Readers of Chinese extract semantic information from parafoveal words

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Evidence for semantic preview benefit (PB) from parafoveal words has been elusive for reading alphabetic scripts such as English. Here we report semantic PB for noncompound characters in Chinese reading with the boundary paradigm. In addition, PBs for orthographic relatedness and, as a numeric trend, for phonological relatedness were obtained. Results are in agreement with other research suggesting that the Chinese writing system is based on a closer association between graphic form and meaning than is alphabetic script. We discuss implications for notions of serial attention shifts and parallel distributed processing of words during reading.

A key result of research on eye movement in reading is that preview of a word to the right of fixation leads to shorter fixations on this word when it is fixated after the next saccade (Rayner, 1975). This preview benefit (PB) of a target word is established relative to fixation durations on unrelated preview words that are replaced by the target word only after the eye crosses an invisible boundary between them. PB has been demonstrated not only for the identical word, but also for words that are orthographically (Inhoff, 1990; Inhoff & Tousman, 1990; Rayner, 1975) or phonologically (e.g., Pollatsek, Lesch, Morris, & Rayner, 1992) related to the target, or that are predictable from prior sentence context (e.g., Balota, Pollatsek, & Rayner, 1985).

Somewhat surprisingly, there is still no statistically reliable result to show that semantic information is extracted from a parafoveal word during either first fixations or gaze durations in alphabetic writing systems (Rayner, Balota, & Pollatsek, 1986; for a review, see Rayner, White, Kambe, Miller, & Liversedge, 2003). This null result is compatible with the assumption that word recognition in alphabetic languages adheres to the well-known triad of orthographic, phonological, and semantic processing (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001),

with semantic information becoming available relatively late in the processing chain. For reasons elaborated below, we expected this to be different for Chinese script, and, indeed, we will demonstrate reliable evidence for early semantic information extraction.

Relevant Features of the Chinese Writing System

Chinese text is written in a series of square-shaped characters with the same width, irrespective of their visual complexity. Characters are formed according to a number of principles (Feng, Miller, Shu, & Zhang, 2001): Most characters are *compound* characters and have two components/radicals (Yin & Rohsenow, 1994), one of which represents the meaning of the character, and the other of which provides a rough clue about its pronunciation.[1] The pronunciation of a certain character cannot be derived directly from its orthography because only about 30% of these characters have the same pronunciation as their phonetic component (Gao, Fan, & Fei, 1993; Zhou & Marslen-Wilson, 1999).

There are also *pictographical* characters (e.g., the characters 马 and 车, which mean *horse* and *wagon*, respectively) that originated from ancient drawings by cave dwellers, and *indicative* characters (e.g., the characters

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上 and 下, which look like upward and downward arrows and mean *top* and *bottom*, respectively) that were formed by analogy or association. In our experiment, we used these visually and structurally simple and relatively common pictographic and indicative characters as target words to achieve independence of orthographic and phonological features and to maximize chances of observing semantic PB. In summary, in comparison with alphabetic languages, Chinese is generally mapped more closely to meaning than to phonology, and this holds especially for the material used in the present experiment.

Perceptual Span in Chinese Reading

In Chinese reading, the perceptual span[2] is surprisingly narrow, extending at most up to one character to the left and two to three characters to the right of fixation (Inhoff & Liu, 1997, 1998; C.-H. Tsai & McConkie, 1995). Given that most Chinese words are only one or two characters long (Yu et al., 1985), the perceptual span translates roughly into two words. On average, word $n + 1$ is closer to the point of fixation on word n in Chinese than in alphabetic languages. In addition, the characters convey more about the meaning of the word than do alphabetic letters, especially because the meaning-carrying radical is more often on the left side of a character. Consequently, word $n + 1$ may benefit from higher visual acuity, and Chinese readers may be in a better position to resolve its semantic influence.

PB in Chinese

There is evidence for PB in Chinese reading. Pollatsek, Tan, and Rayner (2000) obtained reliable facilitation in naming latency by previewing homophonic and orthographically similar characters in isolated character recognition tasks. In reading, Liu, Inhoff, Ye, and Wu (2002) demonstrated PB from graphemically similar previews, as compared with dissimilar previews. In addition, J.-L. Tsai, Lee, Tzeng, Hung, and Yen (2004) reported early and late PBs for orthographically similar homophonic and nonhomophonic previews and a late, purely phonological PB from orthographically dissimilar previews. More recently, Yang, Wang, Xu, and Rayner (in press) reported identity-character PBs of a magnitude similar to those for unrelated-character previews.

