The Role of Words in Chinese Reading

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[–] Abstract and Keywords

The Chinese writing system (and the underlying language) is different from European writing systems (and their underlying languages) in many ways. The most obvious difference is the nonalphabetic form of the Chinese written language, although there are also differences in relation to representations of lexicality, grammaticality, and phonological form. This chapter focuses on issues associated with the nonalphabetic nature of the written form of Chinese and the fact that words are not demarcated by spaces. Despite the surface differences in the orthographies between European languages and Chinese, there is considerable evidence to show that the word is a salient unit for Chinese readers. Properties of words (such as word frequency) as well as character properties (such as character frequency) affect measures of reading time and also affect where eye movements are targeted when passages of text are being read for meaning.

Keywords: word segmentation, interword spacing, saccade target selection, eye movements, Chinese reading

Unlike in many other writing systems, there are no spaces in Chinese text to separate words. Text written in Chinese is formed by strings of equally spaced box-like symbols called characters (Chinese is standardly read from left to right). The fact that Chinese is unspaced, as distinct from the majority of languages that are spaced, may initially appear somewhat surprising. However, some alphabetic languages such as English did not use spaces to demark word boundaries until around 1000 AD (Boorstin, 1983). It is generally believed that introducing spaces to mark word boundaries facilitates reading by providing the reader with explicit visual markers of word beginnings and endings (see reviews by Rayner, 1998, 2009; Zang, Liversedge, Bai, & Yan, 2011). Word spacing also reduces the extent to which adjacent words in text laterally mask each other (Rayner, 1998, 2009; Zang et al., 2011). For these reasons, word spacing is considered to benefit readers (indeed, if spaces are removed from English text, then reading becomes far less efficient; Rayner, Fischer, & Pollatsek, 1998). In this chapter we begin by briefly describing the nonalphabetic nature of the written form of Chinese and the fact that words are not demarcated by spaces. We then review studies exploring how Chinese readers identify word boundaries and how these properties of Chinese affect eye movement behavior during reading unspaced Chinese sentences.

An interesting question is why word spacing has not been adopted in the written form of Chinese. We do not have any definite answers to this question, although we can speculate as to potential reasons why this may be the case. There may be pragmatic historical reasons why spaces were avoided. For example, ancient Chinese text was often written on bamboo or carved into stone, and it may have been necessary to avoid spaces to make maximum use of the available space. Another historical reason is that in ancient Chinese text each character conveyed a particular aspect of meaning, and consequently text was read one character at a time. In fact, there was no term for “word” in Chinese until the concept was imported from the West at the beginning of the twentieth century (Packard, 1998). Also, ancient written Chinese did not contain punctuation to facilitate segmentation at a level even coarser than the word. There is a final factor that we believe may have also contributed to why spacing has not been incorporated into Chinese. Words in Chinese are quite short, as measured by their number of constituent characters. Also, the variance in word length is reduced relative to word length variability in alphabetic languages (as measured by the number of constituent letters). Approximately 97% of words in Chinese are one or two characters in length (token frequency; Lexicon of Common Words in Contemporary Chinese Research Team, 2008). To this extent, the number of potential sites within a character string at which word segmentation might occur is significantly reduced in Chinese, and therefore decisions about where to segment text to form word boundaries might be less of a challenge to Chinese readers than is the case in languages such as English. Thus word spacing may have been less of a necessity for efficient reading in Chinese.

Even without explicit word boundary cues, Chinese readers appear to have little difficulty reading Chinese. If the word is a significant linguistic unit in Chinese – and we will present evidence that it is – Chinese readers have to depend on other mechanisms to segment words in reading. How the lack of interword spaces affects Chinese reading and how Chinese readers segment sentences into words is still far from fully understood. Before we review studies exploring how Chinese readers identify word boundaries during reading within strings of characters forming sentences, we should note that Chinese is not the only written language that doesn't have a space or some other demarcation symbol to mark the boundary between words. For example, Japanese and Thai do not have spaces to mark word boundaries. Thus the studies we review might suggest some phenomena observed in studies of processing in those written systems. Moreover, some alphabetic writing systems such as German and Finnish have long compound words that are complex multimorphemic units written with no spaces separating the component words, and readers of those languages might use similar mechanisms to process such words when they read.

What Is a Word in Chinese?

Chinese linguists define a word as the minimal linguistic unit with specific meaning and pronunciation that could be used alone to constitute a sentence, or as a grammatical component on its own (Hoosain, 1992). Thus a Chinese word can be comprised of one or more morphemes. For reading, a word is comprised of characters, with each character corresponding to a morpheme. Among the 56,008 listed words that are included in one published source (Lexicon of Common Words in Contemporary Chinese Research Team, 2008), 6% are one-character words, 72% are two-character words, 12% are three-character words, and 10% are four-character words. Less than 0.3% of Chinese words are longer than four characters (based on type frequency). When word tokens are taken into account, 70.1% of words are one-character words, 27.1% are two-character words, 1.9% are three-character words, 0.8% are four-character words, and 0.1% are longer than four characters. There are more than 5,000 Chinese characters (Hoosain, 1992), and these differ in their complexity (varying from one to more than 20 stokes). A single character can be a part of different words when combined with other different characters. Most Chinese characters are pronounced identically when they comprise different words; however, some characters are pronounced differently when they appear in different words.

