The Role of Chinese Text Familiarity in Word Segmentation and Lexical Recognition

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Abstract

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Full Text

The Role of Text Familiarity in Chinese Word Segmentation and Lexical Recognition

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Abstract

Based on the E-Z Reader model and the Chinese Reading Model, there is ongoing controversy regarding whether word segmentation and lexical recognition constitute an interactive, unified process. By manipulating text familiarity through altered reading direction, this study investigated its role in word segmentation and lexical recognition. Experiment 1 examined the trade-off between text familiarity and the facilitative effect of inter-word spaces, recording eye movement characteristics of 40 university students during Chinese reading using an Eyelink 1000 system. Results revealed that the facilitative effect of inter-word spaces on Chinese reading disappeared after reading training, indicating a trade-off between text familiarity and the benefits of inter-word spacing. Experiment 2 manipulated text familiarity and word frequency to explore the role of text familiarity in lexical recognition. The findings demonstrated an interaction between text familiarity and word frequency on early-stage measures, while no interaction emerged between reading training and word frequency, suggesting that text familiarity influences the early processing stages of lexical recognition. These results indicate that word segmentation and lexical recognition in Chinese reading may involve sequential processing, supporting the E-Z Reader model.

Keywords: Text Familiarity, Inter-word Spaces, Word Frequency, Word Segmentation, Lexical Recognition

1. Introduction

Chinese is a morphosyllabic writing system with unique orthographic properties, where each character corresponds to a morpheme. Its distinctive characteristics allow readers to process text in different directions, including right-to-left and top-to-bottom orientations (Chung et al., 2017). While modern Chinese defaults to left-to-right text direction, languages such as Hebrew and Arabic use right-to-left as their default orientation (Deutsch & Rayner, 1999). This raises important questions about how readers process unfamiliar text formats: How do readers process linguistically unfamiliar text (e.g., Arabic speakers reading modern Chinese)? Do processing mechanisms differ between familiar and unfamiliar text formats? Does reading performance change as text familiarity varies? These questions hold significant theoretical implications for reading research, making text familiarity in Chinese reading a persistent focus in the field (Li et al., 2016; Ma et al., 2019; Wang, 2015; Yan et al., 2019; Yin et al., 2021).

Furthermore, Chinese word segmentation mechanisms are unique. Unlike alphabetic scripts such as English that contain inherent inter-word spaces as boundary markers, Chinese text lacks explicit word boundary cues, requiring readers to segment words from continuous character strings. Nevertheless, for both Chinese and alphabetic scripts, the word serves as the fundamental independent unit of reading processing, with lexical recognition being the reader' s primary task (Rayner, 2009; Rayner et al., 1998; Inhoff et al., 2000; Li et al., 2009; Perea

& Acha, 2009).

Readers' eye movement patterns sensitively reflect processing characteristics during reading. Numerous eye movement models have been developed to explain reading mechanisms, including SWIFT, SHARE, Glenmore, EMMA, SERIF, Mr. Chips, and the Competition-Activation Model (Yang, 2006), among which the E-Z Reader model has been particularly influential (Rayner, 2009). As a computational model with high transparency, the E-Z Reader model can explain both global eye movement patterns and precisely predict fixation trajectories during reading. However, because Chinese text lacks inter-word spaces, neither the original nor the modified E-Z Reader models can fully simulate Chinese reading processes. Consequently, Li et al. (2009) proposed a computational model for Chinese word segmentation and lexical recognition based on an interactive activation framework, positing that word segmentation and lexical recognition in Chinese reading constitute an interactive, unified process where readers segment words while simultaneously recognizing them, with segmentation completing automatically upon lexical recognition (Li et al., 2011). The E-Z Reader model holds the opposite view, arguing that word segmentation and lexical recognition are not fully synchronous but rather sequential processes. Moreover, Li et al.' s (2009) computational model considered only the lexical level and did not examine this issue during natural reading of Chinese sentences. Although subsequent research refined this model into an integrated model suitable for Chinese reading (Li & Pollatsek, 2020), the integrated model and the original computational model have not achieved complete convergence. Additionally, the integrated model' s primary limitation lies in its neglect of higher-level cognitive processes such as semantic comprehension, whereas such higher-level cognitive factors occupy the highest level in the E-Z Reader model and can top-down influence Chinese word segmentation and lexical recognition processes, making them impossible to ignore.

In summary, the present study capitalized on unique characteristics of Chinese text by manipulating reading direction to examine the role of text familiarity (a higher-level cognitive factor) in Chinese word segmentation and lexical recognition, thereby investigating the processing mechanisms underlying these components during Chinese reading.

The unique mechanism of Chinese word segmentation has long attracted researchers' attention, yet findings remain inconsistent regarding whether inserting inter-word spaces facilitates Chinese reading (Bai et al., 2008; Bassetti, 2009; Li et al., 2009; Cui et al., 2014; Zang et al., 2016; Ma, 2017; Liu & Lu, 2018; Ma & Zhuang, 2018; Zhou et al., 2020). Some studies support the notion that inter-word spaces enhance attention allocation, lexical recognition, and semantic comprehension during Chinese reading (白学军等, 2015; Yan et al., 2010; Zang et al., 2018). However, other studies have failed to find facilitative effects. For instance, Bai et al. (2008) presented Chinese sentences under different segmentation conditions (unspaced, inter-word spaced, inter-character spaced, and nonword spaced) to native Chinese adult readers and found no facilitative effect of inter-word spacing. The researchers hypothesized that while inter-word spaces might indeed facilitate Chinese reading, inserting spaces created unfamiliar text, and the resulting text unfamiliarity offset the facilitative effect. Consequently, Bai et al. (2008) proposed a trade-off hypothesis between text familiarity and the facilitative effect of inter-word spaces.

Subsequent research found that inter-word spaces facilitated Chinese reading among foreign university students and children with reading disabilities (白学军等, 2012; Shen et al., 2012; Zang et al., 2013). These participants shared a common characteristic: insufficient Chinese reading experience, resulting in no significant difference in text familiarity between spaced and unspaced conditions. In contrast, adult native Chinese readers possess extensive reading experience, creating a significant familiarity difference between unfamiliar text (with inserted spaces) and default text (without spaces), thereby offsetting the facilitative effect of inter-word spaces through this familiarity disparity (沈德立等, 2010; Yan et al., 2012). Experiment 1 was designed to investigate whether such a trade-off exists between text familiarity and the facilitative effect of inter-word spaces.

Experiment 1 manipulated text familiarity and word segmentation method to examine this question. First, sentences were presented in four segmentation conditions (unspaced, inter-character spaced, inter-word spaced, and non-word spaced), with native adult readers required to read from right to left (unfamiliar text). If reading speed increased and reading time decreased under inter-word spaced conditions, this would demonstrate that inter-word spaces indeed facilitate Chinese reading of unfamiliar text. Conversely, unchanged reading performance would indicate no facilitative effect. Next, a separate group of 40 native adult readers who had not participated in the first phase underwent 10 days of reading training (right-to-left reading) to increase familiarity with the unfamiliar text format. Comparing pre- and post-training performance would reveal differences in processing between unfamiliar and familiar text. After training, the same four spacing conditions were presented, with readers again reading right-to-left. If the facilitative effect of inter-word spaces diminished or disappeared, this would indicate that the effect was offset (fully or partially) by increased text familiarity, supporting the trade-off hypothesis. If the facilitative effect remained unchanged, it would suggest that text familiarity does not influence the effect of inter-word spaces, refuting the trade-off hypothesis.