In the present experiment, aside from the identity-character preview and an unrelated-character no-preview condition, we provided preview characters that were orthographically, phonologically, or semantically related to the target. The main question was whether fixation durations under any of these related conditions, and, in particular, under the semantic condition, would be shorter than those under the unrelated-character condition.

Parafoveal-on-Foveal Effects in Chinese

An alternative measure of preprocessing is whether the parafoveal properties of the target word influence fixation durations on the word before the boundary. Such effects are referred to as *parafoveal-on-foveal effects* (POFs). In alphabetic languages, there are mostly failures of finding POFs in the boundary paradigm (for a review, see Rayner,

Juhasz, & Brown, 2007), but there are exceptions (see, e.g., Kliegl, Risse, & Laubrock, 2007). Also, POFs are routinely reported for corpus analyses of eye movements in reading (Kennedy & Pynte, 2005; Kliegl, Nuthmann, & Engbert, 2006). In comparison with PB, these effects tend to be weak; even the direction of POFs is not consistent across studies. There is only one report about POFs during Chinese reading. Yang et al. (in press) obtained a POF on character $n - 1$ in two experiments, suggesting that readers of Chinese obtain some information regarding the word to the right of fixation that influences the duration of the current fixation.

METHOD

Subjects

Fifty-one students from the Beijing Normal University, who had normal or corrected-to-normal vision and were native speakers of Chinese, participated in the eye-tracking experiment. Also, independent groups of 51 and 67 students, also native speakers, participated in two norming studies.

Materials

Forty-eight target characters were selected. In order to avoid sublexical/radical activation during reading, we did not select any compound characters. For each target character, four types of preview characters served as orthographically related, phonologically related, semantically related, and unrelated previews. Each target character was embedded as the first character of a two-character word. Due to this manipulation, word-level preview was a regular word only for the identity condition, whereas the preview characters of the four inconsistent conditions (i.e., orthographic, phonological, semantic, and unrelated previews) did not form two-character words with the second character. There were no differences among the five preview types with respect to visual complexity (i.e., number of strokes) [$F(4,188) = 1.0, p > .1$] and frequency [$F(4,188) < 1$].

The sentences containing the target words were 20–25 characters in length ($M = 22.5$, $SD = 1.4$). The target characters were never among the first three or last three words. The invisible boundary that triggered the display change was located just to the left of the space before the target character. Words before the boundary were also always two-character words. Each sentence was presented only once to a subject, and the five preview types were counterbalanced across subjects.

Norming Studies

Relatedness of target word and preview character. We collected independent ratings of orthographic ($n = 18$ subjects), phonological ($n = 17$ subjects), and semantic ($n = 16$ subjects) relatedness between the target and each of the four preview characters on a 5-point scale to ensure that the preview characters were related to the targets only on the desired dimensions. As is shown in Table 1, the ratings nicely reflected the intended design. The ratings ranged from 3.8 to 4.3 on the relevant dimension and were smaller than 1.7 for all other comparisons.

Predictability of critical words from prior sentence context. The sentence contexts were written to be neutral for the critical words. As a check, we presented to the subjects all of the words prior to the critical word and asked them to predict the next word of the sentence. From 3,216 predictions (i.e., 67 subjects × 48 words), the target word was guessed 164 times (5%), and the unrelated preview word was guessed 16 times (0.5%); the related previews were guessed 6 (orthographic), 13 (phonological), and 12 (semantic) times. Thus, as intended, the critical words were of very low predictability overall, and the related previews were guessed correctly even less often than were the unrelated previews. Thus, any PBs for related conditions were unlikely to be due to differences in predictability from prior sentence context.

Table 1
Means and Standard Deviations of Frequency (per Million), Number of Strokes,
and Relatedness Ratings of Target and Preview Characters

			Preview								
	Target		Identical		Orthographic		Phonological		Semantic		Unrelated
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Example	户		户		广		互		门		丹	
Pronunciation	hu4		hu4		guang3		hu4		men2		dan1	
Frequency	1,150	1,728	1,150	1,728	1,154	1,435	1,197	1,757	1,164	1,721	1,163	1,573
No. of strokes	5.0	2.1	5.0	2.1	4.8	1.8	5.1	1.9	5.5	2.6	4.9	1.9
Ortho. rating					**3.8**	**0.8**	1.6	0.3	1.5	0.4	1.6	0.3
Phono. rating					1.2	0.3	**4.3**	**0.6**	1.2	0.2	1.1	0.2
Sem. rating					1.2	0.3	1.2	0.1	**4.1**	**0.6**	1.2	0.2

Note—All characters were embedded into a key word—for example, 户籍 (*domicile*)—and displayed to subjects in the sentence 中国古代的统治者通过**户籍**编制来统治人民 (*Ancient Chinese governors used **domicile** system to control people*). The relevant dimension for each type of preview character is set in boldface.

