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How character complexity modulates eye movement control in Chinese reading

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Abstract This empirical study examined whether the visual complexities of the first and second characters in two-character words play similar roles in modulating the fixation time and saccade target selection during un-spaced Chinese reading. Consistent with prior research, words with low-complexity characters were fixated for shorter times than words with high-complexity characters. Critically, saccade target selection was primarily influenced by the visual complexity of the first character of a two-character word: words with low-complexity first characters were skipped more frequently, and fixation was localized nearer to the center of the word compared with the words with high-complexity first characters. These results are important for understanding the mechanisms of eye movement control in Chinese reading and thus provide benchmark data to test models of eye movement control in Chinese reading.

Keywords Visual complexity · Stroke number · Saccade target selection · Chinese reading

Introduction

Eye movement control studies in reading have primarily focused on two aspects of eye movements: when the eyes are moved (fixation times) and where the eyes are moved to (saccade target selection). These two aspects of eye movements are influenced by the frequency, predictability and lengths of words in both alphabetic

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languages (Rayner, 1998, 2009) and Chinese (Li, Bicknell, Liu, Wei, & Rayner, 2014; Rayner, Li, Juhasz, & Yan, 2005; Yan, Tian, Bai, & Rayner, 2006; see Reilly & Radach, 2012 for a special issue on non-western reading in Reading and Writing). In addition to these important factors, character complexity may be a special factor that affects eye movement control in Chinese reading. Character complexity[1] is commonly measured by the number of strokes that comprise Chinese characters (Coney, 1998; Li et al., 2014; Su & Samuels, 2010). Chinese characters can be very simple and include only a single stroke, such as 一 (*yi*, which means one), but they can also be complex and include more than 20 strokes, such as 馨 (*xin*, which means fragrance). However, how character complexity affects eye movement control in Chinese reading is not well understood. The present study was designed to investigate this question.

We will first introduce some important properties of the Chinese writing system before reviewing studies of character complexity in Chinese reading. In contrast to most alphabetic languages, Chinese texts are constituted by contiguous characters that act as the basic visual units in Chinese reading. Although there are no spaces between Chinese words, a number of studies have revealed that words have a psychological reality in Chinese reading (Bai, Yan, Liversedge, Zang, & Rayner, 2008; Hoosain, 1992; Li, Gu, Liu, & Rayner, 2013; Li et al., 2014; Shen et al., 2012; Zang, Liang, Bai, Yan, & Liversedge, 2013). The uniqueness of Chinese reading is that, although the lengths of most words vary from one to four characters, no direct word length cues (e.g., spaces) are available in the parafovea to guide saccade target selection (Li, Liu, & Rayner, 2011; Ma, Li, & Pollatsek, 2015). These special properties of the Chinese writing system suggest that the mechanism of eye movement control in Chinese reading may be different from that in alphabetic language reading.

Previous studies have revealed that character complexity (as defined by stroke number) can affect the character recognition time in an isolated character recognition task. Naming characters with more strokes requires more time than naming characters with fewer strokes (Peng & Wang, 1997; Yu & Cao, 1992). Moreover, characters with more strokes require larger font sizes to reach the minimal legible size than characters with fewer strokes (Huang & Hsu, 2005). These effects of the stroke number on the character naming times can be explained by a multilevel interactive-activation framework (Taft, Liu, & Zhu, 1999) that assumes that Chinese word recognition begins by extracting character stroke information. A character with more strokes is more difficult to process.

Previous studies have also revealed the role of character complexity in word recognition in natural sentence reading tasks (Just & Carpenter, 1987; Li et al., 2014; Liversedge et al., 2014; Yang & McConkie, 1999). In an eye-tracking study, Just and Carpenter (1987) found that gaze durations on low-complexity characters are shorter than those on high-complexity characters. Yang and McConkie (1999) further found that words with two low-complexity characters are fixated less often

[1] Character complexity can also be measured by the stroke frequency, which is defined by the average number of strokes crossed by the slices in six directions through the Chinese characters (see Zhang, Zhang, Xue, Liu, & Yu, 2008 for more information). The stroke frequency is highly correlated with the stroke number.

and for shorter times than words with two high-complexity characters. These studies suggest that both the fixation time and saccade target selection are modulated by character complexity. In addition to the observed direct effect, the role of character complexity is modulated by word frequency. Liversedge et al. (2014) explored the roles of character complexity and word frequency in Chinese reading using single-character words as target words. These authors observed an interaction effect of the word frequency and character complexity on the fixation time but not on skipping probability. Character complexity can modulate saccade target selection in both low- and high-frequency conditions: higher skipping probabilities are associated with low-complexity single-character words, but fixation times are only affected in low-frequency conditions.

