Eye Movements of Second Language Learners when Reading Spaced and Unspaced Chinese Text

Deli Shen[1], Simon P. Liversedge[2], Jin Tian[1], Chuanli Zang[1], Lei Cui[1],

Xuejun Bai[1], Guoli Yan[1] & Keith Rayner[3]

[1]Academy of Psychology and Behavior,

Tianjin Normal University,

Tianjin, China

[2]School of Psychology

University of Southampton

Southampton, SO17 1BJ

UK

[3]Department of Psychology

University of California,

San Diego, USA.

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Send correspondence to: Simon P. Liversedge

E-mail: s.p.liversedge@soton.ac.uk

Tel: +44 (0) 2380 595399

Fax: +44 (0) 2380 594518

School of Psychology,

University of Southampton,

Southampton, SO17 1BJ,

United Kingdom

Abstract

The effect of spacing in relation to word segmentation was examined for four groups of non-native Chinese speakers (American, Korean, Japanese, and Thai) who were learning Chinese as second language. Chinese sentences with four types of spacing information were used: unspaced text, word spaced text, character spaced text, and nonword spaced text. Also, participants' native languages were different in terms of their basic characteristics: English and Korean are spaced, whereas the other two are unspaced; Japanese is character based whereas the other three are alphabetic. Thus, we assessed whether any spacing effects were modulated by native language characteristics. Eye movement measures showed least disruption to reading for word spaced text and longer reading times for unspaced than character spaced text, with nonword spaced text yielding the most disruption. These effects were uninfluenced by native language (though reading times differed between groups due to Chinese reading experience). Demarcation of word boundaries through spacing reduces non-native readers' uncertainty about the characters that comprise a word, thereby speeding lexical identification, and in turn, reading. More generally, the results indicate that words have psychological reality for those who are learning to read Chinese as a second language, and that segmentation of text into words is more beneficial to successful comprehension than is separating individual Chinese characters with spaces.

Key words: Chinese second language reading, spaced and unspaced text, eye movements.

Learning to speak and read a second language as an adult is a rather difficult proposition. Although there has been considerable research addressing the nature of second language learning in general (e.g., Ellis, 1997; Klein, 1986), there has been no research on learning to read a second language that reports detailed information that monitoring eye movements affords (Liversedge & Findlay, 2000; Rayner, 1998, 2009). Here, we present an experiment designed to examine the extent to which adding spaces between Chinese words facilitates the reading of Chinese text for second language learners of Chinese.

There are two very striking characteristics of written Chinese that are immediately apparent. First, the language is character based, not alphabetic. Second, there are no visible word boundary demarcations in Chinese text (Hoosain, 1992; Tsai & McConkie, 2003; Tsang & Chen, 2008). Written Chinese is logographic, with all of the characters occupying the same unit of space, but differing in their visual and linguistic complexity. They are comprised of a variety of strokes, some of which form radicals that are part of a character. The radicals provide additional linguistic information concerning semantic and phonological properties of the character, as well as morphological cues to the characteristics of compound words. Chinese characters are most analogous to morphemes in alphabetic languages, and consequently, a small proportion of Chinese words are formed by a single character (approximately 20%), while the majority are comprised of two characters (approximately 70%), and the remainder consist of three or more characters (approximately 10%; Modern Chinese Frequency Dictionary, 1986).

Given that Chinese words vary in terms of the number of characters that make them up, and given that there are no spaces (or other forms of demarcation) indicating where words start and end, it is often not at all apparent to a non-Chinese reader which characters belong together to form the words of a sentence. Indeed, it has been argued that there is ambiguity amongst Chinese readers as to which characters comprise a word. Hoosain (1992) reported that when college students were asked to mark the word boundaries in a Chinese text there was disagreement amongst responses. Also, Hoosain (1991) noted that the meaning of the Chinese character for "word" is not very well understood by many ordinary Chinese speakers. However, this said, it is important to also note that for most Chinese words, native Chinese readers with similar levels of experience usually do agree on the characters that comprise them. The most important point to take from this discussion is that because Chinese text does not contain visually salient word boundaries, the strings of characters that comprise the words are not as immediately visually apparent as is the case in spaced languages such as English.

The lack of spaces between words in Chinese is important in relation to theoretical accounts of word identification and eye movement control during reading. Any pervasive theory of word identification or of eye movement control during reading must provide some explanation of how unspaced languages are processed. Word spacing has been shown to be extremely important for efficient eye movement control in alphabetic writing systems (see Rayner, Fischer, & Pollatsek, 1998; Rayner & Pollatsek, 1996). For example, in spaced alphabetic languages, if the spaces between words are removed, then as with Chinese text, the word boundaries are far less apparent.

Furthermore, word spacing has a significant impact on reading performance: Reading speed is dramatically reduced when spacing information is removed from English sentences; fixation durations are increased (Malt & Seamon, 1978; Morris, Rayner, & Pollatsek, 1990; Pollatsek & Rayner, 1982; Rayner & Pollatsek, 1996; Rayner et al., 1998; Spragins, Lefton, & Fisher, 1976; Perea & Acha, 2009) and saccades become shorter (Rayner et al., 1998). In unspaced languages such as Chinese, however, the lack of word demarcation raises the issue of how readers, and particularly those for whom the words of the language are not yet that familiar, identify word boundaries in the absence of spacing information.

The identification of word boundaries during reading is critical to two aspects of processing: saccadic targeting and lexical identification. When we read, we do not make saccades to random locations in the upcoming text. Instead, for readers of alphabetic languages, saccades are targeted towards the middle of upcoming words (Rayner, 1979), or sometimes words are skipped, particularly when they are short, high frequency and predictable (e.g., Rayner, Slattery, Drieghe, & Liversedge, 2011). When text is spaced, the spaces provide a very salient visual cue as to where words start and end, that is, targets for saccades are clearly demarked in the parafovea. However, when text is unspaced, it is far less clear where saccades should be targeted. Increased difficulty in making the decision of where to target saccades results in a delay to saccade initiation, that is, an increase in fixation durations.

The identification of word boundaries is also critical to lexical identification during reading; in order to identify a word it is vital to know which letters or characters within a string comprise it, that is, where it starts and where it ends. In spaced text, the spaces mark the beginnings and endings of words. However, the same is not true for unspaced text. Thus, for lexical identification to occur during reading of unspaced text, an additional process of word segmentation (working out where a word begins and ends) must first be completed. Thus, longer reading times for unspaced alphabetic text are almost certainly due to increased difficulty associated with word identification (Rayner et al., 1998; Perea & Acha, 2009), presumably due to the necessity to perform word segmentation. Word identification is central to reading, arguably being the "engine" driving eye movements as we read (see Rayner, Liversedge, White, & Vergilino-Perez, 2003; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003). Therefore, disruption of this core process will directly impact on reading efficiency. It seems reasonable to assume, then, that the inclusion of spaces within Chinese text might impact similarly on both of these aspects of processing in reading. Word spaced Chinese text should reduce the time taken to select saccade targets during reading, and should remove the need for word segmentation prior to lexical identification.

In addition to the theoretical motivation for this work, however, there is an important applied motivation. Namely, we wished to assess whether a simple manipulation of the visual appearance of an ordinarily unspaced written language might reduce reading difficulty associated with that text in second language learners. If this turned out to be the case, and spacing cues did facilitate reading Chinese as a second language, then an obvious potential application of our word spacing manipulation would be to use it as a tool to support those learning to read Chinese as a second language, and potentially, those learning to read other unspaced languages.

We will now consider empirical literature that is relevant to the present experiments before explaining our manipulations in full and giving our hypotheses. Several studies have been carried out to investigate how spacing information influences reading in languages that are ordinarily unspaced. Thai is alphabetic like English; however, unlike English, but similar to Chinese, it is unspaced. Kohsom and Gobet (1997) carried out an experiment in which they examined sentence reading times for passages of Thai text that either did or did not have spaces inserted between the words. They found that reading times were shorter for texts that were spaced than for those that were unspaced, even though the visual format of the spaced texts appeared very unfamiliar to native readers. More recently, Winskel, Radach, and Luksaneeyanawin (2009) examined the eye movements of Thai - English bilinguals when reading both Thai and English with and without interword spaces, in comparison with English monolinguals. They found interword spaces did facilitate word recognition, but did not affect accuracy of eye guidance, as initial saccade landing positions were similar in spaced and unspaced Thai text. However, removal of spaces severely disrupted reading in English in both bilinguals and monolinguals. Initial landing positions were significantly nearer the beginning of the target words when reading unspaced rather than spaced text (see also Rayner et al., 1998).

Japanese is also an unspaced language, however, it is character based[1]. Korean is alphabetic, though it is comprised of alphabetic blocks that have the appearance of characters[2]. Several experiments have been carried out to investigate the influence of spacing information on eye movements during Japanese reading (e.g., Kajii, Nazir, & Osaka, 2001; Sainio, Hyönä, Bingushi, & Bertram, 2007), though fewer, if any investigations of Korean have been reported. In their eye movement experiment, Sainio et al. investigated the reading of texts comprised either entirely of Hiragana characters (syllabic script) or texts comprised of a mixture of Hiragana and Kanji characters (both syllabic and ideographic script). In addition to manipulating the types of characters that comprised the texts, Sainio et al. also manipulated whether the text appeared normally, in an unspaced format, or instead, with spaces between words. The results were quite striking. For the Hiragana texts, the spacing manipulation facilitated reading, whereas, for the texts comprised of both Hiragana and Kanji characters it did not. Sainio et al. suggested that spacing information provides a strong cue to word boundaries for Hiragana text that is visually uniform. However, for mixed Hiragana and Kanji text, in which the Kanji characters are visually distinctive, those characters provide information about word boundaries, and therefore, the introduction of spacing information is redundant, and consequently, reading was not facilitated. Thus, it appears that for Japanese text that is visually uniform, spacing information can provide an effective cue to word boundaries, and this in turn can speed reading.

