Rayner, Slattery, & Bélanger 2010). For example, Henderson and Ferreira manipulated the difficulty of the fixated word (indexed by word frequency) and the availability of the parafoveal word. They found that readers could perceive more parafoveal information when the fixated word was easy. These studies suggest that the perceptual span varies dynamically during reading: The easier the fixated word, the larger is the perceptual span. For Chinese reading, it might be that the lexical processing difficulty of the currently fixated word affects the size of perception span, and further affects the target selection of the next saccade.

The processing-based strategy claims that Chinese readers attempt to process as much information as possible and then saccade to somewhere that carries novel information. Thus, a character would tend to be skipped if it was processed in parafoveal vision. We tested this prediction in the present study by using a variation of the gaze-contingent boundary paradigm (Rayner, 1975). Participants read a sentence while their eye movements were monitored. When their eyes crossed an invisible boundary, the whole sentence disappeared, and the target stimuli were presented at the position where the eyes landed. The target stimuli were always two characters long, and they were identical to the two characters to the right of the boundary (see Fig. 1). Participants were instructed to make a judgment as to whether or not the target stimuli constituted a word. The reaction times (RTs) in this lexical decision task should reflect the amount of information that had been perceived in parafoveal vision. When more



The word condition

这部分经费主要是用于购买床单和食品等群众急需的物品。

The fund was to purchase urgent materials such as sheet and foods.

The nonword condition

大家都认为通过这个活动可以结识许多新朋友。

It is well known that we could make new friends through the activities.

Fig. 1 Example of the gaze-contingent priming paradigm. The fixation point is depicted by an eye symbol (👁). The invisible boundaries that triggered the display change are marked with vertical bars. When the eyes crossed the boundary before the target stimulus, the sentence disappeared and the target stimulus appeared at the location where the eyes landed. The landing position was on the same horizontal line as the sentence (not displaced downward, as it appears in the figure). Participants were asked to identify whether the target stimulus was a word

information about the target stimuli has been perceived in parafoveal vision, less time should be needed to perceive the word when the eyes fixate on it. As a result, the RTs to the lexical decision task should be shorter. In the present study, we compared RTs as a function of whether the saccade would have landed at the first or the second character to the right of the boundary, if the original sentence had not been replaced. The processing-based view predicts that readers must have perceived more information about the word with parafoveal vision when their eyes landed at the second character after the boundary than when they landed at the first character after the boundary. Thus, RTs should be longer when the saccade would have landed at the first rather than the second character after the boundary.

The logic of the variation of the gaze-contingent boundary paradigm is similar to that of some preview paradigms (Rayner, 1975, 2009). Studies using the preview paradigm have usually used fixation times on the target word to indicate how much the word has been processed in parafoveal vision. The preview paradigm may bring up some issues for the present purposes. As in English reading, fixation position affects word recognition efficiency in Chinese reading (Liu & Li, 2013). Therefore, if we adopted the traditional parafoveal-preview paradigm, the fixation durations would be affected not only by the saccade length, but also by the landing position on a word. The fixation durations on target words are affected by these two factors. In this study, the first character of the target stimulus was always presented at the saccade landing position, so the eccentricities of the target stimuli would be identical for different conditions of the launch sites or landing positions. Therefore, the variation of the gaze-contingent boundary paradigm was more suitable for our purposes than were other paradigms.

Method

Participants

Forty-two native Chinese speakers (28 female, 14 male) from universities in Beijing near the Institute of Psychology, Chinese Academy of Sciences, were paid to participate in the experiment. Their ages ranged from 18 to 26 years (*M* = 22.1). All participants were unaware of the purpose of the experiment and had either normal or corrected-to-normal vision.