Building on Experiment 1, Experiment 2 investigated how text familiarity affects lexical recognition processes. Word frequency effects serve as important indicators of lexical recognition, with low-frequency words (LF) requiring longer processing times than high-frequency words (HF), and HF words showing higher skipping rates than LF words. Research typically manipulates word frequency to examine Chinese lexical recognition mechanisms (Rayner et al., 1998; Rayner, 2009; Liversedge et al., 2014; Liu et al., 2016; Ma et al., 2018). Ma (2017) manipulated word frequency (high vs. low) and spacing (unspaced vs. inter-word spaced) to investigate word segmentation and lexical recognition mechanisms.

Although the hypothesis predicted a significant interaction between inter-word spacing and word frequency, results did not support this prediction, consistent with previous findings (Rayner et al., 1998). However, using survival analysis, the study found that the word frequency effect was delayed by 21 ms under unspaced conditions, aligning with earlier research (Sheridan et al., 2013).

If the integrated model of Chinese reading holds—where word segmentation and lexical recognition are interactive and unified processes—and if Experiment 1 reveals a trade-off between text familiarity and the facilitative effect of inter-word spaces, then text familiarity should top-down influence Chinese word segmentation. Given that segmentation and recognition are inseparable, text familiarity should also top-down influence lexical recognition, resulting in a trade-off between text familiarity and word frequency effects at the lexical recognition level. This trade-off could explain previous findings: inter-word spaces promoted lexical recognition, but this facilitation was partially offset by text unfamiliarity, resulting in only accelerated emergence of the word frequency effect without a significant interaction (Ma, 2017).

Therefore, Experiment 2 manipulated text familiarity (familiar text: left-to-right; unfamiliar text: right-to-left) and word frequency (high vs. low) to investigate the role of text familiarity in lexical recognition. A significant interaction between text familiarity and word frequency would indicate that text familiarity indeed affects lexical recognition in Chinese reading. Conversely, no interaction would suggest that text familiarity does not influence lexical recognition. As in Experiment 1, reading training was conducted to examine whether the word frequency effect would change. A larger or earlier-emerging word frequency effect would indicate a significant interaction between training and word frequency, whereas an unchanged effect would suggest no interaction.

The central question addressed by this research is whether the processing mechanisms of word segmentation and lexical recognition in Chinese reading are fully synchronous or partially dissociated. If the former holds true—where readers segment words while simultaneously recognizing them, with segmentation completing automatically upon lexical recognition—then the two processes are inseparable. Consequently, text familiarity, as a top-down influence on word segmentation, should similarly affect lexical recognition, manifesting in early, late, and overall measures of the word frequency effect. If, however, the processing mechanisms are not fully synchronous, text familiarity would differentially affect lexical recognition and word segmentation, with the trade-off between text familiarity and word frequency effects showing different patterns across early, late, and overall measures. This would imply that Chinese word segmentation and lexical recognition involve sequential processing with distinct stages, supporting the E-Z Reader model.

Experiment 1

Experiment 1 consisted of pre-training and post-training phases. The pre-training eye-tracking experiment aimed to examine whether inter-word spaces facilitate Chinese reading of unfamiliar text. The post-training eye-tracking experiment investigated whether this facilitative effect would diminish or disappear. The purpose of Experiment 1 was to examine whether a trade-off exists between text familiarity and the facilitative effect of inter-word spaces (Bai et al., 2008).

2.1.1 Participants

Pre-training eye-tracking experiment: Forty undergraduate students (mean age = 20.78 ± 1.21 years; 28 females, 12 males) participated. All were native Chinese speakers with normal or corrected-to-normal vision and right-handed. **Post-training eye-tracking experiment:** Forty undergraduate students who had not participated in the pre-training experiment (mean age = 20.50 ± 1.63 years; 31 females, 9 males). All were native Chinese speakers with normal or corrected-to-normal vision and right-handed. All participants provided informed consent prior to the experiment.

2.1.2 Design

A 4 (word segmentation: unspaced condition—Chinese default format with no spaces between characters; inter-character spaced condition—spaces inserted between adjacent characters; inter-word spaced condition—spaces inserted between words; non-word spaced condition—spaces inserted randomly to create non-words) × 2 (text familiarity: unfamiliar text—reading right-to-left before training; familiar text—reading right-to-left after training) mixed design was employed. Word segmentation was a within-subjects factor, while text familiarity was a between-subjects factor.

2.1.3 Materials

The same experimental materials were used for pre- and post-training eye-tracking experiments, with different participants employed to prevent practice effects. Sixty sentences were constructed, each containing 15-17 characters (M = 15.8 characters, SD = 0.80). Thirty participants who did not take part in the experiment rated sentence fluency on a 7-point scale (M = 6.69, where 7 = "very fluent" and 1 = "very disfluent"). Twelve additional participants achieved 91% consistency in sentence segmentation. Four experimental files were created, each containing 60 sentences distributed across four conditions using a Latin square design, with 15 sentences per condition. Sentences were divided into four blocks, each containing sentences from all four conditions in random order. Each file included 12 practice sentences (three per condition) presented before the experimental trials. Comprehension questions (yes/no) followed 22 sentences, with equal numbers of "yes" and "no" responses. Participants read a total of 72 sentences. Example sentences for each condition are shown in Table 1. Reading training materials consisted of 60 Chinese essays selected from high school textbooks (M = 936 characters per essay), converted from left-to-right to right-to-left format using reversal software (see Appendix for examples). Each essay was followed by seven comprehension questions requiring selection of the most appropriate answer.

Table 1. Example sentences from the four conditions in Experiment 1

2.1.4 Apparatus

Eye movements were recorded using an SR Research EyeLink 1000 eye-tracker with a sampling rate of 1000 Hz (one recording per millisecond). Stimuli were presented on a 19-inch Dell monitor with a resolution of 1024$\times 768 pixels. Viewing distance was 70 cm. Stimuli were presented in Song font, size 20.8, with each characters pixels (0.80° of visual angle). The calibration point appeared on the right side of the screen at sentence onset.

2.1.5 Procedure

Pre-training eye-tracking experiment: Participants were instructed to read sentences from right to left as quickly as possible while understanding their meaning, pressing the spacebar to advance to the next sentence. Comprehension questions appeared after some sentences, requiring accurate responses. A chin rest minimized head movements. Calibration was performed before the experiment and readministered as needed. The experiment lasted approximately 20 minutes. Comprehension accuracy was 91.0%, indicating adequate sentence understanding.