There have also been a number of investigations into the influence of spacing on Chinese readers (e.g., Bai, Yan, Liversedge, Zang, & Rayner, 2008; Hsu & Huang, 2000a; 2000b; Inhoff, Liu, Wang, & Fu, 1997; Liu, Yeh, Wang, & Chang, 1974). In the study by Inhoff et al. readers' eye movements were recorded as they read Chinese sentences under three presentation conditions: normal unspaced text, word spaced text in which a space was inserted between each Chinese word, and nonword spaced text in which spaces were randomly added between Chinese characters to produce nonwords. Inhoff et al. found no reliable differences in total reading times, mean fixation durations, and mean saccade lengths for any of their presentation conditions. In contrast to these findings, however, Bai et al. showed a very robust influence of spacing information on eye movements during reading (though, note that the spaces used by Inhoff et al. were much smaller than those used by Bai et al.) In their experiments, sentences appeared in four formats: normal unspaced text, text with spaces between every Chinese character, text with spaces between words, and text with spaces between characters that yielded nonwords.

Bai et al.'s results showed that native Chinese readers found sentences with the visually unfamiliar word spaced format were as easy to read as those with visually familiar unspaced text. However, there was significant disruption to reading for sentences with character spacing or nonword spacing. Bai et al. suggested that for the word spaced text two influences worked against each other: a facilitatory influence of word spacing against an inhibitory influence of the unfamiliar visual format of the text (native Chinese readers had a lifetime of experience reading unspaced text), resulting in no net difference in the speed with which the text was processed. In a follow up experiment Bai et al. used a highlighting manipulation (without the addition of spacing information) and replicated these findings. An important theoretical conclusion that

Bai et al. formed was that the primary unit of information during Chinese reading is the word (see also Li, Rayner, & Cave, 2009; Rayner, Li, Juhasz, & Yan, 2005; Yan, Tian, Bai, & Rayner, 2006), and not the character (as reflected by shorter reading times for word spaced text than character spaced text).

To summarise, there have been a number of studies that have investigated how the introduction of word spacing into unspaced languages affects reading in native speakers. However, to date, there has been little, if any, experimentation to examine the influence of spacing information on the eye movement behavior of people learning to read unspaced languages such as Chinese as a second language. Indeed, for populations learning to read any second language, we know of no eye movement investigations of their reading behavior during processing of their non-native language. Furthermore, to date there has been no systematic investigation of whether characteristics of the native language other than spacing status modulate eye movement behavior during reading in the second language being learnt (something that we will also address in the present study). It should be clear that this represents a somewhat surprising gap in the literature given the prevalence of second language teaching programs as part of standard educational curricula worldwide.

In the present experiment, we examined the eye movements of four groups of young adult readers who were non-native speakers of Chinese (participants from Thailand, Korea, Japan and the US). Note here, that we are not considering studies of second language reading in bilingual or multilingual participant populations (see Frenck-Mestre, 2005; c.f., Wade-Woolley & Geva, 1998), who have very well established skills in two or more languages due an upbringing in a multilingual society or family. Instead, in the present study, we investigated the reading behavior of participants who are actively engaged in learning a second language in early adult life (i.e., college student populations, who as yet, are not expert in their second language).

As we have made clear, although there is little existing research investigating second language learning, there have been several studies that have investigated children's eye movements during reading (Blythe, Liversedge, Joseph, White, Findlay, & Rayner, 2006; Blythe, Liversedge, Joseph, White, & Rayner, 2009; Häikiö, Bertram, Hyönä, & Niemi, 2009; Joseph, Liversedge, Blythe, White, Gathercole, & Rayner, 2008; Rayner, 1986; Shen, Bai, Zang, Yan, Feng, & Fan, 2010). Clearly, children are not as expert in their reading skills as adults, and thus, in some respects at least, their eye movement behavior may be comparable to that of individuals learning a second language in early adult life. Children's eye movements relative to adult (expert) readers can be characterized in terms of increased fixation durations, increased number of fixations, shorter saccades and increased regressions (e.g., Rayner, 1998, 2009 for more details). Thus, in the present study, in which we examined the eye movements of students learning Chinese as a second language, it seems highly likely that we would observe a general slowing of processing during second language reading.

The central theoretical question that we will address in the present paper is whether the introduction of spacing information into Chinese text facilitates reading in individuals who are learning to read Chinese as a second language. It is our contention that the introduction of spacing information to demark word boundaries will facilitate saccadic targeting and word identification in individuals learning Chinese as a second language. Thus, we might anticipate faster reading times in second language learners for spaced than unspaced Chinese text.

In addition, we will address two subsidiary questions, both of which are fundamentally concerned with whether differences in writing systems influence how first language literacy experiences affect cognitive processes in those learning to read a second language (e.g., see Gottardo, Chiappe, Yan, Siegel, & Gu, 2006; Keung & Ho, 2009; Wang, Koda, & Perfetti, 2003, 2004). The basic idea, here, is that commonalities between languages (in terms of shared characteristics, potentially at many different levels), may allow for better mapping of psychological processing between those languages. Thus, when the first and the second language share a characteristic, this might permit more efficient processing in the second language relative to when they do not. In the present experiment, we assess whether any facilitatory spacing effects that we observe are greater for those learning Chinese as a second language when their native language is spaced (e.g., English or Korean) compared with the effects for those whose native language is unspaced (e.g. Thai or Japanese). It seems at least possible that readers who have extensive experience reading written language containing spaces may be more dependent on spacing information for eye guidance and for lexical identification during reading than those whose native language does not contain such information. Second, we will assess the extent to which any spacing effects are modulated by whether the native language of those learning to read Chinese is character based (Japanese) or alphabetic (Korean, Thai and English). There are good a priori grounds why this might be the case. Character based languages are more dense (fewer characters than letters per word) and less horizontally extended than are alphabetic languages (see Hoosain, 1991; Shen, Bai, Yan, & Liversedge, 2008; Sun & Feng, 1999). Probabilistically speaking, therefore, for any particular fixation on a word in an unspaced character based language, there are fewer points between characters downstream from the current fixation at which the current word will end than is the case for any particular fixation in an alphabetic language. That is to say, there are far more potential segmentation points downstream from a fixation in an unspaced alphabetic language than an unspaced character based language. For this reason, it is at least possible that for readers whose native language is unspaced and character based (e.g., Japanese), spacing information in Chinese text may be less facilitative than for readers whose native language is unspaced and alphabetic. Thus, if modulatory effects do occur, then we might expect an interaction such that the greatest facilitation effects of spacing might occur in Thai participants whose language is unspaced and alphabetic.

Method

Participants. There were four participant groups in the experiment: (1) 16 American students (mean age = 19.6 years) from the University of Wisconsin-Madison (Chinese midterm examination score M = 85.1%, SD = 6.6) who may be regarded as readers with an elementary level of Chinese language proficiency; (2) 26 Korean students (mean age = 25.7 years); (3) 20 Japanese students (mean age = 23.3 years); and (4) 20 Thai students (mean age = 22.1 years). All participants were enrolled in the College of International Education and Exchange, Tianjin Normal University. All the non-American students had taken the Elementary and Intermediate Chinese Proficiency Test (Hanyu Shuiping Kaoshi, HSK, Elementary-Intermediate; for further details, see http://www.chinaeducenter.com/en/exams.php), and 74% had passed Level 4, with 14% having passed level 5 and 12% having passed level 6. There were no reliable differences between the Japanese, Korean and Thai participants in terms of their HSK scores ($F < 1.1$) suggesting that their Chinese language proficiency was broadly similar. Based on Tianjin Normal University Admittance criteria the American participants in this study were regarded as having a HSK Basic level of Chinese language proficiency which was below that of the non-American participants who had HSK Elementary-Intermediate Chinese language proficiency. The American participants possessed a mean vocabulary of approximately 1000 commonly used Chinese words, while the non-American participants possessed a vocabulary of 2000-5000 commonly used Chinese words. All participants had normal or corrected to normal vision.

Materials and Design. Based on the Outline of Chinese Standard Vocabulary and Chinese Characters Grading (Hanyu Shuiping Cihui Yu Hanzi Dengji Dagang, 2001 Revised Edition), words for our experimental sentences were selected from the Level A Vocabulary category. Sixty four declarative sentences ranging from 13 to 16 characters in length（$M = 13.88$） were constructed. Naturalness of sentences was rated on a 5-point scale ($M = 4.59$, $SD= 0.17$, where a score of 1 was very unnatural, and a score of 5 was very natural) by 20 Chinese college students from Tianjin Normal University. After this, the difficulty of sentences was rated on a 5-point scale (M =

2.26, SD= 0.38, where a score of 1 was very easy, of 5 was very hard) by 20 different students who were from the same class as those individuals who participated in the eye tracking experiment (a mixture of the four nationalities). The students who participated in the rating experiments did not take part in the eye tracking experiment.

Four text spacing conditions were included in the experiment: (1) normal unspaced text, (2) word spaced text (a single space between each word of the sentence)[3]. (3) single Chinese character spaced text (a single space between each character of the sentence), and (4) nonword spaced text (a single space between Chinese characters such that character clusters between spaces formed nonwords). See Figure 1 for examples of experimental stimuli. Four files were constructed, with each file containing 64 sentences (a full list of stimuli can be obtained from the corresponding author). There were 16 sentences in each condition, and conditions were rotated across files according to a Latin square. Sentences in each condition were presented randomly in a blocked format. Twelve practice sentences and four Yes/No comprehension questions for each spacing condition were included at the beginning of each experimental file. In addition, there were 20 Yes/No comprehension questions (five in each condition) that were associated with each block of experimental sentences.

Insert Figure 1 about here

Apparatus**.** Participants' eye movements were recorded using an EyeLink2000 eye tracker, sampling the eye position at a rate of 1000 Hz (manufactured by SR Research, Toronto). This system is accurate to 0.5° visual angle. The stimuli were presented on a 19-inch DELL monitor with a 1024×768 pixel resolution. The distance between the participant and the screen was 91 cm. Stimuli were presented in Song font, and the size of each Chinese character was 28×28 pixels (with a space of 1 pixel between characters in the unspaced condition). One Chinese character subtended 0.69° visual angle.