Because of the lack of explicit markers to indicate word boundaries in the Chinese writing system, Chinese readers do not always agree with each other on the location of the boundaries between the words of a sentence in text (Hoosain, 1992; Liu, Li, Lin, & Li, 2013). For some words readers almost always agree with each other, but for other words they do not. This inconsistency has caused significant difficulty for researchers designing artificial intelligence systems that attempt to understand Chinese text. To overcome difficulties associated with word segmentation, a Chinese national standard has been established that stipulates word segmentation for artificial information processing systems. Word segmentation according to this system is similar to that which would be derived on the basis of standard linguistic definitions of Chinese words. This standard lists some basic rules for segmenting Chinese text into words (National Standard GB/T 13715–92, 1992). Chinese readers, however, do not always follow the national standard when they are required to segment written sentences into words. Liu et al. (2013) asked Chinese readers to put a slash at word boundary positions in sentences. They then calculated the proportion of subjects that put a slash after each character, noting that the proportion should be 1 or 0 if there was complete agreement among subjects regarding word boundaries. The Chinese readers did not always agree with the national standard when they were required to parse text into words. Their segmentation was influenced by the syntactic categories of consecutive words. Specifically, they were more likely to combine function words (e.g., auxiliary words □ or □) with content words (e.g., nouns, verbs, adjectives, or pronouns) to form single-word units. Furthermore, most readers agreed that the numerals (□ 'one') and quantifiers (□ 'type of'), as well as the verb (□ 'lie') and the preposition (□ 'down'), should be combined with other characters as single word units. Finally, readers usually considered consecutive nouns (e.g., the phrase □□□□ 'forest park') as a whole word. Generally, Chinese readers tended to chunk single words into larger informational units during word segmentation. Although the task used by Liu et al. (2013) is artificial, in that it may not necessarily reflect how subjects segment text into words when they read normally, it is no more so than the judgment of linguists.

The Psychological Reality of Words in Chinese Reading

Given that the word unit in written Chinese text is not clearly demarcated and that there is some ambiguity concerning word boundaries (Hoosain, 1992), is the word a meaningful linguistic unit of information in processing written language in unspaced Chinese text? Furthermore, does the word unit play as central a role in eye movement control during reading for Chinese readers as it does for English readers? The earliest robust evidence of the importance of words as a visual unit in English text reading came from studies investigating the word superiority effect (Reicher, 1969; Wheeler, 1970), such that letter identification is facilitated when the letter is part of a word as compared with when it is embedded in a series of nonword letters or when it is shown in isolation. Similarly, research in reading Chinese (e.g., Cheng, 1981) has demonstrated that Chinese characters were identified more accurately in a briefly presented word than in a string of characters that did not constitute a word. Such a phenomenon indicates that Chinese characters belonging to a word can be perceived as a unit effectively.

Li, Rayner, and Cave (2009) further investigated how word boundaries affected character perception in Chinese reading and found word boundary effects. Participants were shown four Chinese characters in a horizontal row briefly and were asked to report as many characters as possible. These four characters constituted a four-character word in the one-word condition or two two-character words in the two-word condition. Li et al. found that participants usually reported the four-character word in the one-word condition, but could usually only report the first two-character word in the two-word condition even though there were four syllables to be reported in both conditions. This result demonstrates that word segmentation influences character recognition: The word boundary in the two-word condition induced serial processing whereas the lack of it in the one-word condition induced parallel processing of the entire string. In sum, the evidence indicates that word segmentation is a necessary and important procedure in Chinese reading.

Lower-Level Word Segmentation Cues Benefit Reading

Recently, there has been a great deal of interest in investigating how readers use lower-level word segmentation cues like spaces to segment and identify words when reading Chinese text (see Zang et al., 2011 for a review). Given the disagreements among Chinese readers about word boundaries, researchers usually prepare their experimental stimuli very carefully. They only use dictionary defined words. Any character strings for which there is ambiguity concerning their word status are usually avoided or discarded. In addition, after stimulus construction, to confirm that there is general agreement among Chinese readers as to word boundaries, a prescreening test is usually conducted. Bai, Yan, Liversedge, Zang, and Rayner (2008) found that when Chinese adult readers read sentences with spaces inserted between words (or when highlighting was used to demarcate words), they read them as easily as normal unspaced Chinese text. However, when spaces were inserted (or highlighting was used) between characters of a word (in a character segmentation condition) or randomly within words (in a nonword condition), reading was slowed. The results suggest that inserting spaces between the characters of a word in Chinese text slows reading and suggests that inserting spaces between words facilitates, but that the facilitative effect is negated by the fact that the spaces are novel.