Reading training phase: Conducted in group sessions. Participants familiarized themselves with the laboratory environment and received daily reading materials on their desks. Instructions stated: "You will read several articles. Sentences will be presented from right to left. Please read carefully word by word, understanding as much as possible. Each article will be followed by seven comprehension questions. Select the most appropriate answer based on the article." Participants read each article, answered the seven questions, and proceeded to the next. Each participant read for 30 minutes daily for 10 consecutive days.

Post-training eye-tracking experiment: Following training, participants completed the same eye-tracking experiment as in the pre-training phase. Comprehension accuracy was 93.0%, indicating adequate understanding. The experimental procedure is illustrated in Figure 1.

Figure 1. Experimental flowchart

2.2 Data Analysis

The following eye-tracking measures were analyzed: (1) Mean fixation duration: average duration of all fixations on the sentence; (2) Number of fixations: total count of fixations on the sentence; (3) Total time: sum of all fixation durations on the sentence; (4) Reading speed: average number of characters read per second. Time measures (mean fixation duration and total time) were recorded in milliseconds; average saccade amplitude in characters; reading speed in characters per second.

Based on established criteria (Rayner et al., 2006; Bai et al., 2008; Rayner, 2009; Liang et al., 2017; Wang et al., 2018), fixation durations shorter than 80 ms or longer than 800 ms were excluded. Data were also excluded for: (1) incorrect key presses causing interruption; (2) data loss due to incidental factors (e.g., head movement); (3) fewer than four fixations; (4) data points beyond three standard deviations. Invalid data accounted for 2.23% of total data and were excluded from analysis. Descriptive statistics for overall analyses are presented in Table 2.

Table 2. Overall analysis measures

Data were analyzed using linear mixed models (LMM) in R (R Core Team, 2016) with the lme4 package (Bates et al., 2012). Participants and items were specified as crossed random effects (Baayen et al., 2008). Significance estimates were obtained using Markov-Chain Monte Carlo algorithms to derive posterior distributions of model parameters, reflecting variance from both participants and items (Baayen et al., 2012; Josse et al., 2014). t-values greater than 1.96 were considered significant at the 5% level. Dependent variables were log-transformed during model fitting. Fixed effects included word segmentation method, text familiarity, and their interaction. Segmentation 1 contrasted unspaced vs. inter-character spaced conditions; if the interaction between Segmentation 1 and text familiarity was significant (Interaction 1), unspaced and inter-character spaced conditions were compared separately for unfamiliar (Comparison 1) and familiar (Comparison 2) texts. Segmentation 2 contrasted unspaced vs. inter-word spaced conditions; if the interaction between Segmentation 2 and text familiarity was significant (Interaction 2), unspaced and inter-word spaced conditions were compared for unfamiliar (Comparison 3) and familiar (Comparison 4) texts. Segmentation 3 contrasted unspaced vs. non-word spaced conditions; if the interaction between Segmentation 3 and text familiarity was significant (Interaction 3), unspaced and non-word spaced conditions were compared for unfamiliar (Comparison 5) and familiar (Comparison 6) texts.

Fixed effects estimates for overall eye-tracking measures are presented in Table 3.

Table 3. Fixed effects estimates for overall eye-tracking measures

Results showed that, except for mean fixation duration ($b = -0.002$, $SE = 0.022$, $t = -0.104$, $p = 0.918$, 95% CI = [-0.045, 0.041]), main effects of text familiarity were significant for number of fixations ($b = -0.234$, $SE = 0.055$, $t = -4.267$, $p < 0.001$, 95% CI = [-0.342, -0.127]), total time ($b = -0.251$, $SE = 0.064$, $t = -3.894$, $p < 0.001$, 95% CI = [-0.377, -0.125]), and reading speed ($b = 0.252$, $SE = 0.065$, $t = 3.856$, $p < 0.001$, 95% CI = [0.124, 0.381]). Familiar text showed significantly fewer fixations, shorter total reading time, and faster reading speed, demonstrating that reading training (right-to-left) facilitated Chinese reading for adult native readers.

Results also revealed disruptive effects of inter-character and non-word spacing, evident in comparisons between unspaced and inter-character spaced (Segmentation 1) and non-word spaced (Segmentation 3) conditions. Compared to unspaced text, inter-character spaced text showed longer mean fixation duration ($b = -0.097$, $SE = 0.006$, $t = -16.287$, $p < 0.001$, 95% CI = [-0.108, -0.085]), more fixations ($b = 0.113$, $SE = 0.012$, $t = 9.147$, $p < 0.001$, 95% CI = [0.089, 0.138]), longer total time ($b = 0.046$, $SE = 0.013$, $t = -3.440$, $p = 0.001$, 95% CI = [0.020, 0.072]), and slower reading speed ($b = -0.045$, $SE = 0.014$, $t = -3.379$, $p = 0.001$, 95% CI = [-0.072, -0.019]). Similarly, compared to unspaced text, non-word spaced text showed longer mean fixation duration ($b = -0.072$, $SE = 0.006$, $t = -12.618$, $p < 0.001$, 95% CI = [-0.083, -0.061]), more fixations ($b = 0.069$, $SE = 0.011$, $t = 6.396$, $p < 0.001$, 95% CI = [0.048, 0.091]), and slower reading speed ($b = -0.028$, $SE = 0.012$, $t = -2.432$, $p = 0.019$, 95% CI = [-0.051, -0.005]), with total time marginally significant ($b = 0.022$, $SE = 0.012$, $t = 1.845$, $p = 0.070$, 95% CI = [-0.001, 0.045]).

Notably, as text familiarity increased, the disruptive effects of inter-character and non-word spacing became more pronounced. Except for mean fixation duration ($b = 0.007$, $SE = 0.012$, $t = 0.602$, $p = 0.549$, 95% CI = [-0.016, 0.030]), Interaction 1 (Segmentation 1 × Text Familiarity) was significant for number of fixations ($b = 0.060$, $SE = 0.024$, $t = 2.515$, $p = 0.014$, 95% CI = [0.013, 0.107]), total time ($b = 0.056$, $SE = 0.022$, $t = 2.497$, $p = 0.014$, 95% CI = [0.012, 0.100]), and reading speed ($b = -0.057$, $SE = 0.024$, $t = -2.377$, $p = 0.020$, 95% CI = [-0.104, -0.010]). Further analysis revealed that under unfamiliar text, unspaced and inter-character spaced conditions differed significantly in number of fixations, with more fixations in the inter-character spaced condition ($b = 0.084$, $SE = 0.019$, $t = 4.384$, $p < 0.001$, 95% CI = [0.046, 0.121]). As text familiarity increased, this difference became larger in familiar text ($b = 0.142$, $SE = 0.016$, $t = 8.754$, $p < 0.001$, 95% CI = [0.111, 0.174]). Additionally, under unfamiliar text, unspaced and inter-character spaced conditions did not differ significantly in total time ($b = 0.018$, $SE = 0.020$, $t = 0.885$, $p = 0.381$, 95% CI = [-0.022, 0.058]) or reading speed ($b = -0.017$, $SE = 0.022$, $t = -0.775$, $p = 0.443$, 95% CI = [-0.060, 0.026]). However, with increased text familiarity, familiar text in the inter-character spaced condition showed longer total time ($b = 0.072$, $SE = 0.014$, $t = 5.165$, $p < 0.001$, 95% CI = [0.045, 0.100]) and slower reading speed ($b = -0.074$, $SE = 0.016$, $t = -4.605$, $p < 0.001$, 95% CI = [-0.105, -0.042]), demonstrating that inter-character spacing disrupted reading performance.