Apparatus

Viewing was binocular, and eye movements were recorded from each participant's right eye using an EyeLink 1000 eyetracker (SR Research, Osgoode, Canada). The materials were displayed on a 21-in. CRT monitor (resolution 1,024 × 768 pixels, refresh rate 150 Hz) connected to a Dell PC. Participants were seated at a viewing distance of 58 cm from the computer monitor. Each character subtended a visual angle of approximately 1.2°.

Material

A total of 128 experimental sentences were constructed. These sentences were 20 to 28 characters in length, and they were selected from an online corpus.[1] Some of the sentences were slightly revised in order to prevent semantic ambiguities. In the middle of the sentences, we chose a two-character word as the critical word. The critical words were at least five characters from the beginning or the ending of the sentence. All of the two-character words were listed as words according to the Chinese Lexicon (State Key Laboratory of Intelligent Technology and Systems, Tsinghua University, & Institute of Automation, Chinese Academy of Sciences, 2003). The frequency counts of these words ranged from 0.09 to 21.5 occurrences per million (*M* = 3.2). The first and second characters of these words were matched (see Table 1) on character complexity and character frequency (all *t*s < 1.2).

Norming tasks were performed to assess the predictability of the target words and the plausibility of the sentences. Predictability ratings for each target word were calculated from cloze task data provided by 12 native Chinese speakers (none of these participants took part in the eyetracking experiment). These participants did not correctly predict the critical

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[1] Maintained by the Center for Chinese Linguistics at Peking University: http://ccl.pku.edu.cn:8080/ccl_corpus/index.jsp?dir=xiandai

Table 1 Properties of characters in the critical region

	First Character	Second Character	*t*	*p*
Word Condition				
Number of strokes	6.8 (0.2)	7.0 (0.3)	−0.6	.55
Character frequency	943 (183)	853 (105)	0.43	.67
Nonword Condition				
Number of strokes	8.0 (0.2)	8.1 (0.3)	−0.3	.76
Character frequency	1,426 (159)	1,183 (155)	1.16	.25

Character frequency are in occurrences per million. The number of strokes in a character is treated as the index of its visual complexity. Standard errors are shown in parentheses. The *t* values generated from a paired-samples *t* test between the first and second characters

word on the basis of the contextual information shown before them. Therefore, the predictabilities of these critical words were 0.00. Plausibility ratings for each sentence were collected from 12 native speakers of Chinese on a scale from 1 (*unacceptable*) to 7 (*perfectly acceptable*). The average reported plausibility ranged from 6.0 to 6.8 (*M* = 6.4).

Procedure

Participants were tested individually. At the beginning of the experiment, they performed a calibration procedure by looking at a sequence of three fixation points randomly displayed horizontally across the middle of the computer screen. Following calibration, the gaze position error was smaller than 0.5° of visual angle. At the beginning of each trial, a white square (about 1° × 1°) appeared on the left side of the computer screen, indicating the position of the first character in the sentence. Once the participant had fixated the white square successfully, a sentence was presented. Participants were instructed to read the sentences silently to comprehend them and then perform a lexical decision task. When the participants' eyes crossed the invisible boundary, the sentence disappeared and only the target stimulus appeared on the screen. The target stimulus was always two characters long, and its location was modified in such a way that the first character was presented at the position where the eye landed (see Fig. 1). In this way, the target stimuli were always presented at the same position relative to the saccade landing site. It took less than 10 ms to make the display changes. The target stimulus was identical to the two characters that began after the boundary. On half of the trials (the word condition), the two characters made up a word. On the other half of the trials (the nonword condition), they did not make up a word. Participants were asked to judge whether the target stimulus was a word or a nonword by pressing a button on a keypad as accurately and quickly as possible. The whole experiment took approximately 30 min.

Results

The mean accuracy of the responses for the lexical decision task was 97.5% (*SD* = 1.7%). Data from items with incorrect responses (3.7% of the word items and 1.1% of the nonword items) or items with RTs that were three standard deviations above or below the participants' mean RT for each condition (2.9% of the word items and 2.2% of the nonword items) were excluded in all analyses except the accuracy analyses.