Later studies showed that inserting spaces between words could help beginning readers of Chinese to read more efficiently and to learn new words (Blythe et al., 2012; Zang, Liang, Bai, Yan, & Liversedge, 2013). Blythe et al. recorded adults' and second-grade children's (mean age = 8.3 years, range = 7 to 10 years) eye movements as they read novel two-character words (where both characters were known but their combination formed a new word whose meaning could not be derived from the meanings of the two constituent characters). During the learning session of the experiment, subjects read these words embedded in explanatory sentences. Importantly, half of the subjects learned the new words in sentences with word spacing, while the other half learned the new words in unspaced sentences. Subjects returned for a test session on another day where they read the new words again in a different set of sentences. In the test session, all subjects read unspaced text. In the learning session, participants in the spaced groups read the new words more quickly than the matched control participants in the unspaced groups. More importantly, however, children, but not the adults in the spaced group, maintained this benefit in the test session while reading unspaced text. Blythe et al. argued that the spacing manipulation allowed the children either to form stronger connections between the two characters' lexical representations and the corresponding novel orthographic lexical representation of the word or to form a more fully specified novel lexical representation of the word itself (i.e., form a representation for each new word that is specified semantically with novel connections between that semantic unit and phonological and orthographic representations; see Perfetti, Liu, & Tan, 2005 for a review). Follow-up research also showed that word spacing can be useful for beginning readers of Chinese as a second language (Bai et al., 2013; Shen et al., 2012).

Other studies (Li & Shen, 2013; Liu & Li, 2014) explored whether inserting a space before or after a word facilitates the processing of that word during Chinese reading. When a Chinese word (word n) is recognized, its boundaries on both sides are known. Thus, inserting a space before the word to the right (word n+1) does not provide additional word boundary information given that its left boundary has been determined when word n is recognized. However, inserting a space after word n+1 provides information about its right boundary, which helps readers segment it from the text before recognizing it. Consistent with these assumptions, Li and his colleagues found that inserting a space after a word facilitated its processing but that inserting a space before a word did not facilitate processing and in fact may even interfere with its integration into sentential meaning as indicated by total reading times. Therefore, the position of a space may affect the ease of word identification differentially.

Word Properties Influence Reading

So far, our descriptions of studies have just included global measures of reading such as comprehension scores or total reading time. However, most of the studies that we discuss in this section employed more detailed eye movement measures to get local measures of online processing while people read text. Several measures of fixation time on a target region of text are commonly employed (target regions may be a character or a word). The three most common are *first fixation duration*, the duration of the first fixation on a region of text; *first pass time*, the sum of all fixation durations on a region of text until it is exited to the right or left; and *total time*, the sum of all fixation durations on a region of text (i.e., including fixations after regressions back to the region). In all cases, it is assumed that the reader entered the region of text for the first time from the left and that the script being discussed goes from left to right. Other common eye movement measures are the size and direction of the jump (*saccade*) from fixation to fixation. Backward saccades are called *regressions*.

Eye movement studies investigating Chinese reading have shown that a word's linguistic properties, such as its frequency and predictability, affect both the number and the duration of the fixations it will receive, even when the properties of the characters that comprise the word have been controlled (see Zang et al., 2011 for a review). For example, first pass reading times on high-frequency words are significantly shorter than on low-frequency words (Liversedge, Zang, Zhang, Bai, Yan, & Drieghe, 2014; Yan, Tian, Bai, & Rayner, 2006; Yang & McConkie, 1999), and first pass reading times on less predictable words are significantly longer than on more predictable words (Rayner, Li, Juhasz, & Yan, 2005; Wang, Pomplun, Chen, Ko, & Rayner, 2010); Furthermore, readers skip more predictable words more than less predictable words (Rayner et al., 2005) and skip high-frequency words more than low-frequency words (Yan et al., 2006). Yan et al. also found that the character frequency effect was modulated by word frequency, being evident only when word frequency was low but negligible when it was high. A possible explanation for this result is that when a word is frequently used, it is accessed as a single entity in the reader's mental lexicon. In contrast, when it is infrequently used, the word needs to be accessed via the individual characters, and, as a consequence, an effect of character frequency occurs. Thus to some extent, the properties of a word can modulate processing of its constituent characters.

Apart from the linguistic properties of Chinese words, a great deal of research demonstrates that low-level visual information associated with a Chinese word, such as its visual complexity (Liversedge et al., 2014; Yang & McConkie, 1999) and length (Li, Liu, & Rayner, 2011; Li & Shen, 2013), affects lexical identification and saccade programming during reading. Note that in these studies the properties of the words' constituent characters were controlled. For example, Li et al. (2011) reported that saccades leaving a four-character word were longer than saccades leaving a two-character word. This result indicates that the length of the fixated word affects subsequent saccade planning in reading. Taken together, these studies suggest that word properties, either at lower or higher levels, affect eye movement behavior during Chinese reading, and further demonstrate the importance of word-based processing in Chinese reading.