Furthermore, except for mean fixation duration ($b = 0.010$, $SE = 0.011$, $t = 0.898$, $p = 0.372$, 95% CI = [-0.011, 0.031]), Interaction 3 (Segmentation 3 × Text Familiarity) was significant for number of fixations ($b = 0.060$, $SE = 0.021$, $t = 2.835$, $p = 0.006$, 95% CI = [0.019, 0.102]), total time ($b = 0.057$, $SE = 0.021$, t = 2.713, p = 0.008, 95% CI = [0.016, 0.098]), and reading speed (b = -0.067, SE = 0.022, t = -3.039, p = 0.003, 95% CI = [-0.110, -0.024]). Further analysis showed that under unfamiliar text, unspaced and non-word spaced conditions differed significantly in number of fixations, with more fixations in the non-word spaced condition (b = 0.039, SE = 0.017, t = 2.258, p = 0.030, 95% CI = [0.005, 0.073]). As text familiarity increased, this difference became larger in familiar text (b = 0.099, SE = 0.015, t = 6.566, $p < 0.001$, 95% CI = [0.069, 0.128]). Moreover, under unfamiliar text, unspaced and non-word spaced conditions did not differ significantly in total time (b = -0.007, SE = 0.017, t = -0.403, p = 0.690, 95% CI = [-0.040, 0.027]) or reading speed (b = 0.005, SE = 0.017, t = 0.313, p = 0.757, 95% CI = [-0.029, 0.039]). However, with increased text familiarity, familiar text showed significant differences between unspaced and non-word spaced conditions in both total time (b = 0.049, SE = 0.015, t = 3.190, p = 0.002, 95% CI = [0.019, 0.080]) and reading speed (b = -0.061, SE = 0.015, t = -4.194, $p < 0.001$, 95% CI = [-0.090, -0.032]), with longer total time and slower reading speed in the non-word spaced condition. These results indicate that text familiarity also trades off with the disruptive effects of inter-character and non-word spacing, with text unfamiliarity partially offsetting these disruptions. As text familiarity increased, the disruptive effects of inter-character and non-word spacing on Chinese reading became more pronounced.

2.3 Discussion

Experiment 1 examined whether a trade-off exists between text familiarity and the facilitative effect of inter-word spaces, as reflected in comparisons between unspaced and inter-word spaced conditions (Segmentation 2). Except for a marginal effect on number of fixations (b = 0.021, SE = 0.012, t = 1.831, p = 0.070, 95% CI = [-0.002, 0.044]), inter-word spaced text showed shorter mean fixation duration (b = -0.091, SE = 0.005, t = -16.708, $p < 0.001$, 95% CI = [-0.101, -0.080]), shorter total time (b = -0.050, SE = 0.012, t = -4.124, $p < 0.001$, 95% CI = [-0.073, -0.026]), and faster reading speed (b = 0.049, SE = 0.013, t = 3.763, $p < 0.001$, 95% CI = [0.023, 0.074]).

Except for mean fixation duration (b = -0.013, SE = 0.010, t = -1.284, p = 0.203, 95% CI = [-0.033, 0.007]), Interaction 2 (Segmentation 2 × Text Familiarity) was significant for number of fixations (b = 0.074, SE = 0.023, t = 3.271, p = 0.002, 95% CI = [0.030, 0.118]), total time (b = 0.062, SE = 0.022, t = 2.784, p = 0.007, 95% CI = [0.018, 0.105]), and reading speed (b = -0.058, SE = 0.024, t = -2.408, p = 0.018, 95% CI = [-0.105, -0.011]). Further analysis revealed that under unfamiliar text, unspaced and inter-word spaced conditions did not differ significantly in number of fixations (b = -0.015, SE = 0.018, t = -0.832, p = 0.411, 95% CI = [-0.051, 0.021]), whereas under familiar text, the unspaced condition showed significantly fewer fixations than the inter-word spaced condition (b = 0.058, SE = 0.016, t = 3.533, $p < 0.001$, 95% CI = [0.026, 0.090]). Notably, under unfamiliar text, inter-word spaced text showed significantly shorter total time (b = -0.080, SE = 0.018, t = -4.379, $p < 0.001$, 95% CI = [-0.116, -0.044]) and faster reading speed (b = 0.077, SE = 0.020, t = 3.932, $p < 0.001$, 95% CI = [0.039, 0.116]) compared to unspaced text, demonstrating that inter-word spaces as segmentation cues facilitated Chinese reading by reducing total reading time and increasing speed. However, as text familiarity increased, differences between unspaced and inter-word spaced conditions became non-significant for both total time (b = -0.019, SE = 0.016, t = -1.179, p = 0.246, 95% CI = [-0.050, 0.012]) and reading speed (b = 0.020, SE = 0.017, t = 1.168, p = 0.249, 95% CI = [-0.013, 0.053]). This indicates that as text familiarity increased, the facilitative effect of inter-word spaces as segmentation cues disappeared. These results support the hypothesis that inter-word spaces facilitate Chinese reading of unfamiliar text, but after 10 days of reading training that increased experience with right-to-left text and improved text familiarity, this facilitative effect was offset by the unfamiliarity of spaced text. In summary, a trade-off exists between text familiarity and the facilitative effect of inter-word spaces in Chinese reading.

Experiment 1 also revealed a trade-off between text familiarity and the disruptive effects of inter-character and non-word spacing. Compared to unfamiliar text, familiar text showed greater disruption from inter-character and non-word spacing. As reading experience increased and text familiarity improved, differences between inter-character/non-word spaced and unspaced conditions became larger. Specifically, before training, no significant differences were found between inter-character spaced and unspaced conditions or between non-word spaced and unspaced conditions in total time and reading speed. After 10 days of training on unfamiliar text, inter-character and non-word spaced conditions showed longer total time, slower reading speed, and more fixations compared to unspaced text, indicating that these spacing manipulations interfered with word segmentation and disrupted Chinese reading. This disruptive effect was not apparent in unfamiliar text (pre-training) but emerged only after training increased text familiarity, demonstrating that the disruptive effects of inter-character and non-word spacing also trade off with text familiarity.

In conclusion, Experiment 1 supports the existence of a trade-off between text familiarity and the facilitative effect of inter-word spaces. Based on these findings, Experiment 2 investigated the role of text familiarity in Chinese lexical recognition to examine the synchrony of word segmentation and lexical recognition processes—whether they are fully synchronous or partially dissociated, and whether they support the Chinese E-Z Reader model.