Procedure. Participants were informed that they would be required to read and understand sentences that would be presented under different spacing conditions. Each participant was tested individually. They were instructed to keep their head still throughout testing. Although the Eyelink tracker compensates for head movements, a chin rest was employed to ensure that the head was maintained in a still position. Prior to the start of the experiment a calibration procedure was completed. The computer software calculated the position of the point of fixation on the basis of the calibration. After calibration, the sentences were presented one by one (and recalibration was carried out during the experiment whenever necessary). Participants read the sentences silently to themselves and when they finished reading, they pressed a button to terminate the sentence display. Following twenty of the experimental sentences, a comprehension question appeared on the screen and the participant answered this orally. Responses to questions were recorded by the experimenter. In total the experiment took approximately 30 minutes.

Results and Discussion

The mean comprehension rate was 96% indicating the participants read and fully understood the sentences. Note that comprehension rates were high even though participants were reading sentences in a second language that they were still learning.

We adopted four criteria for the exclusion of trials from the data set: (1) premature or erroneous triggering of the button box; (2) any fixations shorter than 80ms or longer than 1200ms; (3) trials on which tracker loss occurred; and (4) all data points above or below 3 standard deviations from the mean. In total 4.9% of the data were removed prior to conducting the analyses. We conducted two sets of analyses, one based on global eye movement measures and the other based on local eye movement measures. Global measures are average indices of reading behavior based on all fixations made across the whole sentence. They provide a measure of the overall reading difficulty associated with the sentence, and reflect the general characteristics of participants' reading behavior across all the words of the sentences. In contrast, the local eye movement measures reflect the time course of linguistic processing associated with particular words within the sentence. Furthermore, by computing different types of local measures (see below) based on different fixations and different patterns of fixation, it is possible to establish for particular words a clear indication of the nature and time course of linguistic processing. We will first consider the global analyses.

Global analyses

We computed the following global reading measures: (1) total sentence reading time (the sum of all the fixation durations made on a sentence); (2) mean fixation duration (the average duration of all the fixations made on a sentence); (3) mean saccade length (the average length of all the saccades made on a sentence); (4) total number of fixations (the number of fixations made on a sentence); and (5) number of regressive saccades (the number of saccades made in a right to left direction to permit portions of the sentence to be re-read). For completeness, we also list forward (left to right) and regressive (right to left) saccade length in Table 1, however, we will focus our discussion on the five measures listed here. We conducted two 4 (presentation condition: unspaced text, single character spaced text, word spaced text, nonword spaced text) × 4 (participant group: American, Korean, Japanese, Thai) repeated measures ANOVAs, computing error variance over participants (F_1) and sentences (F_2) for each of these measures. Participant group was a between participants within items variable. Mean eye movement measures are shown in the Table 1.

Total sentence reading time. There was a very reliable effect of presentation condition ($F_1(3,234) = 74.9$, $p < .001$; $F_2(3,189) = 25.2$, $p < .001$). Total times were shortest for word spaced text (M = 6891ms), and reliably longer (*p*s < .01) for normal unspaced (M = 7408ms) and character spaced text (M = 7520ms) and reliably longer again (*p*s < .01) for nonword spaced text (M = 8202ms). Total times for normal unspaced text and character spaced text were not reliably different (*p*s > .05). These data clearly indicate that word spaced text was easiest for the non-native Chinese readers to process, and in fact, even easier to process than normally presented unspaced Chinese text. The data also indicate that participants found text segmented into nonwords most difficult to read. Given that the total reading times reflect the overall difficulty associated with reading the sentences, it appears that all groups of non-native Chinese readers found that the word spacing manipulation assisted them as they read. Thus, it appears that the word spacing manipulation is a helpful tool to individuals learning to read Chinese as a second language.

We also obtained a highly reliable effect of participant group ($F_1(3,78) = 42.2$, $p < .001$; $F_2(3,189) = 738.7$, $p < .001$). Total reading times were longer for the American participants (M = 11790ms) than for the other three participant groups (all *p*s < .001). Total reading times for the Thai participants (M = 6807ms) were reliably longer (*p*s < .05) than for the Japanese participants (M = 5353ms). However, the difference between the Korean (M = 6071ms) and Japanese participants, and the difference between Korean and Thai participants were not reliable in the participants analysis (*p*s > .05), but were reliable in the items analysis (*p*s < .001). It is worth noting here that based on the numerical differences that the Japanese participants read the sentences quickest, the Koreans took slightly longer followed by the Thai participants, with the American participants taking longest to read the sentences. This is a point that we will return to subsequently.

The interaction between presentation condition and participant group for total sentence reading time was not significant (*F*s < 1), indicating the pattern of spacing effects was similar across different participant groups. Thus, the spacing effect was uninfluenced by the characteristics of the native language, although reading times were different between groups and this is very likely to be due to differences in Chinese reading experience. More importantly, it appears that the use of word spacing as a tool to support Chinese second language learning may be effective in facilitating reading, and that this holds across four participant groups regardless of whether their native language is alphabetic or character based, and spaced or unspaced. Thus, it appears that the word spacing manipulation is, potentially, quite generally effective.

Mean fixation durations. There was a reliable effect of presentation condition ($F_1(3,234) = 175.8$, $p < .001$; $F_2(3,189) = 74.3$, $p < .001$). In fact, all of the presentation conditions were reliably different from each other (all *p*s < .05). Mean fixation durations were longest for normal unspaced text (M = 276ms), shorter for nonword spaced text (M = 267ms), shorter again for word spaced text (M = 253ms) and shortest for character spaced text (M = 249ms). This pattern of effects may initially appear somewhat puzzling, and even at odds with our conclusions based on the total reading time data. If participants found the word spaced text easiest to read, then why were mean fixation durations shortest for character rather than word spaced text? In our view, the mean fixation data reflect two sources of influence. First, there is an inhibitory effect of lateral masking from adjacent characters such that more densely packed characters (unspaced Chinese text) produced longer mean fixations than text that was slightly more spread out (word and nonword spaced text), which in turn produced fixations that were slightly longer than for text that was most spread out (character spaced text). However, the degree of spacing, and hence, lateral masking that the text causes cannot be the only influence, otherwise we should have observed similar mean fixations for the word and nonword spaced text. We suspect that the difference between the word spaced and nonword spaced conditions reflects facilitation of reading for the word spaced text and disruption to reading by the nonword spaced format. Thus, the mean fixation data are indicative of two influences, one from lateral masking and the other from processing difficulty arising from word or nonword segmentation cues.

We also obtained a reliable effect of participant group ($F_1(3,78) = 62.4$, $p < .001$; $F_2(3,189) = 2310.0$, $p < .001$) indicating mean fixation durations were significantly longer (*p*s < .001) for the American participants (M = 335ms) than for the other participant groups (Japanese M = 236ms; Korean M = 230ms; Thai M = 244ms) between whom there were not reliable differences in the participants analysis (*p*s > .05), though they were reliable in the items analysis (*p*s < .001). Once again, the interaction between presentation condition and participant group for mean fixation duration was not significant (*F*s < 1.7, *p*s > .05).

Mean saccade length. There was again a highly reliable effect of presentation condition ($F_1(3,234) = 623.5$, $p < .001$; $F_2(3,189) = 578.8$, $p < .001$). The pattern of differences is very similar to the pattern that we obtained in our analyses of the mean fixation duration, in that there appear to be two sources of influence on saccade length; mean saccade length in each of the conditions was significantly different from one another (all *p*s < .001). Once again, it is the case that the more spread out the text, the longer the mean saccade length. Thus, on average, saccades were longest for character spaced text (M = 3.8 characters), and shortest for unspaced text (M = 2.5 characters). Note once more, however, that it cannot be the case that the spatial characteristics of the text alone are the cause of the differences that we obtained, otherwise we would have found no reliable difference in mean saccade length for word and nonword spaced text. In fact, saccades were significantly shorter for nonword spaced text (M = 3.2 characters) than for word spaced text (M = 3.4 characters). Consistent with the mean fixation duration data, we believe that the difference in saccade extent between word and nonword spaced text reflects the increased processing difficulty associated with reading nonword spaced text relative to that associated with reading word spaced text. The degree to which the text is spaced out in word and nonword text is identical, however, the nonword text is more difficult to read than word spaced text and the increased difficulty causes participants to make shorter saccades. Thus, the saccade length data again reflect two sources of influence.

We also obtained a reliable effect of participant group ($F_1(3,78) = 27.6$, $p < .001$; $F_2(3,189) = 1082.0$, $p < .001$). Saccades were shortest for the American participants (M = 2.4 characters), slightly longer for the Thai participants (M = 3.2 characters), longer for the Korean participants (M = 3.5 characters), and longest for the Japanese participants (M = 3.8 characters) (all differences were reliable, *p*s < .05). Recall that this pattern of differences is similar to that observed for the total reading time where American participants took longest to read the sentences, Thai participants less time followed by Korean participants with Japanese participants reading sentences fastest. If we assume that the total reading times for the sentences provide an index of the ease with which the different participant groups processed the sentences, then we might also assume that this provides an index of the basic Chinese language proficiency of each of the participant groups. If this were the case, then we might expect to see the saccade length data reflect the level of Chinese language proficiency also. Specifically, assuming that saccades will be shorter when participants find the text more difficult, we might expect that saccades would be shortest for the American participants, longer for the Thai participants, longer still for the Korean participants and longest for the

Japanese participants. Indeed, when we consider the pattern of means, this is exactly what we see.

Finally, the interaction between presentation condition and participant group was also significant ($F_1(9,234) = 7.6$, $p < .001$; $F_2(9,567) = 10.4$, $p < .001$). The means for each spacing condition and participant group are shown in Figure 2. Simple effects tests showed that the influence of presentation condition was reliable for each group (American participants, $F_1(3,45) = 125.0$, $p < .001$, $F_2(3,189) = 128.5$, $p < .001$; Korean participants, $F_1(3,75) = 212.8$, $p < .001$, $F_2(3,189) = 302.1$, $p < .001$; Japanese participants, $F_1(3,57) = 211.2$, $p < .001$, $F_2(3,189) = 144.2$, $p < .001$; Thai participants, $F_1(3,57) = 145.0$, $p < .001$, $F_2(3,189) = 182.6$, $p < .001$). Pairwise comparisons showed that for all participant groups saccades were shortest for unspaced text and longest for character spaced text. However, the interaction is driven by the difference between the word and nonword spaced text across participant groups. American participants made saccades that were similar in length under word and nonword spaced conditions (ps > .05). However, for the other three participant groups, saccades were shorter when nonword spaced text was read than when word spaced text was read (all ps < .001) [4].