Apparatus

Eye movements were recorded with an EyeLink II system (500 Hz). Single sentences were presented in the vertical position one third from the top of the screen of a 19-in. ViewSonic G90f monitor (resolution, 1,024 × 768 pixels; frame rate, 100 Hz). Therefore, it took at most 16 msec to complete the display change. The font was Song 40 with one character equal to 1.5º of visual angle. The experiment was controlled by an Intel Pentium 4 computer running at 2.8 GHz in a Windows XP environment. The subjects read with the head positioned on a chinrest 43 cm from the monitor. All recordings and calibrations were binocular. Only 3 subjects reported flashes on the screen (for only a few trials), but they could not report exactly what they had seen.

Procedure

The subjects were calibrated with a 9-point grid for both eyes. They were instructed to read the sentences for comprehension, fixate a dot in the lower right corner of the monitor, and, finally, press a button to signal completion of the trial. On 20 trials, the sentence was replaced by an easy yes/no question. Data for 3 subjects, whose accuracy was below 80%, were excluded. Fixation on the fixation point initiated presentation of the next sentence or a drift correction. An extra calibration occurred if the tracker did not detect that both eyes were fixated within a predefined window around the initial fixation point. All of the subjects read 123 sentences (48 experimental sentences and 75 fillers).

Data Analysis

Data were reduced to a fixation format using an algorithm for the binocular detection of saccades (Engbert & Kliegl, 2003). Sentences containing a blink or loss of measurement (18%) were deleted. Analyses were based on right-eye fixations. First- and single-fixation durations, as well as gaze durations with first-fixation durations shorter than 60 msec or longer than 600 msec (1% of all fixations), were excluded.

The inferential statistics resulted from a priori contrasts, with the unrelated preview serving as the reference for the related and identity previews. Estimates were from a linear mixed-effects model with crossed random effects for subjects and items using the lmer program of the lme4 package (Bates, Maechler, Dai, & Vasishth, 2008) in the R environment for statistical computing and graphics (R Development Core Team, 2008). Effects were also significant in separate ANOVAs over subjects and items.

The durations were shortest in the identity condition in all analyses. These significant contrasts are not interpretable, however, because of the confound between peripheral change versus no change and the change from one-character to two-character words. The identity condition informs us about the maximum potential PB; it is not critical for the theoretical issues under consideration.

RESULTS

Target Word Region: PB

The means and standard errors of first-fixation durations and gaze durations on the target word for each preview type are shown in Figure 1A. Totals of 1,648, 1,648, and 1,229 observations were available for the first-fixation, gaze, and single-fixation duration analyses, respectively.

First-fixation durations. Relative to unrelated previews, there were significant PBs for orthographically and semantically related characters of 12 msec ($SE =$ 6 msec, $t = 2.1$) and 17 msec ($SE =$ 6 msec, $t = 3.1$) for first-fixation durations (including also single-fixation durations); the phonological PB was numerically in the expected direction, but was not significant ($b = 3$ msec, $SE = 6$ msec, $t = 0.6$). In a posteriori contrasts with the semantic condition as the reference, fixations were estimated to be 14 msec longer in the phonological condition ($SE = 6$ msec, $t = 2.4$). Single-fixation durations showed the same profile of results, with the exception that the difference between unrelated and orthographically related previews was only marginally significant ($b = 13$ msec, $SE = 7$ msec, $t = 1.9$).

Gaze durations. Gaze durations were longer for the unrelated than for the orthographical ($b = 22$ msec, $SE =$ 11 msec, $t = 2.1$), phonological ($b = 20$ msec, $SE = 11$ msec, $t = 1.9$), and semantic ($b = 27$ msec, $SE = 11$ msec, $t =$ 2.5) previews (see Figure 1B). Thus, again, there was significant facilitation for at least two of the three conditions.

Skipping rate of target word. The skipping percentage for the unrelated condition was 25%. In a generalized linear mixed model with the contrast specifications used for durations, the skipping percentages were numerically, but not significantly, higher in the three related-preview contrasts (6%, 2%, and 4% for the orthographically, phonologically, and semantically related previews, respectively).