Experiment 2

Building on Experiment 1' s finding of a trade-off between text familiarity and the facilitative effect of inter-word spaces, and given that text familiarity affects word segmentation, the present study aimed to investigate the synchrony of word segmentation and lexical recognition in Chinese reading. How text familiarity influences lexical recognition was the focus of Experiment 2, which manipulated text familiarity and word frequency to examine their roles in lexical recognition.

Following 10 days of reading training on unfamiliar text, the study investigated whether the effects of text familiarity and word frequency on lexical recognition would change. To control for individual differences, the same participants were used pre- and post-training, but with different experimental materials.

3.1.1 Participants

Thirty-two undergraduate students (mean age = 20.21 ± 1.95 years; 24 females, 8 males) participated. All were native Chinese speakers with normal or corrected-to-normal vision and right-handed. Participants provided informed consent and completed eye-tracking experiments before and after reading training, receiving 10 days of reading instruction.

3.1.2 Design

A 2 (text familiarity: unfamiliar vs. familiar text) × 2 (word frequency: high vs. low) within-subjects design was used for the pre-training eye-tracking experiment. For the post-training experiment, a single-factor (word frequency: high vs. low) within-subjects design was employed.

3.1.3 Materials

Pre-training eye-tracking experiment: Forty-eight pairs of two-character words served as target words. Based on the publicly available SUBTLEX-CH database (Cai & Brysbaert, 2010), word and character frequencies were calculated as occurrences per million (OPM). Each pair consisted of one high-frequency word (M = 368.11, SD = 470.72) and one low-frequency word (M = 8.10, SD = 7.56), with significant frequency differences, $t(94) = -5.30$, $p < 0.001$. Character stroke counts were matched between high-frequency (first character: M = 7.52, SD = 2.90; second character: M = 7.65, SD = 2.68) and low-frequency words (first character: M = 8.15, SD = 3.09; second character: M = 7.42, SD = 2.62), first character: $t(94) = 1.02$, $p > 0.1$; second character: $t(94) = -0.42$, $p > 0.1$. First character frequency was marginally significant (high: M = 2481.58, SD = 4724.37; low: M = 1037.95, SD = 2807.45), $t(94) = -1.82$, $p = 0.07$. Second character frequency was higher for high-frequency words (M = 2699.36, SD = 3623.92) than low-frequency words (M = 1206.97, SD = 1809.49), $t(94) = -2.55$, $p < 0.05$.

Ninety-six sentences were constructed with target words embedded in non-initial, non-final positions. Sentence length ranged from 16-23 characters (M = 19.40). Forty participants who did not participate in the eye-tracking experiment rated sentence naturalness on a 7-point scale. Predictability was assessed by having 28 participants provide the upcoming word based on pre-target context. High-frequency and low-frequency conditions were matched for naturalness (HF: M = 6.49, SD = 0.38; LF: M = 6.41, SD = 0.39) and predictability (HF: M = 0.15, SD = 1.46; LF: M = 0.10, SD = 1.02), $ts < 1$. See Table 4 for details.

Table 4. Statistical values for experimental sentences and target words

Four experimental files were created for the pre-training eye-tracking experiment, each containing 96 sentences (24 per condition) rotated using a Latin square design. Sentence order was randomized. Each file included 12 practice sentences (three per condition) and 24 filler sentences (six per condition) that appeared randomly. Comprehension questions (yes/no) followed 22 sentences. Participants read 132 sentences total. Example sentences for each condition are shown in Table 5.

Table 5. Example sentences from the four conditions

Reading training materials were identical to Experiment 1. **Post-training eye-tracking experiment:** Twenty-four pairs of two-character words served as target words. High-frequency words (M = 465.00, SD = 436.55) and low-frequency words (M = 465.00, SD = 436.55) differed significantly in frequency, $t(46) = -5.15$, $p < 0.001$. Stroke counts were matched between high-frequency (first character: M = 8.04, SD = 2.37; second character: M = 7.33, SD = 2.78) and low-frequency words (first character: M = 8.46, SD = 3.45; second character: M = 6.63, SD = 2.84), first character: $t(46) = 0.49$, $p > 0.1$; second character: $t(46) = 0.39$, $p > 0.1$. First character frequency differed significantly (high: M = 1501.60, SD = 1962.25; low: M = 494.67, SD = 599.69), $t(46) = -2.40$, $p = 0.02$. Second character frequency was higher for high-frequency words (M = 2955.16, SD = 3403.15) than low-frequency words (M = 1133.15, SD = 1745.39), $t(46) = -2.33$, $p = 0.02$.

Forty-eight Chinese sentences were constructed with target words in non-initial, non-final positions. Naturalness ratings from 40 non-participants showed no difference between high-frequency (M = 6.33, SD = 0.40) and low-frequency conditions (M = 6.36, SD = 0.42), $t(46) = 0.27$, $p > 0.1$. Predictability was also matched (HF: M = 0.04, SD = 0.20; LF: M = 0.13, SD = 0.34), $t(46) = 1.03$, $p > 0.1$. See Table 6 for details.

Table 6. Statistical values for experimental sentences and target words

Four files were created, each containing 48 sentences (24 per condition) rotated using a Latin square design. Sentence order was randomized. Each file included six practice sentences (three per condition) and 12 filler sentences (six per condition) that appeared randomly. Comprehension questions (yes/no) followed 11 sentences. Participants read 66 sentences total. Example sentences for each condition are shown in Table 7.

Table 7. Example sentences from experimental conditions

3.1.4 Apparatus

Identical to Experiment 1.

3.1.5 Procedure

Pre-training eye-tracking experiment: Identical to Experiment 1. Comprehension accuracy was 91%, indicating careful reading and understanding. **Reading training phase:** Identical to Experiment 1. **Post-training eye-tracking experiment:** Identical to pre-training. Comprehension accuracy was 93%, indicating careful reading and understanding.

3.2 Data Analysis

Data screening criteria were identical to Experiment 1. Invalid data accounted for 2.8% of total data and were excluded from analysis.

The following target word eye-tracking measures were analyzed: (1) First fixation duration: duration of the first fixation on the word, independent of fixation count; (2) Single fixation duration: duration when the word was fixated only once during first-pass reading; (3) Gaze duration: sum of all fixation durations on a word before moving to the next word; (4) Total time: sum of all fixation durations on the target word, including regressions; (5) Skipping probability: probability of skipping the target region during first-pass reading; (6) Refixation probability: probability of multiple fixations on the target region during first-pass reading; (7) Average initial landing position: location of the first fixation on the word, regardless of total fixation count. Time measures were recorded in milliseconds; average initial landing position in characters.

Data were analyzed using linear mixed models (LMM) in R (R Core Team, 2016) with the lme4 package (Bates et al., 2012). Participants and items were specified as crossed random effects (Baayen et al., 2008). Significance estimates were obtained using Markov-Chain Monte Carlo algorithms (Baayen et al., 2012; Josse et al., 2014). t-values greater than 1.96 were considered significant at the 5% level. Dependent variables were log-transformed, while skipping and refixation probabilities were analyzed using logistic LMM. Fixed effects included word frequency, training, text familiarity, and interactions between word frequency $\times$ training and word frequency $\times$ text familiarity. If a significant interaction emerged between word frequency and text familiarity (Interaction 1), high- and low-frequency conditions were compared separately for familiar left-to-right text (Comparison 1) and unfamiliar right-to-left text (Comparison 2) before training. If a significant interaction emerged between word frequency and training (Interaction 2), high- and low-frequency conditions were compared for unfamiliar right-to-left text before training (Comparison 2) and after training (Comparison 3).