This study further examined the effects of visual character complexity on eye movement control in sentence reading. Two-character words were chosen as target words because they constitute more than 70 % of the most commonly used words in the Chinese lexicon. We manipulated the visual complexities of both characters in the two-character target words and thereby created a 2 (first character: low complexity, high complexity) $\times$ 2 (second character: low complexity, high complexity) design. Each set of four two-character words was embedded into the same sentence frame. Using this type of design, we studied whether the first and second characters of two-character words influence Chinese reading in different manners.

Previous studies have shown that the two characters of a word may play different roles in reading. First, it has been shown that the first character of a two-character word plays a more important role in a word's lexical accessibility (Li & Pollatsek, 2011; Li et al., 2013). Li and Pollatsek (2011) examined whether contextual information affects low-level character processing, such as the detection of the location of a character. Readers viewed two Chinese characters that were presented on the left and right sides of the fixation point: one character was intact, but the other was embedded in a noise rectangle. The two characters could constitute a word in one condition but not in the other condition. These researchers found that the intact presentation of the first but not the second character of the word facilitates the processing of its masked counterpart.

Second, the visual acuities of the two characters during reading are different. Although readers can perceive one character to the left of the current fixation and two to three characters to its right (Chen & Tang, 1998; Inhoff & Liu, 1998), they cannot maintain equal visual acuity for both characters of a two-character word, particularly prior to fixating on the two-character word. Chinese text is read from left to right, and visual acuity decreases with increases in eccentricity. Different lexical accessibilities and visual acuities imply that the two characters of a two-character word may play different roles in modulating the fixation time and saccade target selection in Chinese reading.

During sentence reading from left to right, it is easier for readers to obtain the first character's information than the second character's before fixating on the two-character target word. Therefore, the first character's complexity may play more important roles in modulating the fixation time and saccade target selection than the second character. This study provides the first test of this hypothesis in a well-controlled experiment that crosses the visual complexities of the first and second characters of two-character words such that the effects of the character complexities of the first and second characters can be disentangled.

Methods

Participants

Twenty-eight undergraduates from the China Agricultural University were paid to participate in the formal study. All of the participants had either normal or corrected-to-normal vision.

Apparatus

The materials were presented on a 21-inch CRT monitor (resolution: 1,024 × 768 pixels; refresh rate: 150 Hz) connected to a DELL PC. Each sentence was displayed on a single line in Song 20-point font, and the characters were shown in black (RGB: 0, 0, 0) on a gray background (RGB: 128, 128, 128). The participants were seated at a viewing distance of 58 cm from the computer monitor. At this viewing distance, each character subtended a visual angle of approximately 0.7°. The head was stabilized with a chin rest and a forehead rest. The participants read the sentences binocularly, but only their right eyes were monitored. Eye movements were recorded with an SR Research Eyelink 1000 eye tracking system with a sampling rate of 1,000 Hz.

Materials and design

Eighty sets of two-character words were selected as critical materials (see Appendix). Each set contained four two-character words that could fit into the same sentence frame. The first and second characters of the two-character words were of either high complexity or low complexity. For example, in the sentence frame铁匠听到这个消息愤怒的将这些瓦块(糖块/瓦罐/糖罐)摔到了地上 (translation: The blacksmith angrily threw these *tiles* (*sugars*/*crockeries*/*sugar bowls*) to the ground when he heard the news), the critical word region contained the following four conditions: in the LL condition, both characters were low-complexity (瓦块) characters; in the HL condition, the first character was of high complexity, and the second character was of low complexity (糖块); in the LH condition, the first character was a low-complexity character, and the second character was of high complexity (瓦罐); and in the HH condition, both of the characters were high-complexity characters (糖罐).

The low-complexity characters had fewer than seven strokes, and the high-complexity characters had more than 12 strokes.[2] The average complexity of the

[2] The characters with more strokes typically have more radicals, but this issue could not be teased apart in the present study. It is unclear whether radical number affects reading (see review by Su & Samuels, 2010). We primarily focused on character complexity based on stroke number, and characters with more radicals can also be regarded as high-complexity characters.