Characters Belonging to a Word Are Processed as a Unit

Sentence	观众正在台下耐心等待演员出场
Experiment 1	
	Word-window condition
Example 1	※※※※※※耐心※※※※※※ *
Example 2	※※※※※※耐心※※※※※※ *
	Nonword-window condition
Example 1	※※※※※下耐※※※※※※※ *
Example 2	※※※※※下耐※※※※※※※ *

Click to view larger

Figure 1 : An example of the stimuli used in the study by Li, Gu, et al. (2013). The English translation of the sentence is 'The audiences are patiently waiting for actors to come on the stage.' The symbol * indicates the fixation point.

More recently, a series of studies using a variety of paradigms have provided direct evidence that Chinese characters belonging to a word are processed as a unit (e.g., Li, Bicknell, Liu, Wei, & Rayner, 2014; Li, Gu, Liu, & Rayner, 2013; Li & Pollatsek, 2011; Li, Zhao, & Pollatsek, 2012). Li, Gu, et al. (2013) employed a novel variation of the moving window paradigm to test whether reading performance was better when characters belonging to a word were presented simultaneously than when they were not. In *the moving window paradigm* (see Schotter & Rayner, this volume), the area of text around fixation is normal and all other text is replaced by some sort of meaningless alternative material. When the eyes move, the display changes so that this statement now applies to the display around the new fixation point. All of the words in the Li, Gu, et al. sentences were two characters long, and the size of the moving window was also two characters. Thus only two characters were available to be processed on any particular fixation. All the characters outside the window were masked by the symbol ※. In Experiment 1, the two characters in the window constituted a word in the *word-window* condition but did not in the *nonword-window* (or character) condition (see Figure 1). Li, Gu, et al. found that readers made more and longer fixations when they could not see the characters belonging to a word simultaneously compared to when they could. That is, there was a cost when both characters belonging to a word were not available to be processed simultaneously.

In normal Chinese text, when the characters belonging to a word are shown on different lines, readers are not able to process them as being constituent characters of a word simultaneously. Li et al. (2012) examined whether dividing a word across two lines interferes with Chinese reading. In the divided-word condition of the experiment, the last word in a line was shown with one of the characters at the end of one line and the other character at the beginning of the next. In the word boundary condition, the target word was always shown at the end of a line, and no word was shown crossing two lines. Li et al. found that reading time was longer in the divided-word condition than the word boundary condition. The data thus indicated that characters belonging to a word were easier to process when they were presented on a single line than when they were presented on adjacent lines. Again, these findings provide evidence that a word is normally processed as a unit in Chinese reading.

Finally, Li, Bicknell, et al. (2014) systematically evaluated the effects of various word properties on eye movements during Chinese reading to determine whether these word properties have effects above and beyond what could be predicted by the properties of their component characters. These word properties included the length, frequency, and predictability of the current, previous, and following word, and the character properties included the frequency and complexity of a range of characters around the point of fixation. Participants' eye movements were recorded when they read sentences. Li, Bicknell, et al. found that the effects of the properties of the current, prior, and following words (e.g., word frequency, word length, and predictability) were strikingly similar in Chinese to those observed for word-based alphabetic languages on a range of eye movement measures. In addition, Li, Bicknell, et al. revealed a rich pattern of effects of character properties. Crucially, the effects of word frequency, word length, and predictability were highly reliable with and without character properties included in the same model. However, when the word properties were removed from this model, its prediction for the data became significantly worse.

These findings indicate an underlying word-based core to reading that appears to be shared between Chinese and alphabetic language scripts.

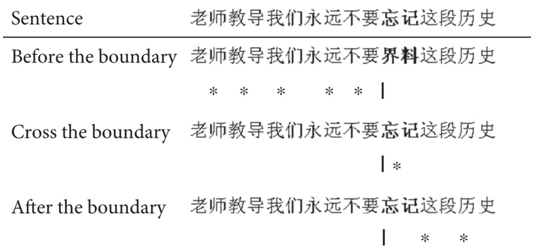

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Figure 2 : An example of a boundary paradigm. The symbol * indicates the fixation point. The invisible boundary that triggers the display change is marked with a vertical line. When the reader's eyes cross the boundary the preview word (e.g., a pseudoword □□ or the other manipulations) changes to the target word (□□ 'forget'). English translation of the sentence is 'The teacher taught us that we should never ***forget*** this period of history'.