3.3 Results

Descriptive statistics for target word eye-tracking measures are presented in Table 8, with analysis results in Table 9.

Table 8. Eye-tracking measures on target words

Table 9. Fixed effects estimates for eye-tracking measures on target words

Reading training increased participants' reading experience and familiarity with unfamiliar right-to-left text. Training showed a marginal main effect on first fixation duration (b = 0.027, SE = 0.014, t = 1.899, p = 0.059, 95% CI = [-0.001, 0.054]) but not on single fixation duration (b = 0.027, SE = 0.019, t = 1.452, p = 0.147, 95% CI = [-0.009, 0.064]). Training effects were significant for other temporal measures (gaze duration: b = -0.068, SE = 0.022, t = -3.044, p = 0.003, 95% CI = [-0.111, -0.024]; total time: b = -0.229, SE = 0.033, t = -6.878, $p < 0.001$, 95% CI = [-0.294, -0.164]), with lower refixation probability after training (b = -0.103, SE = 0.015, t = -6.74, $p < 0.001$, 95% CI = [-0.133, -0.073]). Average initial landing position was marginally further from word onset after training (b = 0.065, SE = 0.038, t = 1.691, p = 0.091, 95% CI = [-0.010, 0.140]). No significant difference emerged in skipping rate (b = -0.017, SE = 0.011, t = -1.51, p = 0.130, 95% CI = [-0.039, 0.005]).

Word frequency effects were significant across all measures (first fixation duration: b = 0.038, SE = 0.012, t = 3.294, $p < 0.001$, 95% CI = [0.016, 0.061]; single fixation duration: b = 0.035, SE = 0.015, t = 2.424, p = 0.016, 95% CI = [0.007, 0.064]; gaze duration: b = 0.119, SE = 0.018, t = 6.540, $p < 0.001$, 95% CI = [0.084, 0.155]; total time: b = 0.232, SE = 0.027, t = 8.500, $p < 0.001$, 95% CI = [0.178, 0.285]; skipping rate: b = -0.035, SE = 0.011, t = -3.191, p = 0.002, 95% CI = [-0.056, -0.013]; refixation probability: b = 0.096, SE = 0.016, t = 5.856, $p < 0.001$, 95% CI = [0.064, 0.128]; average initial landing position: b = -0.077, SE = 0.032, t = -2.43, p = 0.015, 95% CI = [-0.140, -0.015]).

Main effects of text familiarity were significant across all measures (first fixation duration: b = 0.078, SE = 0.015, t = 5.388, $p < 0.001$, 95% CI = [0.049, 0.106]; single fixation duration: b = 0.053, SE = 0.017, t = 3.139, $p < 0.005$, 95% CI = [0.020, 0.087]; gaze duration: b = 0.253, SE = 0.023, t = 11.206, $p < 0.001$, 95% CI = [0.208, 0.297]; total time: b = 0.431, SE = 0.034, t = 12.838, $p < 0.001$, 95% CI = [0.365, 0.497]; skipping rate: b = -0.070, SE = 0.000, t = -3.327, p = 0.001, 95% CI = [-0.092, -0.048]; refixation probability: b = 0.220, SE = 0.016, t = 14.006, $p < 0.001$, 95% CI = [0.189, 0.250]; average initial landing position: b = -0.185, SE = 0.039, t = -4.692, $p < 0.001$, 95% CI = [-0.262, -0.108]). These results align with hypotheses and previous research (Li et al., 2011; Liu et al., 2016; Ma, 2017; Ma et al., 2017; Wang et al., 2018). The character center represents the optimal viewing position for eye movements, where reading efficiency is highest. Fixation efficiency decreases as distance from the character center increases (白学军等, 2014; Li et al., 2011; Yan et al., 2010; Zang et al., 2013). Readers incurred greater processing costs due to text unfamiliarity (Li et al., 2011; Ma, 2017).

Critically, the interaction between word frequency and text familiarity varied across measures. On early measures, the interaction was significant. First fixation duration showed a significant interaction (b = -0.070, SE = 0.029, t = -2.442, p = 0.015, 95% CI = [-0.126, -0.014]), with a significant word frequency effect in familiar text (b = 0.084, SE = 0.021, t = 4.055, $p < 0.001$) but not in unfamiliar text (b = 0.014, SE = 0.020, t = 0.694, p = 0.488). Single fixation duration, considered a sensitive indicator of semantic processing in lexical recognition heavily influenced by word frequency, also showed a significant interaction (b = -0.073, SE = 0.034, t = -2.155, p = 0.032, 95% CI = [-0.139, -0.007]), with a significant word frequency effect in familiar text (b = 0.088, SE = 0.023, t = 3.879, $p < 0.001$) but not in unfamiliar text (b = 0.015, SE = 0.025, t = 0.584, p = 0.559). No significant interaction emerged for gaze duration (b = -0.066, SE = 0.045, t = -1.472, p = 0.142, 95% CI = [-0.154, 0.022]), though the word frequency effect was larger in familiar text (b = 0.156, SE = 0.032, t = 4.837, $p < 0.001$) than in unfamiliar text (b = 0.090, SE = 0.031, t = 2.867, p = 0.004). No significant interaction was found for total time (b = -0.030, SE = 0.067, t = -0.454, p = 0.650, 95% CI = [-0.162, 0.101]), skipping rate (b = 0.013, SE = 0.022, t = 0.584, p = 0.559, 95% CI = [-0.031, 0.057]), refixation probability (b = -0.017, SE = 0.031, t = -0.554, p = 0.580, 95% CI = [-0.078, 0.044]), or average initial landing position (b = -0.022, SE = 0.078, t = -0.275, p = 0.783, 95% CI = [-0.175, 0.132]). Word frequency effects were consistent with previous research (Rayner et al., 1998; Li et al., 2011; Ma, 2017).

Interaction 2 revealed the relationship between word frequency and training. Except for a marginally significant interaction on skipping rate (b = 0.039, SE = 0.022, t = 1.724, p = 0.085, 95% CI = [-0.005, 0.083]; word frequency effect significant before training: b = 0.000, SE = 0.000, t = -2.562, p = 0.011; not significant after training: b = 0.000, SE = 0.000, t = -0.271, p = 0.787), no significant interactions were found for first fixation duration (b = 0.004, SE = 0.028, t = 0.130, p = 0.896, 95% CI = [-0.052, 0.059]), single fixation duration (b = -0.011, SE = 0.037, t = -0.309, p = 0.758, 95% CI = [-0.084, 0.061]), gaze duration (b = 0.023, SE = 0.044, t = 0.521, p = 0.603, 95% CI = [-0.064, 0.110]), total time (b = 0.050, SE = 0.066, t = 0.758, p = 0.449, 95% CI = [-0.080, 0.181]), refixation probability (b = 0.017, SE = 0.030, t = 0.548, p = 0.584, 95% CI = [-0.043, 0.076]), or average initial landing position (b = 0.048, SE = 0.077, t = 0.631, p = 0.528, 95% CI = [-0.102, 0.199]).