Saccade launch site prior to boundary. We expected PB to be larger when the critical saccade was launched from a location closer to the boundary. The analysis of these fixation locations did not reveal significant condition-specific differences. The mean launch site for unrelated previews was 0.24 characters to the right of
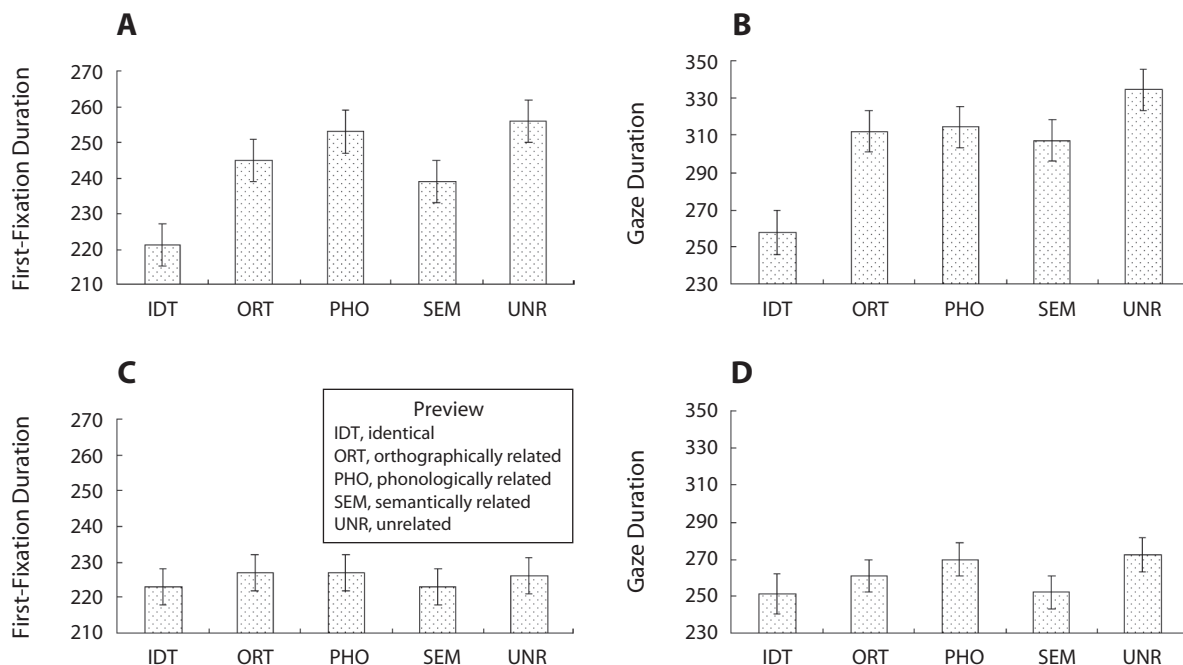
Figure 1. Means and standard errors of first-fixation and gaze duration on target words (panels A and B) and on pretarget words (panels C and D).

word center. Using the same set of contrasts, we found that the differences between the unrelated and related previews were -0.10, -0.08, and $+0.06$ for the orthographically, phonologically, and semantically related previews, respectively. These differences were all within the standard error of 0.08 (all t values < 1.4).

Pretarget Word Region: POFs

The mean profile of first-fixation duration and gaze duration on the pretarget word (based on 1,622 trials) is shown in Figures 1C and 1D. First-fixation and single-fixation durations failed to reach significance in any of these contrasts (all t values < 1). There was, however, a significant semantic POF effect for gaze duration of 21 msec ($SE = 9$ msec, $t = 2.4$). The other two related previews were not significant (POFs = 11 msec and 0 msec, respectively; ts < 1.3). In a posteriori contrasts with the semantic condition serving as the reference, fixations were estimated to be 21 msec ($SE = 9$ msec, $t = 2.4$) and 10 msec ($SE = 9$ msec, $t = 1.2$) longer in the phonological and orthographic conditions, respectively.

DISCUSSION

This experiment examined parafoveal processing during the reading of Chinese sentences. We obtained PB and POF effects. Most important, and in striking contrast to alphabetic languages, readers were able to obtain both orthographic and semantic information from parafoveal characters that they had not yet fixated. Unlike prior studies of Chinese reading, we tested purely character-level processing. Therefore, we focused on simple pictographi-

cal and indicative characters in order to avoid sublexical/radical activation during reading. This select set of characters afforded a clear manipulation of orthographic, semantic, and phonological relatedness. Of course, the semantic PB and POF effects are proofs of principle only; their generalizability to Chinese characters at large still remains to be established.