The preceding discussion should not be taken to imply that Chinese readers process only the fixated word. Instead, there is extensive evidence that Chinese readers also process word(s) in the parafovea (see Zang et al., 2011 for a review). More generally, readers in all languages extract parafoveal information beyond the fixated word that facilitates processing on subsequent fixations. Yen, Tsai, Tzeng, and Hung (2008) used *the boundary paradigm* (Rayner, 1975; see Schotter & Rayner, this volume) to investigate whether parafoveal word recognition occurs during Chinese reading. In this paradigm, an invisible boundary is positioned just to the left of a target word. Before the reader crosses the boundary, there is typically an initial display stimulus (preview) that is different from the target word. When the eyes cross the boundary, the preview is replaced by the target word. Reading times on the target word are significantly shorter when the target is identical to the preview than when it is different. This is usually referred to as *parafoveal preview benefit* (Liversedge & Findlay, 2000; Rayner, 1998; 2009). By manipulating the characteristics of the preview in relation to those of the target word, one may observe differences in readers' oculomotor behavior and infer which characteristics of a parafoveal word are processed before it is fixated (see Figure 2). Yen et al. manipulated whether the preview was a real word or a pseudoword. They found that targets with word previews, even those that were contextually inappropriate and semantically unrelated, were more likely to be skipped than those with pseudoword previews. This result implies that the word preview was processed and identified as a word (as opposed to a pseudoword) in the parafovea.

Cui et al. (2013a) further investigated parafoveal processing across different lexical constituents in the reading of Chinese sentences. The experiment included three types of two-character Chinese target strings: a monomorphemic word, a compound word, or an adjective-noun word pair. The preview of the second character of that string (e.g., □ in the string □□) was either identical to that character (i.e., □) or was a dissimilar pseudocharacter (e.g., □). The pseudocharacters very closely resembled real characters but were completely meaningless. The analyses of Cui et al. on the first constituent (but not on the second constituent or the whole target string) showed that a pseudocharacter preview of the second character of the string increased fixation durations on the first character of that string for monomorphemic words (but not for compound words or phrases). This result indicates that the two constituents of monomorphemic words can be processed in parallel and that the morphological structure of a Chinese word, or the predictability of the second character on the basis of the first character, modulates how the word is processed in reading (see also Cui et al., 2013b).

To summarize, the studies we have discussed show that the word plays an important role during Chinese reading and that preventing Chinese readers from processing the component characters of words simultaneously hinders reading efficiency. The findings also provide evidence that words have a psychological reality during Chinese reading. That is, word representations are important and play a functional role in the process of written language comprehension. To this extent, there is fundamental similarity between Chinese reading processes and processes that underlie reading of alphabetic language scripts. Indeed, the word-based E-Z Reader model of eye movement control (Pollatsek, Reichle, & Rayner, 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998), which was developed to model eye movement behavior for skilled readers of alphabetic languages, was extended to Chinese readers by Rayner, Li, and Pollatsek (2007). They showed that the model accounted for fixation durations and word skipping rates during Chinese reading quite well.

Mechanisms of Word Segmentation

We have summarized results showing that words are important during Chinese reading. However, there are no spaces to mark word boundaries in Chinese text. Without spaces, how do Chinese readers segment words? This question seems like a chicken-and-egg problem. On the one hand, in order for word segmentation to occur, knowledge of the word is needed. On the other hand, to activate word knowledge, readers have to segment the words in order to recognize them.

One approach to this issue has been put forward by Perfetti and Tan (1999), who proposed that Chinese readers prefer to segment two characters into a single word since most words in Chinese are two characters long. To test this idea, they investigated how Chinese readers segmented overlapping ambiguous strings. In the crucial condition, they embedded the overlapping ambiguous strings into sentences where the string should be segmented as A-BC based on sentence context (e.g., □□□ in the experimental sentence frame □□□□□□□□□□□□□□□□, ‘the manager agreed to design products according to the customer’s requirements’). The middle character □ in the critical region could constitute a word with the first character (□□ ‘take care of’), and constitute another word with the third character (□□ ‘custom’). In the control condition, the first character of the ambiguous string was substituted by a character whose meaning was similar so that it did not constitute an overlapping ambiguity with the other characters in the sentence (□□□□□□□□□□□□□□□□, which has the identical meaning to the experimental sentence). For the control condition, in the critical region□□□, the first two characters (□□) are not a word, but the last two characters (□□ ‘custom’) are a word. Perfetti and Tan found that reading times on the target region were longer for the overlapping ambiguous strings than for the control condition. Hence, they concluded that Chinese readers prefer to initially segment the first two characters in an ambiguous string as a word. If readers did decide it was a word and subsequently found that this was incorrect, they then would need to correct the initial erroneous segmentation. This would take additional time, resulting in increased reading times relative to the control condition. Thus, Perfetti and Tan argued that these results supported the preferred processing strategy.

Evidence against the strictly serial parsing hypothesis, which assumes that characters are grouped into words in a strictly sequential order from left to right, was provided by Inhoff and Wu (2005). They monitored readers’ eye movements while they read sentences with a critical four-character sequence (e.g., □□□□ ‘college student’) consisting of two two-character words (□□ ‘college’ and □□ ‘student’). In the ambiguous condition, the central two characters (e.g., □□ ‘science’) also constituted a two-character word, while in the control condition the central two characters did not constitute a word. Inhoff and Wu found that readers spent more time viewing the critical four-character sequence and its two center characters (□□) in the ambiguous condition than in the unambiguous condition. They concluded that the assignment of characters to words is not a strictly serial left-to-right process. Instead, all of the possible words that can be combined by the characters falling into the perceptual span are activated during the reading of Chinese text. When more words are activated, it takes longer to make the decision regarding how the words should be segmented, resulting in longer reading times in the ambiguous condition than in the unambiguous condition. It should be noted that word frequency might also play an important roles in this kind of segmentation. We will discuss this later.