It is likely that these differences are driven by the Chinese language proficiency of the participants in each of the groups. The American participants were least proficient, and their total reading time data indicate that they had serious difficulty when reading the sentences. The saccade extent data suggest that this group of participants targeted their saccades based entirely on spacing information, regardless of whether the spacing information demarked words or nonwords. In contrast, the more proficient readers not only showed an influence of the spacing format of the Chinese text, but also an influence of increased processing difficulty associated with reading text with spacing demarking Chinese nonwords (relative to word spaced Chinese text). Thus, the differential pattern of effects observed for the American participants relative to the other participant groups appears to indicate a less rapid sensitivity to the lexical status of a character string demarked by spacing information. In contrast, the more proficient readers of Chinese were more sensitive to the lexical status of character strings demarked by spaces, and the disruption they experienced when processing character strings demarked as nonwords had a direct influence on the magnitude of the saccades they made. When processing nonword spaced Chinese text, the more proficient participants made shorter saccades. If this explanation is correct, then it suggests that the level of proficiency in Chinese as a second language, and therefore sensitivity to the lexical status of character strings, modulates the disruptive influence of text segmented by spaces as nonwords.

Total number of fixations. We anticipated that the patterns that we would observe for this measure would be very similar to those we obtained for the total sentence reading times given that total times and number of fixations are highly correlated. Although it was the case that we obtained a highly reliable main effect of presentation condition ($F_1(3,234) = 81.3$, $p < .001$; $F_2(3,189) = 28.4$, $p < .001$), the pattern of effects was subtly different from that obtained in the total reading times. Once again, the number of fixations was greatest for the nonword spaced text (M = 25.6), and there were on average slightly fewer for character spaced text (M = 24.8). Both these means were significantly different from the two remaining conditions (*p*s > .001). However, although we found that total reading times were shortest for word spaced text and somewhat longer for normal unspaced text, our analyses of the number of fixations showed that there was only a very small difference in this direction which was not reliable (word spaced M = 22.4, unspaced M = 22.6; *p*s > .05). Although this result may initially appear to be an inconsistency, it is clearly not, when considered in relation to the average fixation duration data. Comparable numbers of total fixations on average combined with reduced average fixation durations for word spaced relative to unspaced text, jointly result in the pattern of effects seen in the total reading times (i.e., shorter overall reading times for word spaced compared to unspaced text).

The effect of participant group was also highly reliable ($F_1(3,78) = 13.4$, $p < .001$; $F_2(3,189) = 352.1$, $p < .001$). Here the data did mirror the total reading times very closely. The American participants made the most total fixations (M = 31.0), there were fewer for the Thai participants (M = 23.6), and fewer for the Japanese and Korean participants (*p*s < .05). However, the differences between the Korean and Japanese participants, and between the Korean and Thai participants were not significant in the subject analysis (*p*s > .05), but were significant in the item analysis (*p*s < .001).

Finally, and again consistent with the total reading time results, the interaction between the presentation condition and participant group was not significant ($F_1(9,234) = 1.0$, $p > .05$; $F_2(9,567) = 0.3$, $p > .05$). These results, alongside the total reading time data are very interesting. They show, again, that the influence of nonword spacing is detrimental to efficient reading, and that character spaced reading is also disruptive. Furthermore, when participants read word spaced text, they made as few fixations as when they read normally presented unspaced Chinese text. Thus, it seems reasonable to suggest that word spacing in Chinese is not in any way disruptive to written comprehension in second language learners, whereas other forms of spacing are. Note, however, the finding that there was only a very small and non-reliable difference in the total number of fixations that participants made under normal unspaced and word spaced conditions contrasts with the finding that total reading times were reliably shorter for word spaced text than unspaced text. Clearly it is the case that word spacing has a much greater facilitatory influence on the duration of fixations that second language learners make, than on the number of fixations that they make as they read Chinese. Given that fixations durations, and to a lesser extent, the number of fixations that readers make are directly related to the ease with which words are lexically identified during reading (Liversedge & Findlay, 2000; Rayner, 1998, 2009), these data provide very strong evidence to suggest that word spacing facilitated lexical identification in Chinese reading in second language learners. It is also noteworthy that the total number of fixations analyses showed no interactive effects between presentation condition and participant group (though again, there were differences between the groups reflecting proficiency in the second language). The lack of an interaction indicates that these effects held in all participant groups regardless of basic characteristics of the native language. Again, this finding reinforces our suggestion that the word spacing manipulation could be an excellent support mechanism to those learning Chinese as a second language, regardless of the characteristics of the native language in terms of spacing and alphabetic status.

Number of regressive saccades. As with all the previous measures, we observed a highly reliable effect of presentation condition ($F_1(3,234) = 38.0$, $p < .001$; $F_2(3,189) = 14.2$, $p < .001$). The most striking thing about the regression data is that participants made reliably more regressions (ps < .001) for nonword spaced text (M = 5.9) than for text presented in any of the other spacing conditions (unspaced M = 4.9; word spaced M = 5.0; character spaced M = 5.3). The number of regressions made for character spaced text was reliably greater than the number made for unspaced text (ps < .001). Also, the number of regressions made for character spaced text was reliably greater in the subjects analysis ($p < .001$) and marginally greater in the items analysis ($p = .1$) than for word spaced text. Finally, the regressions for word spaced text were not reliably different from the regressions for normal unspaced text (ps > .05). Once again, the basic pattern suggests that word spaced text caused no more regressive saccades in second language learners than did normal unspaced text, whereas for nonword and character spaced text they made more regressions indicating that these spacing conditions produced disruption to processing.

In contrast with earlier analyses, the effect of participant group was not reliable ($F_1(3,78) = 1.2$, $p > .05$; $F_2(3,189) = 23.0$, $p < .001$). Presumably this is due to all of the participants making many regressions overall (presumably due to their lack of proficiency with Chinese). Given that participants made on average between 5 and 6 regressions for each sentence, it seems likely that ceiling effects may well have occurred for this measure. Finally, and consistent with the earlier analyses, the interaction between the presentation condition and participant group did not approach significance ($F_1(9,234) = 1.3$, $p > .05$; $F_2(9,567) = 1.0$, $p > .05$). To reiterate, the regression data indicate that Chinese second language learners found word spaced text as easy to process as normal unspaced text, while nonword spaced and character spaced text produced disruption to processing.

Local Analyses

In addition to the Global Analyses, we conducted a set of Local Analyses in which we considered smaller regions of the sentences comprised of two character words under normal unspaced and word spaced conditions. In these analyses, we focused exclusively on the spaced and unspaced conditions because they provide an opportunity for us to directly examine how word spacing influenced word identification and eye guidance compared to normal unspaced text during reading across the four participant groups. In addition, this comparison permitted direct comparisons between regions with identical content irrespective of spacing. We identified between one and four regions that were comprised of two character words for each sentence. These target regions never occurred at the beginning or the end of the sentences.

For these analyses we computed a series of measures of processing time for the target words that we had identified. We computed two processing time measures (Liversedge & Findlay, 2000; Rayner, 1998, 2009): first fixation duration (the duration of the first fixation on a word), a very early measure of lexical processing that takes place when a word is first fixated, and gaze duration (the sum of all fixations on a word before moving to another word), which is also usually taken as an indication of the time readers spend lexically processing a word[5]. We also computed refixation probability (the probability of making a second fixation on a word before leaving the word). This measure indexes the extent to which processing of the target word led to an interruption to the sequence of left-to-right of saccades that frequently occurs during normal reading. Finally, we computed the total reading time (the sum of all fixations on a word) and the number of fixations on a word. These measures provide an indication of the overall difficulty a particular word caused the reader by taking account of both initial inspection and reinspection fixations. These measures are often associated with processing required for the integration of the word's meaning into the representation of the sentence or the discourse as a whole. The mean values for the local measures are given in Table 2.

Insert Table 2 about here

All the local measures consistently showed a highly reliable effect of word spacing (all *F*s > 15.08, all *p*s < .001), with shorter first fixation durations, gaze durations, reduced refixation probability, shorter total times and fewer fixations for word spaced than for normal unspaced text. As with the global analyses, these local analyses demonstrated clearly that word processing was easier while reading word spaced text than normally presented unspaced text for the non-native Chinese readers. In addition, all the measures showed a highly reliable effect of participant group (all *F*s > 10.91, all *p*s < .001), with increased numbers of fixations and refixations, increased fixation durations and longer total times for the American participants than for the other three participant groups (all *p*s < .001). Again, these findings are entirely consistent with the global analyses, indicating that the American participants took much longer not only to read the entire sentence but also the selected target words than the other groups, reflecting their poorer Chinese language proficiency.

The interaction between presentation condition and participant group for first fixation duration, refixation probability and the number of fixations was not significant (all *F*s < 1.74, all *p*s > .05), indicating the pattern of spacing effects was similar across different participant groups for these measures, which again replicated the data from the Global Analyses. The gaze duration and total reading time did show a reliable interaction (*F*s > 3.75, *p*s < .05). *T*-tests showed that the spacing effect was significant for each participant group (all *t*s > 3.60, *p*s < .01), but that it was much larger for the American participants than the other participants (197ms, 105ms, 86ms, and 87ms benefit for gaze durations and 428ms, 252ms, 219ms, 191ms benefit for total reading times for American, Korean, Thai and Japanese participants respectively). This is a similar pattern to the word spacing effects we obtained for the total reading time data in the global analyses (809ms, 445ms, 387ms, 427ms spacing effect for American, Korean, Thai and Japanese participants respectively). Note that in the local analyses we were only able to directly compare the word spaced and unspaced conditions across the participant groups because these were the only conditions in which both character content and spacing were consistent in the regions of analysis. Thus, it is clear from both the local and the global analyses that word spacing reduced the time non-native Chinese readers spent fixating, and refixating Chinese words, with this effect being particularly pronounced for participants with poor Chinese proficiency.