Table 1 Properties of the critical stimuli in the present study

	Word	First character		Second character	
	Frequency	Frequency	Stroke number	Frequency	Stroke number
LL	4 (5)	381 (597)	5.5 (1.4)	384 (382)	5.5 (1.4)
HL	5 (5)	348 (532)	15.1 (2.1)	384 (382)	5.5 (1.4)
LH	4 (6)	381 (597)	5.5 (1.4)	329 (488)	14.1 (2.5)
HH	4 (6)	343 (558)	13.5 (1.8)	360 (529)	14.1 (2.5)

The standard deviations are reported in parentheses. The character and word frequencies were measured in units of frequencies per million

first character was lower in the LL condition than in the HL condition (see Table 1), $t(79) = -37.24$, $p < .001$, and the average complexity of the first character was lower in the LH condition than in the HH condition, $t(79) = -32.76$, $p < .001$. The average complexity of the second character was lower in the LL condition than in the LH condition, $t(79) = -26.63$, $p < .001$, and lower in the HL condition than in the HH condition, $t(79) = -26.01$, $p < .001$. We matched the two-character word frequencies for each condition, Fs <1. All of the critical words were low-frequency words because it was impossible to select a sufficient amount of material to generate an orthogonal design using high-frequency two-character words. We also matched the character frequencies such that no difference was found between each condition in terms of either the first character or the second character, Fs <1.

Each set of four two-character words was embedded into the same sentence frame to create 320 sentences in total. All of the words were plausible in the sentences. We made four lists of trials, each of which contained 20 trials of each condition. Each participant read one list comprising 80 sentences. The length of each sentence ranged from 20 to 25 characters. There was no ambiguity in the word boundaries, and all of the four additional participants agreed that the critical words should have been grouped into words. These four participants did not participate in the formal study. We also assessed the predictability of the critical target words to ensure low levels of predictability (close to 0) in the four conditions.

Procedure

When the participants entered the lab, they read the instructions for the experiment and a brief description of the apparatus. The height of the chin rest and the chair were then adjusted to make the participants feel comfortable. The eye tracker was calibrated at the beginning of the experiment and again during the experiment as needed. A three-point calibration and validation procedure was used. The maximal error of the validation was a visual angle of 0.5°. Each participant then read six sentences for practice and 80 experimental sentences in a random order. The participants were asked to read silently and to answer questions after reading 27 sentences. The questions were created to ensure that the participants read the sentences carefully. Each sentence appeared after the participants had successfully fixated on a character-sized box at the location of the first character of the sentence. After reading a sentence, the participants were asked to press a response button to start the next trial.

Data analysis

The accuracy of the comprehension questions was high (95 %), which suggests that the participants understood the sentences well. Trials in which the participants blinked at least three times and those in which they blinked at least once at the target word region were excluded from the analysis, which resulted in a loss of 2 % of the trials. Fixations lasting longer than 1,000 ms or less than 80 ms (a total of approximately 2 %) were also excluded from the analysis.

We report the eye movement measures in relation to the critical two-character target word region[3] using the following five indicators of eye movements (Radach & Kennedy, 2004; Rayner, 1998): (a) first fixation duration (duration of the first fixation within a word, irrespective of whether more fixations followed); (b) gaze duration (summed duration of all fixations before leaving the word); (c) fixation probability (relative frequency with which a word was fixated at least once); (d) landing position (position within a word (in terms of characters) at which the initial fixation was located; the first character was coded as zero, and the second was coded as one; thus, a landing position value of 0.5 on a two-character word indicates a position in the middle of the first and the second characters); and (e) saccade-in length (the length of the saccade landing on the critical word region on first-pass reading). The data were analyzed using a linear mixed-effects model for continuous variables and a generalized mixed-effects model for binary variables in which the participants and items were considered crossed random effects (Baayen, Davidson, & Bates, 2008; Jaeger, 2008). The analyses were performed with the *lme4* package (Bates, Maechler, & Bolker, 2013) in an R environment (R Core Team, 2013). Analyses of log-transformed durations yielded results similar to those obtained from the untransformed analyses. Separate repeated-measures ANOVAs revealed results similar to those obtained from the LMM analysis.