Orthographic and Phonological Relatedness in Chinese Characters

Viewing orthographically related nonhomophonic preview characters reduced first-fixation duration on the target words. This result replicates previously reported orthographic PBs in Chinese reading (Pollatsek et al., 2000; J.-L. Tsai et al., 2004). Liu et al. (2002) also reported parafoveal PBs from graphemically similar previews relative to findings in a dissimilar condition. They argued that orthographic PB was due to the shared phonetic radicals, rather than to stroke overlap, thus implying a priority of radical-level activation. In the present study, the orthographically related previews were noncompounds without phonetic radicals. Therefore, the orthographic PB reported here should have originated from the character, not the sublexical, level.

Phonological information can be extracted parafoveally in alphabetic reading (Pollatsek et al., 1992). This could be due to a direct, early, and automatic phonological activation through orthography (see, e.g., Grainger & Holcomb, in press). For Chinese reading, there is evidence for a comparatively small contribution of phonological activation to character identification (for a review, see Feng et al., 2001), and it is generally accepted that the Chinese

writing system has a stronger emphasis on meaning than on sound (for a summary, see Hoosain, 1991).

Like Feng et al. (2001), who reported early phonological activation in English, but not in Chinese, we did not find statistically significant evidence for early phonological PB in the present study, but there was a numerical trend for phonological facilitation. Pollatsek et al. (2000) reported significant facilitation in naming latency with the preview of homophonic characters, irrespective of orthographic form, in isolated character recognition tasks. In contrast, J.-L. Tsai et al. (2004) reported a significant early phonological PB when the previews were orthographically similar to the target (by sharing radicals); when previews were orthographically dissimilar, the effect appeared only in late measures. We certainly do not want to argue the null hypothesis for phonological PB on the basis of this experiment, but it seems justified to argue that the effect is weaker or comes in later than the semantic PB, at least for pictographic and indicative characters.

Semantic Relatedness

The Chinese writing system is based on a close association between graphic form and meaning, as supported by strong evidence for direct access from orthography to semantics, known as *two-route activation* in Chinese word/character identification (Zhou & Marslen-Wilson, 1999, 2000). According to this proposal, phonological mediation may be bypassed under some circumstances (Chen & Shu, 2001; Meng, Jian, Shu, Tian, & Zhou, 2008). Against the background of this research documenting that Chinese readers are sensitive to semantic information, it was reasonable to expect that parafoveally previewing a semantically related character would reduce the subsequent fixation duration on this target.

The main result of this experiment is a semantic PB for first-fixation durations. Indeed, numerically, this was the strongest PB of the three conditions. For gaze durations, the overall PB was significant, with significant effects of comparable size in the expected direction for all of the related conditions. Moreover, we observed significantly shorter gaze durations on pretarget words in the semantic preview condition than on those in the unrelated previews (a semantic POF effect).

If we take size of effect as a guide, the results suggest that semantic information is available at least as early as is phonological information. This is critical because there is a pervasive argument that semantic information about a parafoveal word is not obtained during fixations in alphabetic writing systems (Rayner et al., 1986). Indeed, Rayner et al. (2003) concluded that "the basis for the robust parafoveal preview benefit obtained in numerous studies is not any type of semantic code" (p. 230), noting also that such effects would be problematic for serial-attention-shift models (for a review, see, e.g., Reichle, Liversedge, Pollatsek, & Rayner, 2009). On the surface, such semantic PB effects appear to be less problematic for models that assume parallel distributed processing within the perceptual span with eye movements guided by attentional gradients (e.g., Engbert, Nuthmann, Richter, & Kliegl, 2005; Kliegl et al., 2006).[3]

In conclusion, we propose that low-level orthographic information serves as the basic visual input for reading in general. Then, depending on the properties of a writing system, different information (e.g., phonological in alphabetic, or semantic in Chinese) may be preprocessed parafoveally with different priority. The present study is an example of cross-language comparison, revealing a mind that flexibly adapts its processing priority to the information provided in the environment.

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NOTES

1. There are different terms for this type of character. Researchers have called them *phonograms* (Lee et al., 2007), *semantic–phonetic compound characters* (Shu, Chen, Anderson, Wu, & Xuan, 2003), and *compound characters* (Perfetti, Liu, & Tan, 2005).

2. The perceptual span is the region of effective vision from which useful information can be obtained during fixation (McConkie & Rayner, 1975).

3. We do not want to rule out that the simple noncompound Chinese characters act like Hebrew root morphemes. These morphemes do not necessarily occur at the word beginning and lead to PBs for the target word (Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2003). Such morphological preprocessing is within the scope of some serial attention shift models.