Li, Rayner, and Cave (2009) proposed a computational model of Chinese word segmentation based on an interactive activation perspective (McClelland & Rumelhart, 1981). According to that model, characters in the perceptual span are processed in parallel and the processing of these characters is constrained by how far they are from the point of fixation and by visual attention. The activation of each unit containing a visible character feeds forward to the word recognition level activating the word unit. When the activation of a word unit reaches a certain level, it feeds activation back to the characters belonging to the activated word. Hence the characters belonging to the activated word will be activated faster than the other characters. In this way, the word level representations compete with each other until a single word unit wins the competition. At that point, the word is recognized and segmentation occurs. Thus, according to this model, word segmentation and word recognition happen simultaneously.

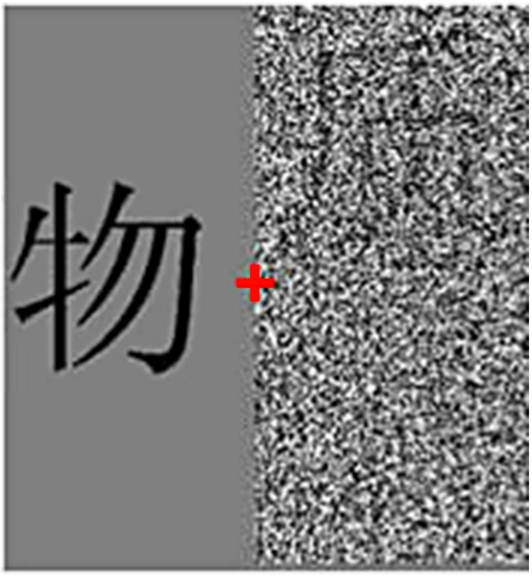

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Figure 3 : An example of the stimuli: (target is on right). The contrast shown in this figure is the maximum contrast in the experimental display.

Some of the assumptions of the word segmentation model were supported by subsequent evidence. Li and Pollatsek (2011) showed that word recognition in Chinese reading is an interactive process such that word knowledge affects lower-level processing during reading. In their study, Chinese readers viewed two Chinese characters. One character was intact, but the other (the target) was embedded in a rectangle of visual noise, but it increased in visibility over time (see Figure 3). The two characters comprised a word in one condition but not in the other condition. The task was to press a button to indicate whether the character in the noise was at the top or bottom of the rectangle (participants did not have to identify the character). Response times were faster in the word condition than in the nonword condition. As the wordness of the stimulus was logically irrelevant to judging the location of the target character, the data indicate that processing at the word level can feed back to fairly low level judgments such as where a character is. Thus, these results supported the interactive structure adopted by Li et al. (2009).

Segmentation of Spatially Ambiguous Words

As discussed earlier, there are some complex situations in which word boundaries are ambiguous. The first kind of ambiguity has been called *progressive ambiguity* (Li et al., 2009), where the first one or two characters of a multiple-character word sometimes also constitute another word. For example, in the string □□□ 'the wife of the boss,' □□ 'boss' is a word, but the three-character string is a word as well. In this example, the word unit □□□ receives feed-forward activation from all of the three characters, while the word □□ only receives feed-forward activation from two characters. Thus the model proposed by Li et al. (2009) predicts that the word with more characters is always more likely to be initially recognized and selected. For the three characters □□□, the model will make an initial commitment to parse them as a three-character word (□□□) rather than a two-character word (□□), since the word □□□ is activated by all three constituent characters.

The second kind of ambiguity occurs (Ma, Li, & Rayner, 2014) when a central character within a string may either be the final character of an earlier word in the string or the first character in a later word in the string, a so-called *overlapping ambiguous string*. For example, in the overlapping ambiguous string □□□, both □□ 'take care of' and □□ 'customer' are words, but the whole three-character string does not form a word. Ma et al. (2014) explored how Chinese readers segment overlapping ambiguous strings. In Experiment 1, participants were shown three-character ambiguous strings and were simply instructed to name the middle character of the string. The middle character constitutes a two-character word with the first character and constitutes another two-character word with the second character and was pronounced differently when it paired with each. For each ambiguous string, the frequency of one word was higher than the other, and participants tended to pronounce it as if it belonged to the higher-frequency word, regardless of that word's position (left or right). These results showed that Chinese readers do not always assign the middle character of an overlapping ambiguous string to the left word. Instead, they assigned it to the word that wins the (frequency mediated) competition, at least when there is little time pressure.