Results

The results are shown in Table 2. The fixation times on the target words were modulated by the character complexity. First fixation durations for the words with low-complexity first characters ($M = 289$ ms, $SD = 34$ ms) were shorter than those

[3] No parafoveal-on-foveal effect or spillover effect was found for character complexity. First fixation durations on the pre-targets were 265 ms ($SD = 37$ ms), 267 ms ($SD = 39$ ms), 263 ms ($SD = 36$ ms), and 264 ms ($SD = 34$ ms) under the LL, HL, LH and HH conditions, respectively, Fs < 1. Gaze durations for each of the respective conditions were 308 ms ($SD = 59$ ms), 313 ms ($SD = 59$ ms), 304 ms ($SD = 28$ ms), and 319 ms ($SD = 69$ ms), ts < 1.4. First fixation durations on the post-targets were 279 ms ($SD = 31$ ms), 276 ms ($SD = 33$ ms), 274 ms ($SD = 33$ ms), and 278 ms ($SD = 33$ ms) in the LL, HL, LH and HH conditions, respectively, ts < 1. These results are consistent with the corpus analysis reported by Li et al. (2014).

Table 2 Eye movement measures on the target words under different conditions

	LL	HL	LH	HH
First fixation duration	291 (38)	292 (38)	287 (38)	305 (37)
Gaze duration	347 (62)	363 (76)	361 (75)	388 (81)
Fixation probability	0.87 (0.12)	0.91 (0.09)	0.87 (0.12)	0.90 (0.11)
Landing position	0.48 (0.13)	0.40 (0.13)	0.44 (0.13)	0.40 (0.13)
Saccade-in length	2.32 (0.41)	2.14 (0.45)	2.28 (0.47)	2.21 (0.44)

First fixation duration and gaze duration were measured in milliseconds. The standard deviations are reported in parentheses

for the words with high-complexity first characters ($M = 299$ ms, $SD = 33$ ms), $b = -0.013$, $SE = 0.006$, $t = -2.01$. The complexity of the second character did not exhibit a statistically significant influence on first fixation duration, and there were no statistically significant interactions between the first and second characters (ts < 1).

Gaze durations on words with low-complexity first characters ($M = 354$ ms, $SD = 63$ ms) were shorter than those on words with high-complexity first characters ($M = 375$ ms, $SD = 74$ ms), $b = -0.026$, $SE = 0.008$, $t = -3.09$. Unlike first fixation duration, gaze duration (the relatively later indicator of word processing compared to first fixation duration) revealed that the complexity of the second character had the same effect as that of the first character. Gaze durations on the words with low-complexity second characters ($M = 355$ ms, $SD = 66$ ms) were shorter than that on words with high-complexity second characters ($M = 374$ ms, $SD = 74$ ms), $b = -0.023$, $SE = 0.008$, $t = -2.74$. The interaction between the first and second characters' complexities was not statistically significant, $t < 1$.

Saccade target selection was also affected by character complexity. Fixation probabilities on the target words were lower for words with low-complexity first characters ($M = 0.87$, $SD = 0.11$) than for words with high-complexity first characters ($M = 0.91$, $SD = 0.09$), $b = -0.033$, $SE = 0.012$, $t = -2.67$. However, the complexity of the second character did not affect fixation probability, $t < 1$, and the interaction between the first and second characters was not significant, $t < 1$. Fixation probabilities on the first and second characters were further analyzed. We found that fixation probability on the first character was lower for low-complexity first characters ($M = 0.47$, $SD = 0.11$) than for high-complexity first characters ($M = 0.54$, $SD = 0.12$), $b = -0.073$, $SE = 0.021$, $t = -3.51$. Regarding the second character, the average fixation probabilities were 0.59 ($SD = 17$), 0.59 ($SD = 17$), 0.59 ($SD = 14$) and 0.62 ($SD = 18$) under the LL, HL, LH and HH conditions, respectively, and no statistically significant differences were observed between these values, ts < 1.

Landing position and saccade-in length were also only influenced by manipulation of the complexities of the first character. The landing position was found to be farther from the word's beginning for words with low-complexity first characters ($M = 0.46$, $SD = 0.11$) than for words with high-complexity first characters ($M = 0.40$, $SD = 0.11$), $b = 0.063$, $SE = 0.022$, $t = 2.85$. No other effect was statistically significant, $t < 1$. The saccade-in length was longer for words with low-complexity first characters ($M = 2.30$, $SD = 0.41$) than for words with high-complexity first characters ($M = 2.17$, $SD = 0.43$), $b = 0.121$, $SE = 0.022$, $t = 3.29$. No other effect of saccade-in length was statistically significant, $t < 1$.