In conducting our local analyses, we also had the opportunity to investigate an alternative account of our findings. As explained earlier, so far we have assumed that readers found word spaced text easier to process because spacing facilitated word segmentation, thereby speeding lexical identification. However, it might actually be the case that under word spaced conditions, readers targeted their saccades more effectively to the upcoming word (Rayner, 1979). The Preferred Viewing Location (PVL), about halfway between the beginning and the middle of a word, is the place where readers tend to initially fixate within a word. Rayner argued that readers target the middle of a word but tend to fall short and fixate the PVL. A related phenomenon, the Optimal Viewing Position (OVP; see O'Regan & Jacobs, 1992) is the position at which fixation times are shortest reflecting most efficient lexical identification. The OVP is usually the middle of a word for words that are comparatively short in length.

If readers targeted their saccades more effectively in spaced than unspaced conditions, then correspondingly shorter reading times might also result[6]. If this were the case, then the reduced reading times for word spaced text would arise due to facilitation of lexical processing through more efficient saccadic targeting, rather than though effects of word segmentation. To test this possibility, in our local analyses, we examined distributions of landing positions on words in the spaced and unspaced conditions for first fixations, single fixations and the first fixation of multiple fixations on words.

Recently, Yan, Kliegl, Richter and Shu (2010) and Li, Liu and Rayner (2011) reported analyses of saccadic targeting for adult Chinese readers, and Zang, Liversedge, Liang, Bai and Yan (2011) reported landing position data from adults and children reading spaced and unspaced Chinese text. While the results are quite consistent across the three studies, we will focus on Zang et al. as they showed that children and adults' saccadic targeting patterned very similarly for both spaced and unspaced text. In their analyses, Zang et al. initially considered the distribution of first fixations on two character words and found that readers targeted their saccades towards the beginning of a word rather than towards the end of a word. However, in subsequent analyses, they separated the data set into single fixations, and the first of multiple fixations on words, and showed differential effects for these two distinct populations of fixations. Single fixation distributions were distributed roughly normally over the word with the PVL being towards the center of the word. In contrast, when the initial fixation on a word was the first of multiple fixations, readers saccades were closer to the word beginning. These landing position patterns occurred regardless of whether the text was spaced or unspaced. Zang et al. argued that the differential effects for single fixations and the first of multiple fixations probably arose due to the need to make a refixation when the initial fixation on a word was away from the PVL, but not when it was located at the PVL.

The current data set offers us the opportunity to examine whether similar saccadic targeting effects occur in readers learning Chinese as a second language as those that occurred in children and adults for spaced and unspaced text. On the basis of Zang et al.'s findings, we predicted that if our reading time differences arose as a consequence of differences in landing position distributions, then we should observe differential patterns of effects for spaced and unspaced text, with saccades being targeted much more closely to the PVL in the word spaced condition than in the unspaced condition. In contrast, if our data pattern as per those of Zang et al., then we should obtain similar landing position effects regardless of whether the text was spaced or unspaced. Furthermore, as per Zang et al., we should find differential patterns of effects when we consider the single fixation and the first fixation of multiple fixation data sets separately.

Insert Figure 3 about here

Our results were very clear and replicated the findings of Zang et al. almost perfectly (see Figure 3). Readers targeted their saccades very similarly under spaced and unspaced conditions. Also, for single fixations, landing positions were normally distributed about the PVL. However, for the first of multiple fixations, saccades landed towards the beginning of words, again consistent with the data reported by Zang et al. There are two implications of these findings. First, it appears that when readers landed close to the PVL, then they only needed to make one fixation on the word, whereas when they landed towards the beginning of a word and away from the PVL, they were much more likely to require a refixation on the word. The second, more important implication, is that the reduced reading times for word spaced text that we have obtained in the present study were not caused by participants targeting their saccades more effectively to the PVL. Clearly, similar saccadic targeting occurred regardless of word spacing.

General Discussion

In the present study, we examined the eye movements of students learning to read Chinese as a second language, and investigated the role of inter-word spaces for non-native Chinese readers. We conducted both global and local analyses of eye movement behavior. The results of this study and the patterns of effects that we observed for the different participant groups seem quite straightforward to explain. The total sentence reading times showed that word spaced text was easiest for non-native Chinese readers to process, and in fact, even easier to process than normally presented unspaced Chinese text. In contrast, character spaced text and nonword spaced text interfered with reading (Bai et al., 2008). On the assumption that the overall time that it took participants to read the sentences reflected the ease with which the text was processed, these data provide very strong evidence that word spacing made reading Chinese text easier for second language learners.

We also considered four other global eye movement measures: mean fixation duration, mean saccade length, total number of fixations and number of regressions. Mean fixation durations, number of fixations and regressions all showed that each of the participant groups found reading word spaced text, on average, at least as easy, if not easier to read than normal unspaced Chinese text. Furthermore, variability in the patterns of effects that occurred is reasonably well explained in terms of the influences of lateral masking, increased spacing, and the disruptive effect of demarking character clusters as nonwords. Again, the results together indicate that word spacing was not at all disruptive to processing, and if anything facilitative, when participants read Chinese as a second language, while character and nonword spacing clearly did produce disruption.

Note that these effects held regardless of the participant group. Recall that we carefully selected our participant groups in relation to the characteristics of their native language. The Thai and Japanese languages are unspaced, whereas English and Korean languages are spaced. Furthermore, Japanese is a character based language, whereas Korean, English and Thai are alphabetic. Regardless of whether the native language was spaced or unspaced, or character based or alphabetic, the effects were similar: word spaced text was as easy, if not easier to read than normal unspaced text, while character and nonword spaced text was much more difficult. It did not appear to matter whether readers ordinarily use spacing cues in relation to segmenting text into words in their native language, or are used in processing dense non-alphabetic character strings as words, the spacing effects in the second language, Chinese, remained very similar. To this extent, the mapping relations between the native and second language in terms of spacing and alphabetic status did not modulate reading performance.

In our view, there is a very simple explanation as to why this pattern of effects occurred. When a fluent Chinese reader processes a sentence, presumably, a primary and ongoing process that must occur prior to successful language comprehension is the segmentation of the text string comprising the sentence into appropriate word units (Li et al., 2009). Only once the decision as to the characters that comprise a particular word has been made, can saccades be effectively targeted and can successful lexical identification take place. Using spaces to demark the word boundaries for individuals reading Chinese as a second language does two things. First, it reduces non-native readers' uncertainty about the characters that comprise a word, and second, it removes any need for the segmentation of the text string into words (effectively rendering the psychological process of word segmentation unnecessary). Both of these factors allow for saccades to be effectively targeted and for lexical processing to be initiated more immediately than would be the case for Chinese text presented normally (i.e., unspaced). In this way, reading is speeded for word spaced Chinese text in non-native readers.

This aspect of the data also has important practical implications in relation to the used of word spacing as a potential tool to facilitate second language learning in Chinese (and perhaps other unspaced languages too). The fact that we obtained similar facilitatory effects for all our groups of participants regardless of their native language characteristics (and in fact, regardless of their second language competency, i.e., the American participant group in comparison to the other groups), speaks to the potential of word spacing as a general facilitatory tool for second language learners. For example, if we had only found facilitatory effects for, say, those participants whose native language was spaced, then this would limit the usefulness of spacing as a general learning tool. This was not the case, and the fact that we found similar effects across groups of participants with different native languages with different characteristics, and across groups with different levels of competency in the second language, strongly suggest the value of word spacing as a tool to support Chinese second language learners. At a very general level, our results are the first experimental demonstration of the efficacy of this technique in relation to Chinese second language learning, and it is currently an open question as to whether these findings would generalize to those learning to read other unspaced languages. What should be clear, however, is that it seems very likely that the application of word spacing in Chinese second language learning offers a simple and effective learning support technique that could underpin more effective reading in non-native readers as their second language proficiency develops.

All of the measures showed a reliable main effect of participant group. American participants took longest to read the sentences and made the shortest saccades. This strongly supports the suggestion that they had the lowest level of proficiency with Chinese as a second language (due to them receiving the shortest period of formal instruction). There was little difference between the Korean, Thai and Japanese readers, although it is important to note that they showed the same pattern of effects for the different spacing conditions, and other than the saccade length data, the pattern was the same as that observed for the American participants. The between groups differences are almost certainly caused by differences in Chinese language proficiency.

As we can see from the global data analyses, the only interaction occurred for the mean saccade length data. As discussed earlier, the American participants made the shortest saccades and these did not differ between word and nonword spaced conditions. In contrast, all the other participants made longer saccades overall, with saccades being shorter for nonword than word spaced text. This interaction suggests that for Chinese second language learners with comparatively poor Chinese proficiency we observed floor level performance in terms of saccade extent. Presumably this occurred because their poor language proficiency meant that they adopted a very cautious reading strategy, and that they were less immediately sensitive to the lexical status of the character strings segmented by spaces. Thus, there was no additional cost for nonword spaced text relative to word spaced text. However, for more proficient readers with a more immediate sensitivity to the lexical status of a Chinese character string, nonword spacing did produce an additional cost for saccade extent relative to that which occurred for word spaced text. Thus, the interaction for this measure reflects an influence of spacing effects in relation reading proficiency and lexicallity of segmented text.

It should be noted that the findings in the present study did not arise simply due to spaced text being more horizontally extended than unspaced text. Admittedly, inserting spaces between words, characters, and nonwords did increase sentence length (to differing degrees) in comparison to the normal unspaced condition. This in turn produced longer saccade lengths across all spaced compared with unspaced conditions. Even so, the total sentence reading times were much shorter for word spaced text than for nonword spaced text, even though the spatial extent of the text under these two conditions was directly comparable. Thus, it is not simply the case that text that was more spatially extended was harder to read than text that was less spatially extended (as would be the case if acuity limitations alone modulated comprehension of word and nonword spaced text, for example). Furthermore, in previous studies (Bai et al., 2008;

Shen et al., 2010), highlighting was used to create analogous conditions to the spacing conditions used here, but with the spatial extent of sentences controlled across conditions. Note also that in the Bai et al. the Shen et al. studies, adult readers and beginning readers, respectively, were tested. Despite sentences having identical horizontal spatial extents across conditions in these studies, similar influences of word and nonword demarcation were obtained (facilitatory effects for text demarked as words and inhibitory effects for text demarked as nonwords). Also, the effects were very similar for both adult readers as well as beginning readers. Once more, these results indicate that it is not spacing *per se* that produces differential effects, but instead, spacing in relation to the identity of the constituent words of a sentence that affects reading performance.