In Experiment 2 of Ma et al. (2014), two sets of overlapping ambiguous strings with identical first words (AB) but different second words (BC or BD) were embedded in the same sentence frames. The second word in these two strings was either a high-frequency word or a low-frequency word. Eye movements were monitored as these sentences were read. Fixation times on the region AB were longer when the second word was high in frequency than when it was low in frequency. These results showed that the second word in the ambiguous string competes for processing time with the first word when the string is processed. A third experiment investigated how the segmentation of an ambiguous string is constrained by local information such as the frequencies of the two words and global information such as sentential context. Second pass reading times (the sum of all fixations in a region following the initial first pass time, including zero times when a region was not refixated) were shorter and regressions into the ambiguous region were reduced when the segmentation that was based on a frequency fit with the sentential context. The results support a competition account such that the characters in the perceptual span activate all of the words they may potentially constitute, and any of those candidates can win the competition for identification if its activation is sufficiently high. One way to interpret these results is that word segmentation is at least a two stage process. During the first stage, word segmentation is determined mainly by local segmentation cues such as relative word frequencies. At a later stage, readers may adjust their initial segmentation commitments if they conflict with sentence context.

Saccade Target Selection in Chinese Reading

In the preceding sections, the fact that the visual and linguistic properties of words in the fovea and parafovea influence eye movement control in reading has been taken as evidence that the word is a basic unit of information associated with ongoing processing in reading. Further evidence that this is the case comes from the observation of a *preferred viewing location* (PVL) on a word in Chinese reading. The PVL (Rayner, 1979) refers to a position on a word that the eyes tend to initially fixate when making a first pass saccade onto a word (see also Schotter & Rayner, this volume). More technically, it is usually reported as a histogram with letter or character position on the x-axis and probability of fixating on the y-axis, which forms the PVL curve. Rayner (1979) reported that for scripts that are printed from left to right, such as English and French, the PVL is slightly to the left of the center of a word. However, for scripts that are printed from right to left such as Hebrew (see Deutsch & Rayner, 1999), the PVL on a word is between the middle of the word and the right-most letter (which is the beginning of the word) rather than the left-most letter (as in English). It is generally assumed that readers aim their eyes to the center of a word but for various reasons tend to initially land short of that location on the PVL (see McConkie, Kerr, Reddix, & Zola, 1988; Engbert & Krügel, 2010). These studies suggest that words may be not only the basic units of perceptual encoding but also the functional targets of saccades.

In contrast to the consistency of evidence and views regarding word based saccadic targeting during reading of alphabetic language scripts, there has been disagreement about whether Chinese readers adopt such a strategy. If Chinese words can be segmented parafoveally, and then saccades targeted on the basis of that parafoveally encoded unit, there should be a tendency for initial fixations on a word to land toward a specific location within words. Yang and McConkie (1999) recorded readers' eye movements while reading Chinese sentences and computed the frequency with which the initial fixation on all two-character words in the sentences was located at different positions in the word. They did not find any differences in terms of the probability of initial fixations on each character; initial fixations landed randomly over the whole word. They thus claimed that there was no preferred viewing location in two-character words. Furthermore, Tsai and McConkie (2003), making an assumption of spatial parity between a two-character Chinese word and a seven-letter English word, found patterns similar to those of Yang and McConkie, such that the PVL curves for both Chinese words and characters were flatter than for English words in reading normally presented text. They concluded that their results provided no evidence for a word-based saccadic targeting strategy in Chinese reading.

In contrast to this finding, Yan, Kliegl, Richter, Nuthmann, and Shu (2010) did report that there were more fixations near the beginnings of Chinese words. Their findings were based on corpus analyses of two-, three-, and four-character words in a Chinese text. They further divided the data into single fixation cases, where readers made only one first pass fixation on a word, and cases where more than one first pass fixation was made. The PVL peaked at the word center for words that received single fixations, but peaked at the word beginning when more than one fixation was made on a word (for similar results see Shu, Zhou, Yan, & Kliegl, 2011). Yan et al. argued that Chinese readers target their saccades to the word center if they are able to segment the word in parafoveal vision. If they are not able to do this, they adopt a more cautious targeting strategy: they aim saccades at the word beginning and engage in extra processing on the word after the initial fixation in order to decide where the currently fixated word ends. Thus Yan et al. proposed that Chinese readers use a word-based strategy to select their saccade target.

Yan et al.'s arguments seem reasonable; however the situation may be more complicated than this. Li, Liu, and Rayner (2011) reported experimental data that argue against this model. They embedded either a two-character word or a four-character word in identical sentence frames and compared the fixation distributions on a four-character region of interest, which contained either a two-character word and then another two characters in the two-character word condition, or the whole two-character target word in the four-character condition. (The size of the two regions was identical in the two conditions.) Li et al. assumed that if Chinese readers selected the word center as their saccadic target, the mean and mode of the PVL curve in the four-character condition should be further to the right than in the two-character condition. However, the PVL curves were almost identical in the two conditions. Additional Bayesian analyses (Rouder, Speckman, Sun, Morey, & Iverson, 2009) showed that the null hypothesis was highly preferred over the alternative hypothesis. This result argues against a saccade target selection strategy based on the length of the upcoming word in Chinese reading.