Discussion

This study examined how the visual complexities of the first and second characters of two-character words modulate eye movement control in Chinese reading. The results revealed that both the fixation time and saccade target selection are modulated by character complexity. Gaze durations were found to be modulated by the complexities of both the first and the second characters. Words with low-complexity characters were fixated for shorter times than words with high-complexity characters in the same first or second character position. Saccade target selection was only influenced by the first character's complexity. Words with low-complexity first characters were skipped more and fixated closer to the word's center than words with high-complexity first characters. These results have important implications in understanding the mechanisms of eye movement control in Chinese reading. The following section first discusses the effects of character complexity on both the fixation time and saccade target selection. The latter section elaborates further on previous empirical findings and their supports on the processing-based saccade targeting. Finally, the theoretical implications of the findings for modeling work are discussed.

Character complexity is an important factor that influences the fixation time in Chinese reading. The present findings are consistent with the results of a corpus analysis reported by Li et al. (2014), in which words with low-complexity characters were found to be fixated for shorter times than words with high-complexity characters. Our findings are also consistent with the results of isolated word recognition studies that have shown that characters with more strokes are more difficult to recognize (Peng & Wang, 1997; Yu & Cao, 1992). The character complexity effect appears to be straightforward because character recognition begins with the extraction of stroke information (Taft et al., 1999). Therefore, characters with more strokes require more time to be recognized.

Character complexity is also important in determining saccade targeting in Chinese reading. We found that the complexity of the first character in a two-character word can modulate fixation probability, landing position and saccade-in length. These findings suggests that the first character's complexity can be assessed before fixating on the target word and subsequently used to guide saccade target selection. Specifically, the first character's complexity can modulate the fixation probabilities of both the first character and the whole two-character word; thus, visual complexity may operate on both the character and word levels. It appears safe to assume that character features operate very early in the time line of word processing. Processing the first character in the parafovea may be crucial for modulating saccade programming. If this first character is of low complexity, it would be more likely to be recognized in the parafovea, which may result in an attempt to skip the identified character (or even word) or may at least shift the intended landing position to the right, leading to a longer saccade-in length. This mechanism may operate in a manner similar to the effect of parafoveal orthographic regularity in alphabetic scripts in which low-regularity (difficult to process) word-beginning letter combinations are associated with more leftward saccade landing positions (Hyönä, 1995; Radach, Heller, & Inhoff, 2004; White & Liversedge, 2004).

The first character's complexity effect on saccade target selection is consistent with findings obtained from Japanese Kanji reading. Japanese Kanji originates from traditional Chinese characters and possesses a similar visual complexity. White, Hirotani, and Liversedge (2012) explored the role of Kanji character complexity in Japanese reading in their second experiment, in which they manipulated the complexities of the first characters in two-character Kanji words in Japanese sentences. These authors found that the landing position was numerically closer to the word's beginning when the first character was of high complexity. However, in their study, at least three characters around the Kanji characters were hiragana characters, which exhibit large visual differences from Kanji characters. Thus, the visual saliencies of the two-Kanji character words may have provided explicit cues that guide saccade target selection. In the present study, all of the critical words were embedded into Chinese sentences, and no explicit cues marked the word boundaries. Thus, there is no doubt regarding our conclusion that the first character's complexity can guide saccade target selection.

The results of the current study are consistent with a processing-based view of saccade target selection in Chinese reading. Because there are no spaces that mark word boundaries in Chinese texts, Chinese readers cannot directly use parafoveal word length information to guide saccade target selection (Li et al., 2011). According to the processing-based hypothesis, eye movements are determined by the amount of information that is processed in the parafovea (Li et al., 2011; Wei, Li, & Pollatsek, 2013). During each fixation, Chinese readers make their best attempt to process as many characters as possible (regardless of whether the characters are single-character words or constituents of longer words) and then move their eyes away from these processed characters. In this situation, the more parafoveal character information perceived, the longer the saccades that the readers make. The results of the present study are consistent with this processing-based hypothesis: when the first character was of low complexity, it was more likely to be recognized in the parafovea, which allowed the readers to skip it more often and make longer saccades.