The results of our local analyses, in which eye movements associated with specific words were compared for the word spaced and unspaced conditions, showed a number of important effects. First, the basic facilitatory word spacing effect observed in the global measures was replicated. In the local analyses, reading were shorter under word spaced than unspaced conditions, and these effects held across participant groups regardless of Chinese reading proficiency. Second, the local analyses showed that readers targeted upcoming words differentially contingent on whether they were fixated once or more than once, and they did this regardless of whether the text was spaced or unspaced. This finding is consistent with the results of Zang et al. (2011). Most importantly, however, the saccadic targeting data allow us to rule out the possibility that differences in reading time under spaced and unspaced conditions occurred as a consequence of differences in saccadic targeting under the two conditions. If readers' initial fixations on words had landed more closely and were more tightly distributed around (roughly) the middle of a word, then reduced reading times could have arisen due to more efficient saccadic targeting rather than more efficient lexical processing. This was clearly not the case. Note also that the fact that initial landing positions on words were similar for spaced and unspaced text indicates that readers did indeed compute saccade targets as accurately under both conditions, however, it took them longer to do so (as suggested by the increased fixation durations) under unspaced than word spaced text. Thus the landing position results from the local analyses are also consistent with our claims that readers take extra time to compute saccade targets under unspaced than spaced conditions.

The results of the present study also demonstrate that the words have psychological reality for those who are learning to read Chinese as a second language, and that grouping Chinese characters into word units is more beneficial to successful language comprehension than is separating individual Chinese characters with spaces. Thus, we argue that word units are critical to Chinese text comprehension, and the process of segmenting a stream of unspaced characters into word units is a necessary and very important stage of processing in Chinese. If Chinese characters alone were the most fundamental unit of processing in Chinese reading, and if grouping of characters into word units was not necessary for successful Chinese text comprehension, then adding spaces between characters should have led to facilitatory effects (decreased total reading time). However, no effect of facilitation under character spaced conditions was found, and in fact, character spaced text appeared to be disruptive to normal reading (albeit, not as disruptive as nonword spacing). There is a growing body of research on the eye movements of Chinese readers that has demonstrated word-based effects. In particular, the studies of Bai et al. (2008), Li et al. (2009), Rayner et al. (2005), Shen et al. (2010), Yan et al. (2006), and Yang, Wang, Xu, and Rayner (2009) all showed strong evidence for word-based processing during Chinese reading. Yen, Tsai, Tzeng, and Hung (2008) and Yang et al. (2009) used the boundary paradigm (Rayner, 1975) to show that Chinese readers obtain word based information from the parafovea. Yan et al. (2010) found that when Chinese readers make a single fixation on a character string, they tend to initially fixate near a word centre, and when they do make multiple fixations, they initially fixate towards the word beginning (as is the case in alphabetic languages). These landing position effects in Chinese provide further support for the contention that eye movement control in Chinese is word based.

The existence of word based effects in Chinese reading suggests that a model of eye movement control for Chinese reading should operate on the basis of word, rather than individual character units (e.g., see Yang & McConkie, 1999; Tsai & McConkie, 2003). In fact, Rayner, Li, and Pollatsek (2007) successfully extended the E-Z reader model to account for Chinese reading whilst maintaining word based assumptions that hold for alphabetic languages (e.g., utilisation of a word-targeting strategy whilst treating characters as orthographic units). The results from the current study are consistent with, and provide further support for, the word based view of Chinese reading, and indicate that these effects not only hold for individuals with differing levels of proficiency reading Chinese as a native language (Bai et al, 2008; Shen et al, 2010), but also for individuals of differing proficiency learning to read Chinese as a second language.

Finally, given the increasing prevalence of unspaced second language teaching programs as part of standard educational curricula world wide, the findings of the present study also have important implications for teaching and learning of Chinese (and other unspaced languages). A clear application that follows from our experimental findings is the use of word spacing as a teaching support tool to assist second language learners when they are learning to read Chinese text. It is very simple to include word spacing in second language learning materials, and the current results provide the first empirical evidence to support the view that word spacing is effective in facilitating Chinese reading in non-native readers who are receiving instruction in understanding written Chinese text. Our results very clearly showed that second language learners found word spaced text easier to read than normal unspaced text, and this is probably because the spaces demarcate the words of the sentence, thereby removing the need for second language learners to carry out a word segmentation process prior to word identification. To this extent, at least during the early stages of learning to read Chinese as a second language, the spacing manipulation seems to ease difficulties associated with identifying targets for saccades and computing the identity of the words of the sentence, and it is our belief that easing difficulties associated with reading Chinese in this way will accelerate second language learning. To conclude, these experimental results provide the first evidence to suggest that word spacing facilitates reading in Chinese second language learners, and are very suggestive that word spacing in Chinese reading materials that are used in second language tuition may be beneficial to non-native Chinese learners across a range of proficiencies, and regardless of alphabetic status and word spacing in the native language.

References

Bai, X., Yan, G., Liversedge, S.P., Zang, C., & Rayner, K. (2008). Reading spaced and unspaced Chinese text: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 1277-1287.

Bassetti, B. (2007). Bilingualism, biliteracy and metalinguistic awareness: Word awareness in English and Japanese users of Chinese as a second language. *Birkbeck Studies in Applied Linguistics, 2,* 1-21.

Blythe, H.I., Liversedge, S.P., Joseph, H.S.S.L., White, S.J., Findlay, J. M, & Rayner, K. (2006). The binocular coordination of eye movements during reading in children and adults. *Vision Research, 46,* 3898-3908.

Blythe, H.I., Liversedge, S.P., Joseph, H.S.S.L., White, S.J., & Rayner, K. (2009). Visual information capture during fixations in reading for children and adults. *Vision Research, 49,* 1583-1582.

Clifton, C., Jr., Staub, A., & Rayner, K. (2007). Eye movements in reading words and sentences. In: R. van Gompel (Ed.), *Eye movements: A window on mind and brain* 341-372. Amsterdam: Elsevier.

Cho, J-R., & Chen, H-C. (1999). Orthographic and phonological activation in the semantic processing of Korean Hanja and Hangul. *Language and Cognitive Processes, 14,* 481-502.

Daniels, P. T., & Bright, W. (1996). *The world's writing systems*. Oxford: Oxford University Press.

Ellis, R. (1997). *Second language acquisition*. Oxford University Press.

Frenck-Mestre, C. (2005). Eye-movement recording as a tool for studying syntactic processing in a second language: A review of methodologies and experimental findings. *Second Language Research, 21*, 175-198.

Gottardo, A., Chiappe, P., Yan, B., Siegel, L., & Gu, Y. (2006). Relationships between first and second language phonological processing skills and reading in Chinese-English speakers living in English-speaking contexts. *Educational Psychology, 26*, 367-393.

Häikiö, T., Bertram, R., Hyönä, J., & Niemi, P. (2009). Development of the letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of Experimental Child Psychology, 102*, 167-181.

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

Hoosain, R. (1992). Psychological Reality of the word in Chinese. In H.-C. Chen & O. J.-L.Tzeng. (Eds.), *Language processing in Chinese* (pp. 111-130). Amsterdam, Netherlands: North-Holland.

Hsu, S-H., & Huang, K-C. (2000a). Effects of word spacing on reading Chinese text from a video display terminal. *Perceptual & Motor Skills, 90*, 81-92.

Hsu, S-H., & Huang, K-C. (2000b). Interword spacing in Chinese text layout. *Perceptual & Motor Skills, 91*, 355-365.

Inhoff, A. W., Liu, W., Wang, J., & Fu, D. J. (1997). Use of spatial information during the reading of Chinese text. In D.L. Peng, H. Shu, & H.C. Chen (Eds.), *Cognitive research on Chinese language* (pp. 296-329). Jinan: Shan Dong Educational

Publishing.

Joseph, H.S.S.L., Liversedge, S.P., Blythe, H.I., White, S.J., Gathercole, S.E., & Rayner, K. (2008). Children's and adults' processing of anomaly and implausability during reading: Evidence from eye movements. *Quarterly Journal of Experimental Psychology, 61*,708-723.

Kajii, N., Nazir, T.A., & Osaka, N. (2001). Eye movement control in reading unspaced text: The case of Japanese script. *Vision Research, 41*, 2503-2510.

Keung, Y-C., & Ho, C. S-K. (2009). Transfer of reading-related cognitive skills in learning to read Chinese (L1) and English (L2) among Chinese elementary school children. *Contemporary Educational Psychology, 34*, 103-112.

Klein, W. (1986). *Second language acquisition.* Cambridge University Press.

Kohsom, C., & Gobet, F. (1997). Adding spaces to Thai and English: Effects on reading. *Proceedings of the Cognitive Science Society, 19*, 388-393.

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

Li, X., Rayner, K., & Cave, K. R. (2009). On the segmentation of Chinese words during reading. *Cognitive Psychology, 58*, 525-552.

Liu, I.-M., Yeh, J.-S., Wang, L.-H., & Chang, Y.-K. (1974). Effects of arranging Chinese words as units on reading efficiency. *Chinese Journal of Psychology, 16*, 25-32.

Liversedge, S.P., & Findlay, J.M. (2000). Saccadic eye movements and cognition. *Trends in Cognitive Science, 4*, 6-14.

Malt, B.C., & Seamon, J.G. (1978). Peripheral and cognitive components of eye guidance in filled-space reading. *Perception & Psychophysics*, *23*, 399-402.

Morris, R.K., Rayner, K., & Pollatsek, A. (1990). Eye movement guidance in reading. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 268-281.

O'Regan, J. K., & Jacobs, A. M. (1992). The optimal viewing position effect in word recognition: A challenge to current theory. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 185–197.