Li et al. also considered landing distributions of single fixations and the first of multiple fixations separately, as Yan et al. (2010) did, and their data replicated Yan et al.'s findings for both word lengths. The PVL peaked at the word center in single fixation cases but at the beginning in multiple fixation cases. However Li et al. (2011) argued that these kinds of PVL curves did not necessarily support the word-based targeting strategy. The eyes might fixate toward the word center by chance, and because word processing is more efficient when the eyes fixate at this position (O'Regan, 1981; O'Regan & Lévy-Schoen, 1987), a refixation on the same word may be not necessary. To reinforce this point, simulations showed that a model in which saccadic targeting was not based on words (e.g., a constant saccade length model) produced very similar patterns of effects. Both the experiment and the simulation of Li et al. indicated that there is no convincing evidence that Chinese readers target any specific position within a word.

A recent study reported by Zang, Liang, et al. (2013) provided converging evidence against Yan et al.'s (2010) claim that Chinese readers move their eyes to a word's center when they are able to segment words in the parafovea, but at a word's beginning when they could not. Yan et al.'s claim would predict that Chinese readers should always move their eyes to a word's center when spaces are inserted between words since readers should easily perceive word boundary information in the parafovea under these circumstances. Zang, Liang, et al. (2013) examined whether the addition of interword spaces to Chinese text would alter patterns of saccadic targeting during reading. They found that word spacing effects occurred to a similar degree for both children and adults with differential landing position effects for single and multiple fixation situations. As with Yan et al., for single fixations readers initially targeted their saccades to a word center. For multiple fixations, initial landing positions were closer to word beginnings (for similar results see Zang, Meng, Liang, Bai, & Yan, 2013). Note again that under interword spaced conditions the beginnings and ends of words are clearly demarcated, and therefore higher order parafoveal word segmentation is no longer necessary. Thus Zang et al.'s results run counter to the prediction of Yan et al.

If Chinese readers do not simply use a word-based strategy or a constant length strategy when selecting a saccade target, what strategy do they adopt? Wei, Li, and Pollatsek (2013) proposed that Chinese readers might estimate how many characters they are processing efficiently on any particular fixation and then send their eyes somewhere to the right of those characters. They termed this possibility a processing-based strategy. Using this strategy, the processing difficulty of the fixated words should affect the length of the saccade from that fixation: the easier the current processing, the longer should be the outgoing saccade. Wei et al. manipulated word length and word frequency separately in two experiments. In the first experiment, the target region was a four-character string that was either a word (one-word condition), or a phrase comprised of two two-character words (two-word condition), where the former has been shown to be easier to process than the latter. In the second experiment, the target region was either a high-frequency two-character word or a low-frequency two-character word. Each pair of the target words was fit into each sentence frame. Wei et al. found that the outgoing saccade length from the last fixation on the target region was longer in the one-word condition than the two-word condition and was longer in the high-frequency two-character word condition than in the low-frequency two-character word condition. These results indicate that the properties of words that are being fixated affect the length of the outgoing saccade from them. Similar findings were reported in Li, Bicknell, et al. (2014). They analyzed a corpus of eye movement data during Chinese reading using a mixed-effects regression model and found that the outgoing saccade length was affected by the predictability, frequency, and length of the currently fixated word. This finding was consistent with the processing-based view of eye movement control in Chinese reading, and it confirmed the previous finding that outgoing saccade length was affected by the properties of the fixated word. Moreover, Li, Bicknell et al. found that character fixation probability did not differ as a function of within-word position, confirming the findings by Li et al. (2011) of no PVL in Chinese reading.

In summary, saccade targeting may operate in a different and more complicated manner in Chinese than in most alphabetic languages. As suggested by Zang, Liang, et al., “information such as a word’s predictability, parafoveal familiarity, within-word character positional probability, between-word character transitional probability, as well as other sources of information could all contribute to saccadic targeting decisions in Chinese” (2013, p. 731). Much more work is needed to clarify this issue in the future.

Concluding Remarks

One important difference between Chinese and many other writing systems is that there are no spaces to mark word boundaries between words. Because the characters in Chinese reading are salient units, character processing might play an important role in Chinese reading. This does not mean that words are not important in Chinese reading, however. As we have described, numerous studies have shown that words have psychological reality and play an important role in Chinese reading. Considerable progress has been made recently to develop our understanding of the factors affecting eye movements during reading in Chinese, and a substantial proportion of this work has focused on issues related to the role of the word in Chinese, as well as how word segmentation occurs during normal Chinese reading. Recent progress has improved our understanding of the mechanisms of Chinese reading, both generally, in relation to how processing occurs compared with other languages, and more specifically, in relation to the unique properties of the Chinese writing system itself. Finally, it is likely that the findings reviewed in this chapter will also generalize to other writing systems that do not have explicit word boundaries.

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