The processing-based saccade targeting strategy can account for many other findings related to saccade target selection in Chinese reading. Previous studies have revealed that the skipping probability can be modulated by the word frequency (Yan et al., 2006), word predictability (Rayner et al., 2005), word length (Wei et al., 2013) and positional probability (some characters are more likely to be the first character of a word, whereas others are more likely to be the last character of a word) (Yen, Radach, Tzeng, & Tsai, 2012). Words with higher frequencies, greater predictabilities, shorter lengths and higher positional probabilities are more likely to be skipped. These findings are not difficult to integrate into the processing-based saccade targeting strategy because these factors make a word (or characters) in the parafovea easier to process. When the word in the parafovea is easier to process, it is more likely to be skipped, which explains why the above four factors along with visual complexity can modulate saccade target selection in Chinese reading.

The alternative non-processing-based hypotheses (non-linguistic processing), such as the constant distance saccade model, cannot explain the results of the current study. The constant distance saccade model assumes that saccades travel a constant distance (with some variance) that is not affected by the linguistic properties of the words currently being processed. However, as we noted in the above paragraph, saccade targeting was modulated by many linguistic properties. Thus, an absolute non-processing-based hypothesis is not practical in Chinese reading. Note that there is a variant of the processing-based hypothesis termed as the parafoveal word segmentation hypothesis (Yan, Kliegl, Richter, Nuthmann, & Shu, 2010), which has been used to explain saccade target selection in Chinese reading. In this hypothesis, when readers are able to successfully segment a word in the parafovea, they fixate on the word center but fixate on the beginning of the word when word segmentation fails. However, this hypothesis is associated with many controversies (Li et al., 2011; Ma et al., 2015). Therefore, we can only safely conclude that the processing-based hypothesis suggested by Li et al. (2011) is a particularly parsimonious account that harmonizes well with the present data.

The results of the present study on visual complexity have implications for current models of eye movement control in Chinese reading. Rayner, Li and Pollatsek (2007) successfully extended sequential processing models (e.g., the E-Z Reader model, see Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003) to Chinese reading. As in the English version, lexical processing requires two stages: an early “familiarity check” stage (L1) and a later “lexical access” stage (L2). However, only the word frequency and predictability are involved in the model of the determination of the L1 stage of lexical processing. Because Chinese word recognition begins by the extraction of character stroke information (Taft et al., 1999) and character complexity can modulate the fixation times in Chinese reading, visual complexity should be regarded as an important factor in future modeling work. Additionally, Liversedge et al. (2014) reported an interaction between character complexity and word frequency, which suggests that visual complexity may play a role in the L1 stage that is similar to that played by the word frequency.

Similarly, parallel processing models, such as the SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005) and Glenmore models (Reilly & Radach, 2006), should also incorporate the visual character complexity to better simulate eye movement control. These two models are strongly influenced by Findlay and Walker’s (1999) saccade generation theory. Both of these models implement a similar concept of a saliency map in which words can compete to be the target of a saccade. In the SWIFT model, low-level word difficulty is only indirectly reflected by the word frequency, which could be supplemented with a measure of visual complexity in Chinese. Because word recognition begins from stroke recognition (Taft et al., 1999), visual character complexity should affect word difficulty in the first stage (i.e., the preprocessing stage in the SWIFT model) of lexical processing. In the

Glenmore model, word competition in the saliency map is influenced by the visual saliency of each letter. Similarly, the visual character complexity should also play a role in the saliency map. Moreover, the interactive framework used in the Glenmore model may have potential advantages for dealing with the interactive relationship between character and word recognition in Chinese reading (see also Li et al., 2009).

In summary, the present study found that character complexity modulates eye movement control in Chinese reading and that the first character in a two-character word has a greater influence on guiding saccade selection than the second character. These results are consistent with the processing-based hypothesis, which should thus be highlighted in future modeling work on Chinese reading.

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Appendix: Sentences used in the experiment