3.4 Discussion

Experiment 2 manipulated text familiarity and word frequency to examine their roles in lexical recognition, then conducted reading training to investigate whether these effects would change.

Results showed better reading performance under familiar text and high-frequency word conditions. Notably, a significant interaction between text familiarity and word frequency emerged on early measures (first fixation duration and single fixation duration), with word frequency effects appearing in familiar but not unfamiliar text. No significant interactions were found on other temporal measures, indicating that text familiarity affects early processing in lexical recognition. Text unfamiliarity delayed the word frequency effect, consistent with previous findings that unspaced text delayed the effect by 21 ms (Ma, 2017). Prior research did not find an interaction between inter-word spacing and word frequency (Rayner et al., 1998) but observed that the word frequency effect emerged 21 ms earlier under inter-word spaced conditions (Sheridan et al., 2013; Ma, 2017). This suggests that inter-word spacing may facilitate lexical recognition, but this facilitation is offset by text unfamiliarity caused by inserting spaces. Experiment 2 supports this hypothesis: during early stages of Chinese lexical recognition, the word frequency effect is traded off by text unfamiliarity.

Additionally, a significant interaction on refixation probability was found. Refixation probability sensitively reflects cognitive processing efficiency during reading; lower refixation efficiency indicates that readers can locate the optimal viewing position (OVP) with fewer fixations, acquiring more information. Therefore, text familiarity influences processing efficiency during lexical recognition. While training showed significant main effects on late and overall temporal measures, the effect on first fixation duration was only marginal. This inconsistency may reflect that reading experience with unfamiliar right-to-left text has greater impact on later recognition processes. Moreover, although reading training increased Chinese reading experience, word frequency effects still did not emerge on early measures, possibly because early measures are more influenced by other factors (e.g., Chinese character visual features) while reading experience more strongly affects semantic-level processing that top-down influences lexical recognition. Experiment 2 demonstrates that text unfamiliarity affects early processing in lexical recognition, with text familiarity and word frequency interacting on early measures.

4. General Discussion

This study investigated Chinese word segmentation and lexical recognition mechanisms by examining the role of text familiarity in these processes. Experiment 1 revealed a trade-off between text familiarity and the facilitative effect of inter-word spaces. Experiment 2 found an interaction between text familiarity and word frequency on early measures, with text familiarity primarily affecting early processing in lexical recognition. These findings support the hypothesis that Chinese word segmentation and lexical recognition are not fully synchronous but may involve sequential processing, providing support for the E-Z Reader model.

The trade-off between text familiarity and the facilitative effect of inter-word spaces was the central question of Experiment 1. Bai et al. (2008) failed to find facilitative effects of inter-word spacing for adult native readers and proposed this hypothesis. By manipulating text familiarity, Experiment 1 found faster reading speed under inter-word spaced conditions, confirming that inter-word spaces can facilitate Chinese reading for adult native readers (Hsu & Huang, 2000; Inhoff et al., 2000; Inhoff & Radach, 2002; Liu et al., 2014; Ma et al., 2014). After 10 days of training that increased familiarity with right-to-left text, no significant differences in reading speed or total time were found between unspaced and inter-word spaced conditions, indicating that the facilitative effect disappeared. Experiment 1 thus supports the existence of a trade-off between text familiarity and inter-word spacing facilitation in Chinese reading.

At the level of Chinese word segmentation, the underlying mechanism of this trade-off involves an interaction between low-level visual factors (inter-word spaces as segmentation cues) and high-level cognitive factors (reading experience). Even highly skilled native Chinese readers experience comprehension difficulties when encountering ambiguous or complex text (e.g., "花生长在土地中" can be segmented as "花生长在土地中" or "花生长在土地中"). The significance of Experiment 1 lies in demonstrating that inter-word spaces can improve reading performance for native Chinese readers when processing unfamiliar text. Furthermore, for children with reading disabilities and adult learners, inter-word spaces can effectively alleviate visual crowding effects during reading, and reading efficiency can be improved through artificial word segmentation of reading materials. Additionally, reading training experience influences the speed and efficiency of lexical recognition (Li et al., 2011; Yan et al., 2012). The finding that even highly skilled adult native readers can benefit from short-term training using unfamiliar text formats provides implications for future research, suggesting that reading training need not be limited to special populations (Berends & Reitsma, 2006; Snellings et al., 2009).

Experiment 1' s demonstration of a trade-off between text familiarity and inter-word spacing facilitation indicates that high-level cognitive factors (reading experience) top-down influence Chinese word segmentation. Computational models of Chinese word segmentation and lexical recognition include feedforward and holistic hypotheses (Li et al., 2009). The feedforward hypothesis posits that the character recognition system extracts visual information from characters, transfers it to the word segmentation stage, and then integrates it into lexical recognition, with processing proceeding only bottom-up without top-down feedback. In contrast, the holistic hypothesis proposes that visual information, character recognition, and lexical recognition systems interactively influence word segmentation and lexical recognition stages. Based on the holistic hypothesis, inter-word spaces as low-level visual information bottom-up influence processing, while reading experience as a high-level cognitive factor top-down influences processing. Therefore, the high-level cognitive factor underlying text familiarity (reading experience) trades off with low-level visual cues like inter-word spaces. This explains why previous studies failed to find facilitative effects of inter-word spacing for experienced adult native readers (Bai et al., 2008; Shen et al., 2010; Yan et al., 2012). Reading experience as a high-level cognitive factor influences the facilitative effect of low-level visual cues like inter-word spaces.

Inter-word spaces have been shown to facilitate lexical recognition for foreign university students with limited Chinese reading experience (Shen et al., 2012; Gu et al., 2017; Zhou et al., 2020). The present study suggests that the holistic hypothesis is more appropriate for Chinese word segmentation mechanisms (Li et al., 2011; Ma, 2017; Ma & Zhuang, 2018). Building on Experiment 1, Experiment 2 examined the role of text familiarity (reading experience) as a high-level cognitive factor in lexical recognition, with the presence of a trade-off at the lexical recognition level reflecting the synchrony of word segmentation and lexical recognition mechanisms. Experiment 2 results showed a significant interaction between text familiarity and word frequency only on early temporal measures, with no significant interactions on late or overall measures. Text unfamiliarity delayed the word frequency effect, similar to previous findings that unspaced text delayed the effect by 21 ms (Ma, 2017). Prior research did not find an interaction between inter-word spacing and word frequency (Rayner et al., 1998) but observed that the word frequency effect emerged 21 ms earlier under inter-word spaced conditions (Sheridan et al., 2013; Ma, 2017). This led to the speculation that inter-word spacing facilitates lexical recognition but is offset by text unfamiliarity caused by inserting spaces. Experiment 2 supports this hypothesis: during early stages of Chinese lexical recognition, the word frequency effect is traded off by text unfamiliarity.