The mean length of the cross-boundary saccade was 2.21 characters long (*SD* = 0.56) in the word condition, and the mean launch site was 1.21 characters to the left of the boundary (*SD* = 0.32) in that condition. Finally, the duration of the last fixation before crossing the boundary was 252 ms (*SD* = 41) in the word condition. The percentages of trials as a function of the launch sites and landing positions of the cross-boundary saccades (i.e., if the sentence had not disappeared) are shown in Table 2.

We analyzed the RTs using a linear mixed model. This method eliminates the need to estimate the value of missing data and gives each individual observation equal weight. This analysis was conducted using the *lme4* package of the R statistical software (Baayen, Davidson, & Bates 2008; Bates, 2010; Bates & Maechler, 2010). The analysis included the landing position as a centered fixed effect, as well as the random intercepts for both subjects and items. We report coefficients and standard error estimates for the fixed effects, as well as the estimated *t* values, with *t*s greater than 2 indicating statistical significance. Previous priming studies had either found no priming effect at all for nonword targets (Forster & Davis, 1984) or much smaller effects than for word targets (Forster, Mohan, & Hector 2003; Perea & Rosa, 2000). We also found no differences in RTs for the nonword targets.[2] Hence, we will only focus on the results in the word condition.

The primary goal of the experiment was to explore the relation between the amount of information perceived at the parafovea and the saccade landing position. Thus, we compared RTs at different saccade landing positions. We first compared RTs when the cross-boundary saccade would have landed at the first or the second character after the boundary, regardless of where the cross-boundary saccade had been launched from. The processing-based view predicted that RTs should be longer when saccades land farther from the end of a word. Therefore, RTs should be longer when the cross-boundary saccade landed at the first character after the boundary rather than at the second character after the boundary. The results confirmed this prediction. In the word condition, RTs were

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[2] In the nonword condition, the difference in RTs between saccades to the first character of the target (*M* = 1,080 ms, *SE* = 43) and those to the second character (*M* = 1,095 ms, *SE* = 42) was not significant, *b* = 16.1, *SE* = 14.8, *t* = 1.1, *p* = .28.

Table 2 Percentages of trials as a function of the launch site and landing position of the saccade that crossed the invisible boundary

	Launch From Character $n - 1$			Launch From Character $n - 2$			Launch From Character $n - 3$ to $n - 6$		
	Land at $n + 1$	Land at $n + 2$	Land at $n + 3$ or $n + 4$	Land at $n + 1$	Land at $n + 2$	Land at $n + 3$ or $n + 4$	Land at $n + 1$	Land at $n + 2$	Land at $n + 3$ or $n + 4$
Nonword	16.8%	23.9%	8.9%	25.6%	6.4%	2.9%	11.3%	2.9%	1.3%
Word	19.8%	22.9%	5.9%	27.5%	6.3%	1.6%	11.5%	3.3%	1.1%

For convenience of presentation, we refer to the first character to the left of the invisible boundary as character $n - 1$, the second character to the left of the boundary as character $n - 2$, and so on. Similarly, we refer to the character to the right of the boundary as character $n + 1$, the second character to the right as $n + 2$, and so on

longer[3] when the cross-boundary saccade landed at the first character after the boundary ($M = 1{,}175$ ms, $SE = 51$) than at the second character after the boundary ($M = 1{,}103$ ms, $SE = 49$), $b = 63.9$, $SE = 19.4$, $t = 3.3$, $p = .001$.