Item	LL	HL	LH	HH	Sentence
1	白肉	精肉	白露	朝露	当地百姓正在收集白肉准备出售给新来的药剂师
2	巴县	新县	巴蜀	集镇	那些远道而来参观巴县著名景点的人在晚上离开了
3	补写	题写	补编	整编	编委会必须按照教材的要求重新补写书籍的最后一部分
4	车价	牌价	车道	跑道	记者独自承担起调查车价设置是否合理的重要任务
5	饭厅	歌厅	饭锅	蒸锅	情报人员把密函藏进饭厅里面可以做到掩人耳目
6	泛红	潮红	泛酸	强酸	实验室助手悄悄的将这些泛红液体倒进了马桶里
7	飞刀	藏刀	飞艇	赛艇	这位知名的慈善家准备将拍卖飞刀所得的善款捐给灾区
8	负极	磁极	负数	频数	小学生经过适当的训练也能理解负极的相应概念
9	古乐	鼓乐	古装	童装	反对者认为偏好古乐的人一般都表现出心智不够成熟
10	谷仓	粮仓	谷穗	稻穗	看守粮食的官兵眼望着所有谷仓被大雨席卷一空
11	欢声	鼓声	欢歌	楚辞	这些无忧无虑的孩童听到欢声就像疯了似的朝门外跑去
12	幻术	骗术	幻像	蜡像	教官详细讲解了辨别幻术要掌握的三个基本原则
13	灰布	墙布	灰墙	矮墙	这里装修完成并拆除灰布之后就能看到对面的绿色草坪
14	夹层	煤层	夹缝	裂缝	探险队这次深入险地是为了探测夹层中埋藏的稀有矿物
15	拒付	缴付	拒赔	蒙骗	申请破产的公司拒付大量赔款之后迅速离开了大陆
16	冷饭	熟饭	冷餐	稻穗	那位朴实的主妇在收拾冷饭的时候找到了顾客的皮夹子
17	民风	新风	民需	新歌	该报刊这次采访的主角正是关注民风的艺术家唐韬
18	木门	楼门	木器	暗器	当时有许多墨家高手沉迷于探索木门的设计原理
19	汤包	箱包	汤锅	鼓琴	戴墨镜的男子在购买汤包之后迅速离开了商铺
20	帐册	簿册	账簿	缘簿	精打细算的姑妈核对帐册之后确定了最终的选择
21	才华	精华	才智	睿智	此次高层论坛是各位专家展示非凡才华的绝佳时机
22	池边	墙边	池塘	澡塘	联邦调查局的人员拒绝介入调查池边发生的案件