Regarding the processing mechanisms of Chinese word segmentation and lexical recognition, the integrated model posits that these processes are interactive, with segmentation occurring simultaneously with lexical recognition and completing automatically upon word recognition (Li et al., 2009; Ma, 2017). Lexical recognition follows a "winner-take-all" pattern where word onset and offset are determined upon word identification, segmenting the word from continuous text (Li & Pollatsek, 2020), suggesting synchronous processing. In contrast, the E-Z Reader model proposes sequential rather than parallel processing. The model contains two core stages: (1) the familiarity check (L1) stage, where early processing of word n triggers a saccade program to move the eyes to word n+1; (2) the lexical access (L2) stage, where processing of word n completes and attention shifts from word n to word n+1. Saccade programming and attention shifts are sequential, with attention focused on only one word at a time. The model also assumes an early pre-attentive stage where low-level visual information (e.g., inter-word spaces as segmentation cues) is used by the oculomotor system for target selection, while high-level visual information (e.g., features needed for character identification) is selected by attention for further lexical processing. Although the E-Z Reader model is the most influential and theoretically comprehensive, Chinese text's lack of inter-word spaces creates substantial differences in eye movement patterns compared to alphabetic scripts, preventing even the modified Chinese E-Z Reader model from perfectly simulating Chinese reading. The integrated model of lexical processing and eye movement control in Chinese reading considers only word segmentation and lexical processing levels, neglecting higher-level cognitive factors like semantic comprehension, and neither the original computational model (Li et al., 2009) nor the refined integrated model (Li & Pollatsek, 2020) achieves perfect convergence or fits natural Chinese reading processes. Both models require further empirical validation and refinement.

During Chinese reading, the word currently being attended to is called the target word (word N), and the next word is the preview word (word N+1). Parafoveal preview benefit refers to readers' ability to process information to the right of fixation through parafoveal vision, allowing partial or complete processing of the preview word (word N+1) during the preview stage (Schotter et al., 2012). Based on results from Experiments 1 and 2, text familiarity' s differential effects on word segmentation and lexical recognition suggest an alternative possibility: word segmentation and lexical recognition are not fully synchronous parallel processes but may be sequential. Readers may complete or partially complete word segmentation before lexical recognition. Under familiar text, participants may complete or partially complete segmentation of word N+1 during the preview stage, entering lexical recognition with the word frequency effect appearing on early fixation measures. Under unfamiliar text, insufficient reading experience requires greater processing costs, and segmentation of word N+1 may not be completed during the preview stage, delaying familiarity verification and resulting in a delayed word frequency effect. Conversely, if segmentation and lexical recognition were fully synchronous, text familiarity' s influence on the word frequency effect should be evident across all processing stages. However, Experiment 2 showed that the text familiarity × word frequency interaction appeared only on early measures (first fixation duration and single fixation duration). On late measures, word frequency effects appeared in both familiar and unfamiliar text, indicating that segmentation of word N+1 was complete and processing had entered the lexical recognition stage. In summary, Chinese word segmentation and lexical recognition may involve sequential rather than fully synchronous parallel processing, supporting the E-Z Reader model and providing empirical evidence for a Chinese reading model (Li & Pollatsek, 2020). However, the processing mechanisms are complex, and future research should investigate whether trade-offs exist between different processing levels (visual and character, character and lexical, visual and lexical, and visual-character-lexical levels).

In conclusion, this study demonstrates that: (1) a trade-off exists between text familiarity and the facilitative effect of inter-word spaces in Chinese reading; (2) text familiarity affects early processing in lexical recognition; (3) word segmentation and lexical recognition in Chinese reading may involve sequential processing, supporting the E-Z Reader model.

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Appendix: Example Reading Training Materials for Experiments 1 and 2

Hand to Heart with Small Scissors

How can one cut by oneself? Put it down quickly! The child picked up the scissors for the first time to take care of his grandmother, who was frightened: "The child has been scared badly!" The child put down the scissors obediently. "What can you do with scissors? You can' t bite off buttons with your teeth!" The mother said. The child hesitated, lowering his head to bite the button hard. "Where are the scissors, child?" Mother asked. "Hand to heart with small scissors," the child was warned. The child looked at his own hand, then at the shiny scissors. "Mother will help you cut. What are you making?" The child gave the scissors to his mother reluctantly. After school, the child learned handicrafts. The teacher assigned a homework project: make a handmade craft and give it to father. The child just picked up the scissors when father saw him. "Hand to heart with small scissors," mother warned the child. The child' s fingernails had grown long. Mother said: "Never use scissors with small fingers and heart." The child also bit the corners of his clothes, which wouldn' t work. The child wanted to use the scissors to trim the four corners of his leather notebook. "What if you need to use scissors?" The students asked curiously. "Isn' t it simple? Find an adult!" The students laughed. "If you need to use scissors, what will you do?" The teacher friend told me about an incident. Once, she taught children to do handicrafts, and to her surprise, nearly half the children couldn' t or dared not use scissors, preferring to tear paper crookedly with their hands. "How is this possible?" She asked them in surprise: "Haven' t you used scissors at home?" The children answered: "My parents won' t let me use scissors, saying it' s dangerous." Some children were even more afraid of scissors after being cut. From then on, they dared not touch scissors again. Every time they picked up scissors, adults would warn them: "Hand to heart with small scissors." This was originally a well-intentioned reminder to protect children from mistakes and danger. However, this reminder created an invisible pressure and burden for the children. Every time they picked up scissors, they would hear this warning from parents or other elders. Some children, already timid, became even more afraid of scissors and wouldn' t use them at all. Others, already frustrated, simply stopped using scissors altogether. If you need to use scissors, what will you do? The teacher friend asked the whole class. "Find an adult to help!" "Ask a classmate!" "Ask some classmates!" The survey found that nearly half the students couldn' t, dared not, or wouldn' t use scissors. Why? Because they had heard warnings from elders or parents every time they picked up scissors, or they had been cut by scissors before. Why do you think nearly half the students can' t use scissors? A. They don' t like using scissors themselves. B. Their parents won' t let them. C. They' re more accustomed to tearing.

Why do you think the teacher friend surveyed this situation? A. She had been cut by scissors before. B. She heard warnings from elders or parents every time she picked up scissors. C. She had hurt others with scissors.

Why did she say "Hand to heart with small scissors" when children pick up scissors? A. To keep children away from mistakes and danger. B. To prevent children from hurting themselves and affecting their future health. C. To give children the courage to use scissors, which will help them develop in the future.

Is this the first time you' ve read this article? A. Yes. B. No.

How easy do you think this article is to read? A. Very easy. B. Easy. C. Not easy. D. Very difficult.

How much do you like the content of this article? A. Like very much. B. Like. C. Don' t like. D. Don' t like very much.

Note: Figure translations are in progress. See original paper for figures.

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