Outline of Chinese Standard Vocabulary and Chinese Characters Grading (Hanyu Shuiping Cihui Yu Hanzi Dengji Dagang). (2001). Beijing, China: Economic Science Press.

Perea, M., & Acha. (2009). Space information is important for reading. *Vision Research, 49,* 1994–2000.

Pollatsek, A., & Rayner, K. (1982). Eye movement control in reading: The role of word boundaries. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 817-833.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*, 65-81.

Rayner, K. (1979). Eye guidance in reading: Fixation locations within words. *Perception, 8*, 21–30.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology,* 41, 211-236.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*, 372-422.

Rayner K. (2009). The thirty-fifth Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology, 62*, 1457-1506.

Rayner, K., Fischer, M.H., & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. *Vision Research, 38*, 1129-1144.

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

Rayner, K., Li, X., & Pollatsek, A. (2007). Extending the E-Z Reader model to Chinese reading. *Cognitive Science*, *31*, 1021-1033.

Rayner, K., Liversedge, S.P., White, S.J., & Vergilino-Perez, D. (2003). Reading disappearing text: Evidence for cognitive control of eye movements. *Psychological Science*, *124,* 372-422.

Rayner, K., & Pollatsek, A. (1996). Reading unspaced text is not easy: Comments on the implications of Epelboim et al.'s study for models of eye movement control in reading. *Vision Research*, *36*, 461-465.

Rayner, K., Slattery, T.J., Drieghe, D., & Liversedge, S.P. (2011). Eye movements and word skipping during reading: Effects of word length and predictability. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 514-528.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*, 125-157.

Reichle, E.D., Rayner, K., & Pollatsek, A. (2003). The E-Z Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences, 26*, 445-476.

Sainio, M., Hyönä, J., Bingushi, K., & Bertram, R. (2007). The role of interword spacing in reading Japanese: An eye movement study. *Vision Research*, *47*, 2575-2584.

Shen, D., Bai, X., Yan, G., & Liversedge, S.P. (2008). The perceptual span in Chinese reading. In K. Rayner, D. Shen, X. Bai, & G. Yan (Eds.). *Cognitive and cultural influences on eye movements* (pp.255-276). Tianjin: Tianjin People's Publishing House.

Shen, D., Bai, X., Zang, C., Yan, G., Feng, B., & Fan, X. (2010). Effect of word segmentation on beginners' reading: Evidence from eye movements. *Acta Psychologica Sinic*a, *42*, 159-172.

Spragins, A.B., Lefton, L.A., & Fisher, D.F. (1976). Eye movements while reading and searching spatially transformed text: A developmental examination. *Memory & Cognition, 4*, 36-42.

Sun, F., & Feng, D. (1999). Eye movements in reading Chinese and English text. In J. Wang, A. W. Inhoff, & H.C. Chen (eds.). *Reading Chinese script: A cognitive analysis* (pp. 189-206). Lawerence Erlbaum Associates. , Inc , Mahwah, NJ.

Taylor, I. (1997). Psycholinguistic reasons for keeping Chinese characters in Korean and Japanese. In H.-C. Chen (Ed.), *Cognitive Processing of Chinese and Related*

Asian Languages (pp.299–319). Hong Kong: Chinese University Press.

Tsai, J. L., & McConkie, G. W. (2003). Where do Chinese readers send their eyes? In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 159–176). Oxford, UK: Elsevier.

Tsang, Y.K., & Chen, H.-C. (2008). Eye movements in reading Chinese. In K. Rayner., D. Shen, X. Bai, & G. Yan (Eds.). *Cognitive and cultural influences on eye movements* (pp. 235-254). Tianjin, China, Tianjin People's Publishing House.

Wade-Woolley, L., & Geva, E. (1998). Processing inflected morphology in second language word recognition: Russian-speakers and English-speakers read Hebrew. *Reading and Writing: An Interdisciplinary Journal, 11*, 321-343.

Wang, M., Koda, K, & Perfetti, C.A. (2003). Alphabetic and non-alphabetic L1 effects in English word identification: A comparison of Korean and Chinese English L2 learners. *Cognition, 87,* 129–149.

Wang, M., Koda, K., & Perfetti, C.A. (2004). Language and writing systems are both important in learning to read: a reply to Yamada. *Cognition, 93,* 133-137.

Winskel, H., Radach, R., & Luksaneeyanawin, S. (2009). Eye movements when reading spaced and unspaced Thai and English: A comparison of Thai-English bilinguals and English monolinguals. *Journal of Memory and Language, 61,* 339-351.

Yan, M., Kliegl, R., Richter, E., Nuthmann, A., & Shu, H. (2010). Flexible saccade target selection in Chinese reading. *The Quarterly Journal of Experimental Psychology, 63*, 705-725.

Yan, G., Tian, H., Bai, X., & Rayner, K. (2006). The effect of word and character frequency on the eye movements of Chinese readers. *British Journal of Psychology, 97*, 259-268.

Yan, M., Kliegl, R., Richter, E., Nuthmann, A., & Shu, H. (2010). Flexible saccade target selection in Chinese reading. *The Quarterly Journal of Experimental Psychology, 63*, 705-725.

Yang, H.-M., & McConkie, G. W. (1999). Reading Chinese: Some basic eye-movement characteristics. In H.-C. Chen (Ed.), *Reading Chinese script: A cognitive analysis* (pp. 207–222). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Yang, J., Wang, S., Xu, Y., & Rayner, K. (2009). Do Chinese readers obtain preview benefit from word n + 2? Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1192-1204.

Yen, M. H., Tsai, J.L., Tzeng, O.J-L, & Hung, D.L. (2008). Eye movements and parafoveal word processing in reading Chinese. *Memory & Cognition*, *36*, 1033-1045.

Zang, C., Liversedge, S.P., Liang, F., Bai, X., & Yan, G. (2011). Interword spacing and landing position effects during Chinese reading in children and adults, *Journal of Experimental Psychology: Human Perception and Performance*, under review.

Author Note

Correspondence regarding this article should be addressed to Simon P. Liversedge, School of Psychology, Shackleton Building, Highfield Campus, Southampton, SO17 1BJ (e-mail: s.p.liversedge@soton.ac.uk). The work described in this article was supported by a Grant from the Royal Society awarded to the second and the seventh author, a Grant from the Natural Science Foundation of China (30870781) to the sixth author, and a Postgraduate Scholarship from the China Scholarship Council to the fourth author. Preparation of the article was aided by grant HD26765 from the National Institute of Health and by grant the ESRC (Res 000-22-3398). The authors are grateful to Albrecht Inhoff and two anonymous reviewers for their helpful comments.

Footnotes

1. Written Japanese text is comprised of two categories of characters: Kanji (Chinese) characters which are morphemes that relate to grammatical categories, and Kana characters, a category comprising Hiragana and Katakana characters. Hiragana characters represent grammatical elements in the sentence such as particles, affixes and auxiliaries, while Katakana characters are used to write foreign words, exclamations and specialized terminology. Kana characters are phonographic and complete orthographies in that any word in Japanese can be represented in these syllabries. Most often, however, Japanese sentences are comprised of a mixture of Kanji and Kana characters, and the standard Japanese writing script does not use interword spacing, except for Braille and for texts intended for foreigners or primary school children. For Japanese children, texts are written in Kana and spacing delimits phrases, whereas for learners of Japanese, texts are romanized, and spacing delimits words, but there are no absolutely unambiguous conventions for determining word boundaries (see Bassetti, 2007; Daniels & Bright, 1996; Kajii, Nazir, & Osaka, 2001; Sainio, Hyönä, Bingushi, & Bertram, 2007 for further details).

2. Written Korean uses both an alphabetic script (Hangul) and a logographic script (Hanja) which is borrowed from Chinese (Cho & Chen, 1999; Wang, Koda, & Perfetti, 2003; also see Taylor, 1997 for further details). However, the use of Hanja in Korea has decreased in the past several decades. Hanja may be currently used for the purpose of emphasis, or used to resolve homography in Korean. Modern Korean is typically written in Hangul alphabet. Hangul has 24 letters, each letter corresponds to a phoneme

of the Korean language and can be pronounced independently. Although it is an alphabet, the alphabetic characters are organized into a square-like syllable block, in which two or more letters are arranged left to right and top to bottom. Its overall shape makes Korean appear very similar to Chinese in terms of spatial configuration of the graphic units.

3. To confirm the Chinese readers agreed on the word boundaries, 16 Chinese readers who did not participate in the eye tracking experiment were required to indicate the word boundaries within the sentences. This reliability prescreen produced 95.7% (ranging from 75% to 100%) agreement amongst participants.

4. In addition to the analyses of overall saccade extent, we broke down this data set to consider forward and regressive saccade extents separately. Both these sets of analyses showed the same effects to the overall analyses of saccade length. The analyses showed reliable main effects of presentation condition and participant group along with an interaction between the two. In addition, the pattern of means was exactly the same as those reported for overall analyses, with differential effects for the American participants relative to the non-American participants.

5. Note, that both first fixation and gaze duration effects can also reflect higher order influences such as those of syntactic and semantic processing (Clifton, Staub & Rayner, 2007).

6. We are grateful to Albrecht Inhoff for pointing out this possibility in his review.

Table 1 Global eye movement measures for four participant groups across four presentation conditions.