Item	LL	HL	LH	HH	Sentence
23	吊床	藤床	吊装	童装	几位新潮的妈妈在购买吊床之后结伴回到了住处
24	豆包	糖包	豆酱	辣酱	乖巧的孩子拎着豆包从厨房美滋滋的走了出来
25	儿戏	影戏	儿歌	新歌	他认为学会如何欣赏儿戏不是一件轻而易举的事情
26	耳尖	嘴尖	耳膜	鼓膜	这些细微的动作可能会损伤耳尖并带来未知的严重后果
27	犯忌	避忌	犯禁	解禁	教练们正在讨论队员犯忌之后如何进入下一步的程序
28	分岔	道岔	分道	就餐	后勤人员正在搜索分岔的地方以确保活动顺利进行
29	工兵	新兵	工联	篮联	队长讲了这么多只是为了让大家理解工兵担负的责任
30	弓步	碎步	弓腰	塌腰	导演要求所有演员积极练习弓步动作以节省拍摄时间
31	攻歼	聚歼	攻错	催逼	如果这个时候攻歼敌军恐怕会给全军带来灭顶之灾
32	互补	填补	互惠	精确	远洋运输公司采用互补的措施来缓和当前贸易的摩擦
33	火龙	游龙	火警	港警	这些知识丰富的学者非常理解火龙所特有的生存方式
34	讥讽	嘲讽	讥嘲	数落	每一个有心理理论的人都应知道讥讽别人是不对的行为
35	坚冰	薄冰	坚壁	腹壁	他们眼睁睁的看着那块坚冰在外力撞击下顷刻瓦解
36	讲义	疑义	讲题	答题	评审专家最后总结发现很多讲义都阐述的不清不楚
37	旧历	藏历	旧貌	镇貌	人们预测多年之后这些旧历就会消失在人们的记忆里
38	考订	增订	考量	馈赠	这些中央机构感谢专家组为他们考订了一批新的时评杂志
39	狂风	微风	狂想	暗想	忽然而来的一阵狂风让这些充满报复的队员更加意气风发
40	老兵	精兵	老龄	超龄	主席团交待大家对待老兵队员要拿出足够多的诚意
41	礼让	避让	礼遇	摆渡	老禅师告诫徒弟积极礼让他人是高修为的重要表现
42	米汤	鲜汤	米粥	稀粥	老友着急的喝了半碗米汤就迅速地离开了宴会厅
43	木匠	鞋匠	木雕	蜜蜂	举报者在电话里声称有大量木匠聚集在这座院子里
44	牛刀	腰刀	牛粪	蜂群	这些昆虫发现眼前的牛刀已经威胁到自己的生存
45	牛肚	爆肚	牛筋	蹄筋	性格直爽的篮球健将坦言小炒牛肚是他最爱吃的佳肴
46	扭扯	攀扯	扭摆	喧腾	新员工因为工资的事情前来扭扯了半天也没能解决问题
47	劝导	督导	劝慰	解雇	没曾想到经理把这份负责劝导员工的工作推给了我
48	入口	路口	入境	隧道	当列车行驶过入口处就会把这些垃圾全部丢掉
49	沙坝	筑坝	沙窝	黑窝	必须一鼓作气将所有沙坝摧毁并妥善安排善后工作
50	石材	管材	石像	鼓楼	公司保安的工作还包括保护石材不受自然界的侵蚀
51	帅才	蠢才	帅旗	锦旗	球队队员都知道这些帅才都是教练亲自挑选的
52	丝巾	餐巾	丝棉	植棉	半个小时过后那位收购丝巾的老汉已经消失在夕阳下
53	私财	横财	私藏	量器	发福的官员声称自己有很多私财是不能被外人知道的
54	私访	察访	私藏	窝藏	任何部门以外的人只要私访要犯就会受到来自刑部的重罚
55	台灯	路灯	台盟	楼道	激进的学生声称台灯对他们来说没有任何用途
56	汤池	粪池	汤罐	糖罐	车辆还没有到达现场就已经闻到汤池中飘来阵阵恶臭
57	秃驴	蠢驴	秃鹰	鹞鹰	那次登山活动中被称为秃驴的家伙让人印象特别深刻
58	土牢	黑牢	土蜂	雄蜂	这些工匠之所以如此害怕是因为都曾受过土牢的残酷折磨
59	瓦块	糖块	瓦罐	糖罐	铁匠听到这个消息愤怒的将这些瓦块摔的破碎不堪
60	王孙	曾孙	王储	影楼	管家嘱咐这几个跟班的要仔细看好王孙的贵重物品
61	尾巴	嘴巴	尾翼	鼻翼	雕塑馆的艺术家惊叹燕子尾巴被雕刻的如此逼真
62	尾灯	警灯	尾翼	鼻翼	谨慎的乘客发现尾灯两侧存在问题并及时告知了乘务员
63	纤夫	樵夫	纤瘦	黑熊	当地人们普遍认为纤夫的身材是健康的重要指示符
64	闲扯	瞎扯	闲游	漂游	许久不见的老哥们在外面闲扯了半天才回到住所
65	邪火	煤火	邪魔	睡魔	经验丰富的巫师居然担心邪火侵害自己的健康

Item	LL	HL	LH	HH	Sentence
66	刑场	操场	刑期	赛期	新上任的队长已经准备着手调查刑场内发生的案件
67	玄鸟	蜂鸟	玄奥	鼹鼠	他们这次野外旅行的目的是观察玄鸟的生活习性
68	血红	鲜红	血糖	蜜糖	视力的过早衰退导致他已经无法辨别血红的颜色
69	严守	镇守	严整	镇慑	将军来这里严守城池使得这里的百姓能够安居乐业
70	手记	题记	手稿	新楼	愚钝的主编在搜索手记上花费了太多不必要的时间
71	厌弃	嫌弃	厌腻	凝想	当聪明的学生厌弃这一行为时就会产生负面效应
72	羊肠	腊肠	羊膜	黏糕	培训师正训练大家如何挑选羊肠并将其晒干磨成中药粉
73	异邦	盟邦	异趣	童趣	许多家长都深信异邦训练能够提高孩子的个人能力
74	邮车	餐车	邮路	管路	这些只注重结果的领导从不关心是否邮车出了问题
75	幼犬	鹰犬	幼雏	雏鹰	训练师把食物放在手心里等待幼犬缓缓的靠近
76	幼芽	嫩芽	幼嫩	滑嫩	该公司已经熟练掌握提取幼芽的表面物质来制作化妆品
77	玉女	舞女	玉器	富豪	最后筛选阶段曾经让人热捧的顶级玉女最终却惨遭淘汰
78	云团	疑团	云影	暗影	越野高手坦言说目前云团重重不适合继续前行
79	召回	撤回	召集	邀集	曾经一败涂地的将军决定召回自己的旧部一起谋事
80	纸币	硬币	纸牌	雕像	在真正的行家眼里很多纸币都是具有收藏价值的

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