It might be argued that the results may have been influenced by the launch site, because saccades leading to the same landing position could be launched from different locations. The launch site can determine how much information is obtained from the target parafoveally prior to its subsequent fixation (Hand, Miellet, O'Donnell, & Sereno 2010; Slattery, Staub, & Rayner 2012). Thus, we compared trials that were launched from the same position. We present the results only for trials whose cross-boundary saccade was launched from the first character to the left of the boundary and would have landed at either the first or the second character after the boundary, because each of these cells contained a reasonable number of data points (see Table 2). In the word condition, when the cross-boundary saccade was launched from the first character to the left of the boundary, RTs were longer when the cross-boundary saccade landed at the first character after the boundary ($M = 1{,}223$ ms, $SE = 77$) rather than at the second character after the boundary ($M = 1{,}088$ ms, $SE = 44$), $b = 106.9$, $SE = 29.2$, $t = 3.7$, $p < .001$.

Discussion

The experiment was designed to test one prediction of the processing-based strategy of saccade target selection in Chinese reading. The view assumes that Chinese readers attempt to process as much information as possible and then move their eyes beyond the characters carrying the processed information. Therefore, this view predicts that the saccade should land closer to the end of that word when more information about that word was perceived in parafoveal vision. This prediction was confirmed by the results of the present study using a variation of the gaze-contingent boundary paradigm (Rayner, 1975). When the target was a word, RTs in the lexical decision task were longer when the cross-boundary saccade landed at the first character after the boundary rather than the second character.

That Chinese readers adopt a processing-based strategy when planning saccade targets during Chinese reading is not peculiar. Since there are no spaces between words in Chinese reading, Chinese readers cannot determine word boundaries in parafoveal vision and cannot guide their eyes to any specific position of a word. A model of Chinese word segmentation presented by Li, Rayner, and Cave (2009) assumes that word segmentation and word identification are the same, without one happening earlier than the other. Only when a word is recognized is it segmented from the text. Therefore, Chinese readers do not know where the word boundaries are until they recognize the word. From this perspective, targeting any specific position within a word is not easy for Chinese readers. The processing-based strategy is also very efficient, because Chinese readers determine where to move their eyes on the basis of how much information they have processed, so that the saccade length is optimal. If Chinese readers did not adopt this strategy, the saccade length might be too short or too long to be optimum. If a saccade is too short, most information at the landing position might have been processed in parafoveal vision, and thus the reader cannot perceive much new information in that position. Conversely, if a saccade is too long, readers may have to make regressive saccades. In comparison, the processing-based strategy may overcome these shortcomings and make Chinese reading more efficient.

Although we started by testing a prediction of the processing-based strategy, the results are consistent with any model that assumes that Chinese readers dynamically adjust their saccade target selection on the basis of the amount of information that they perceive in the parafovea. Yan et al. (2010) proposed that Chinese readers target their saccades to the word center if they can successfully segment that word in parafoveal vision, but saccade to the word beginning if they have failed to do so. However, Yan et al. did not make any

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[3] Note that the mean RTs of this study were more than 1,000 ms. These RTs are longer than those in most traditional lexical decision tasks (e.g., Liu & Li, 2013; Yap, Balota, & Tan 2013). One reason for this may be task switching: The lexical decision task was presented unexpectedly (and randomly) when participants were reading sentences. Therefore, Chinese readers generally have to switch from reading comprehension to the lexical decision task. This procedural difference may have caused the RTs to be longer than normal.

specific claim about how Chinese readers segment words. If that model made an assumption that words are processed to a deeper level when they are segmented, their model could potentially explain the present findings. Note that the debate between Li et al. (2011) and Yan et al. (2010) is not the focus of the present study, so we will not go into that debate further here.

To summarize, we explored the relationship between saccade landing position and the amount of information processed in parafoveal vision. We found that more information about the word had been perceived in parafoveal vision when the saccade landed closer to the end of a word. This result suggests that Chinese readers dynamically adjust their saccade lengths to improve their reading performance. These findings are important to understand the eye movement control in Chinese reading, and any further models of eye movement control in Chinese reading should take these findings into account.

Author note This research was supported by 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 Sebastien Miellet and an anonymous reviewer for their helpful suggestions on a previous version of themanuscript. Xingshan Li and Pingping Liu contributed equally to the paper.

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