		Participant Groups							
		Japanese		Korean		Thai		American	
Measure	Presentation Condition	M	SD	M	SD	M	SD	M	SD
Total Sentence Reading Time(ms)	Normal Unspaced	5215	1487	6010	1830	6618	1622	11788	3185
	Word Spaced	4788	1282	5565	1741	6231	1471	10979	2345
	Character Spaced	5447	1540	5975	1796	6759	1735	11900	2477
	Nonword Spaced	5961	1487	6735	1992	7621	1922	12492	2779
Mean Fixation Duration(ms)	Normal Unspaced	253	31	244	20	257	32	351	31
	Word Spaced	228	30	223	18	239	29	323	27
	Character Spaced	225	29	216	17	229	26	325	32
	Nonword Spaced	239	32	236	22	249	32	342	33
Mean Saccade Length (character spaces)	Normal Unspaced	3.0	0.5	2.6	0.5	2.4	0.5	1.8	0.3
	Word Spaced	4.1	0.6	3.8	0.6	3.4	0.7	2.4	0.4
	Character Spaced	4.5	0.6	4.1	0.6	3.8	0.7	2.8	0.4
	Nonword Spaced	3.7	0.5	3.4	0.5	3.1	0.6	2.4	0.4
Forward Saccade Length (character spaces)	Normal Unspaced	2.5	0.5	2.1	0.4	2.1	0.4	1.7	0.2
	Word Spaced	3.5	0.5	3.0	0.5	3.0	0.6	2.4	0.3
	Character Spaced	3.6	0.5	3.2	0.5	3.1	0.6	2.6	0.3
	Nonword Spaced	3.2	0.5	2.8	0.5	2.7	0.5	2.4	0.3
Regressive Saccade	Normal Unspaced	5.1	1.1	5.4	1.6	4.5	1.4	3.4	1.3

Length (character spaces)	Word Spaced	7.8	1.4	7.6	1.7	6.1	1.5	4.0	1.1
	Character Spaced	8.6	2.0	8.9	2.4	7.4	2.3	5.1	1.3
	Nonword Spaced	6.0	1.1	6.5	1.9	5.3	1.5	4.2	1.1
Total Number of Fixations	Normal Unspaced	17.6	5.0	20.7	6.3	22.1	5.4	29.8	8.0
	Word Spaced	17.3	4.0	20.2	5.7	21.9	5.1	30.1	6.9
	Character Spaced	20.0	4.8	22.5	6.5	24.7	5.8	32.0	7.5
	Nonword Spaced	20.9	4.6	23.6	7.0	25.8	6.2	32.1	7.2
Number of Regressive Saccades	Normal Unspaced	4.3	1.4	4.8	2.5	4.9	1.9	5.4	2.5
	Word Spaced	4.2	1.1	4.7	2.0	5.2	2.2	5.7	2.3
	Character Spaced	4.6	1.6	5.1	2.1	5.5	2.4	6.0	2.2
	Nonword Spaced	5.4	1.5	5.7	2.5	6.4	2.6	6.2	2.4

Table 2　Local eye movement measures for the four participant groups under normal unspaced and word spaced conditions.

Measures	Presentation	Participant Groups							
		Japanese		Korean		Thai		American	
		M	SD	M	SD	M	SD	M	SD
First Fixation Duration(ms)	Normal unspaced	263	35	251	26	261	30	366	31
	Word spaced	246	31	239	30	253	35	350	56
Gaze Duration(ms)	Normal unspaced	389	75	419	49	467	77	916	106
	Word spaced	302	68	314	56	381	76	719	224
Refixation Probability	Normal unspaced	0.19	0.07	0.26	0.11	0.34	0.16	0.37	0.06
	Word spaced	0.09	0.07	0.16	0.08	0.22	0.12	0.30	0.10
Total Reading Time(ms)	Normal unspaced	654	137	743	200	809	256	1464	309
	Word spaced	463	131	491	147	590	168	1036	252
The Number of Fixations	Normal unspaced	2.64	0.59	3.04	0.81	3.25	1.04	4.09	0.96
	Word spaced	2.00	0.56	2.18	0.61	2.44	0.70	3.17	0.70

Figure Legends

1. An example of one of the Chinese sentences used in the four spacing conditions in the experiment. The sentence means “I can understand the Chinese sentence on the blackboard“.

2. The mean length of saccades for each of the participant groups in each of the spacing conditions.

3. The landing position data for all first fixations (Panel a), single fixations (Panel b) and first of multiple fixations (Panel C) for the four participant groups under normal unspaced and word spaced conditions.

Figure 1

(1) Normal unspaced condition

我能够理解黑板上那些中文句子。

(2) Word spaced condition

我 能够 理解 黑板 上 那些 中文 句子。

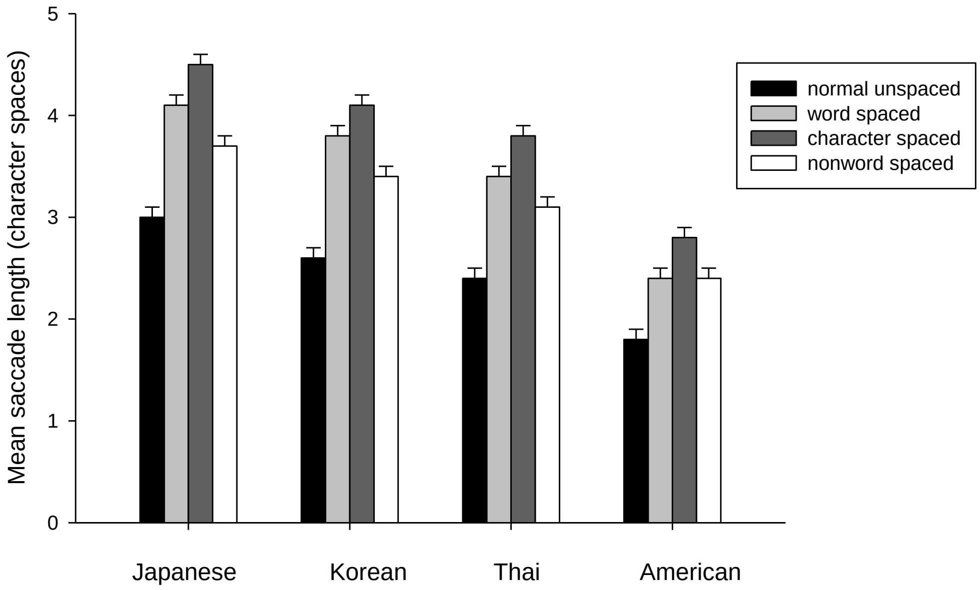
(3) Single Chinese character spaced condition

我 能 够 理 解 黑 板 上 那 些 中 文 句 子。

(4) Nonword spaced condition

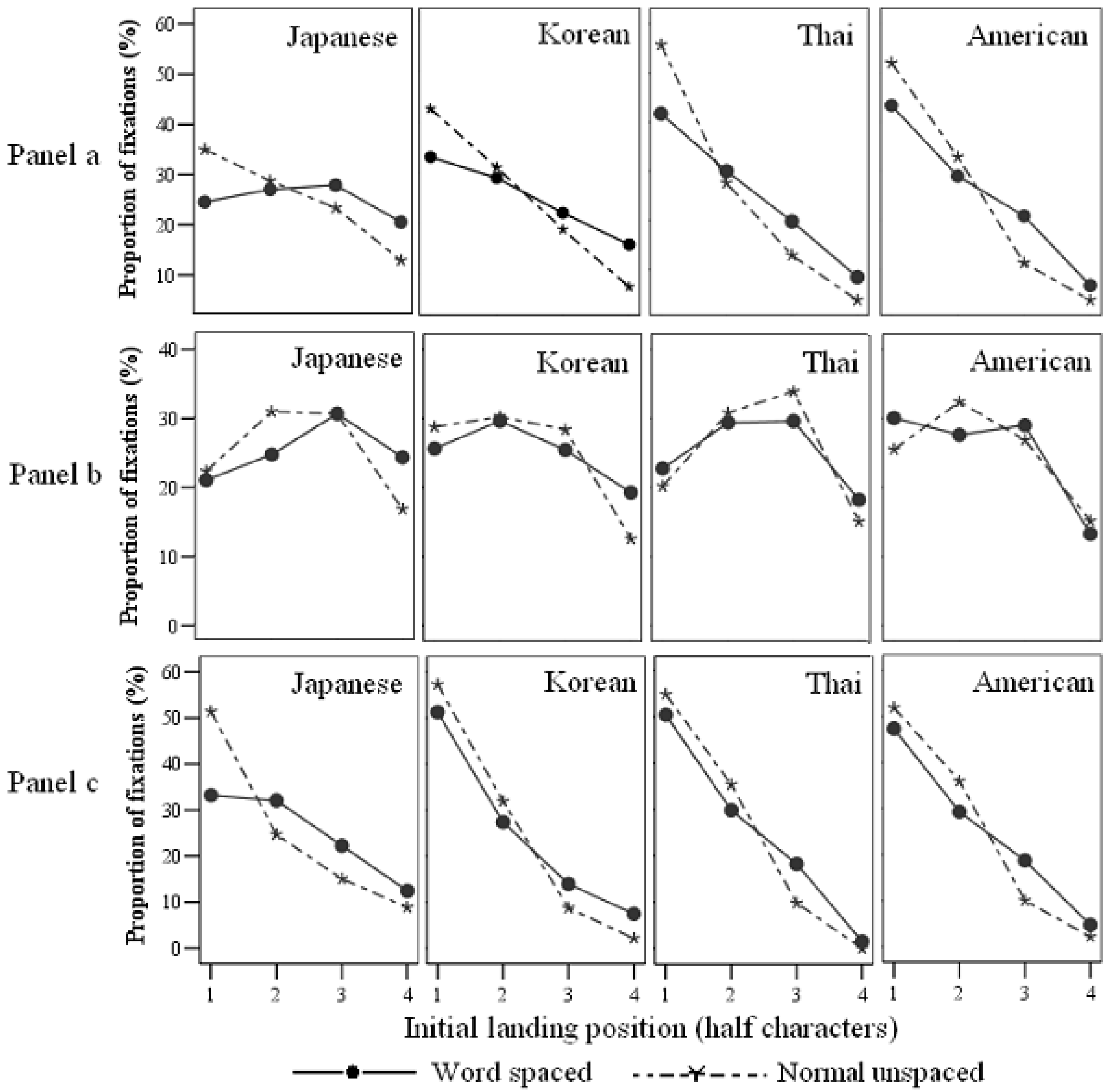
我能 够理 解黑 板上 那 些中 文句 子。

Figure 2



Mean saccade length (character spaces)
0
1
2
3
4
5
Japanese
Korean
Thai
American
normal unspaced
word spaced
character spaced
nonword spaced

Figure 3


Panel a
Panel b
Panel c
Japanese
Korean
Thai
American
Proportion of fixations (%)
Initial landing position (half characters)
Word spaced
Normal unspaced