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Lexical and Sub-lexical Semantic Preview Benefits in Chinese Reading

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ABSTRACT

Semantic processing from parafoveal words is an elusive phenomenon in alphabetic languages, but it has been demonstrated only for a restricted set of non-compound Chinese characters. Using the gaze contingent boundary paradigm, this experiment examined whether parafoveal lexical and sub-lexical semantic information was extracted from compound preview characters. Results generalized parafoveal semantic processing to this representative set of Chinese characters and extended the parafoveal processing to radical (sub-lexical) level semantic information extraction. Implications for notions of parafoveal information extraction during Chinese reading are discussed.

Keywords: semantic, preview benefit, reading, Chinese

The when and where of eye movements during reading involve dynamic adjustments to the visual and language-related properties of the reading material. During each fixation, not only lexical information (e.g., orthographic, phonological, syntactic, or semantic properties) of the fixated foveal word is extracted, but also some information about upcoming (i.e., parafoveal) words in a sentence becomes available for cognitive processing and saccadic programming (see Rayner, 2009, for a review). In the boundary paradigm (Rayner, 1975) where the type of information of the to-be-fixated word N+1 available during a fixation on word N is under experimental control, different preview words are replaced by the target word once the eye crosses an invisible boundary located between words N and N+1. The preview benefit (PB) is indicated in a positive difference between fixation durations on target word N+1 when preview is denied compared to when preview is available during the previous fixation. Parafoveal preview benefits have been consistently demonstrated for orthographic (Inhoff, 1990) and phonological (Pollatsek, Lesch, Morris, & Rayner, 1992) features of words. One of the recent debates is whether semantic information can be extracted from parafoveal words in alphabetic languages: there is little evidence for integration of semantic information across saccades in alphabetic scripts especially in English (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Rayner, Balota, & Pollatsek, 1986). On the other hand, due to a more regular mapping between orthography and phonology in German which presumably facilitates lexical access in orthography-to-phonology-to-semantics route, evidence for semantic preview benefit has been established for German (Hohenstein, Laubrock, & Kliegl, 2010; Hohenstein

& Kliegl, 2011) and for a restricted set of simple Chinese characters (Yan, Richter, Shu, & Kliegl, 2009). There is also some evidence for semantic preview for other characters, but the authors favored an alternative explanation in terms of plausibility (Yang, Wang, Tong, & Rayner, 2011). This research is reviewed below.

Morphemes are the smallest units which usually contain some fairly consistent aspects of meaning, they are often considered to behave similarly to semantic information (Kambe, 2004). In agreement with the view that high-level information is not available parafoveally, there are many studies which have failed to find evidence for morphological (or morpho-semantic) parafoveal processing in English or Finnish scripts (Bertram & Hyönä, 2007; Inhoff, 1989; Kambe, 2004; Juhasz, White, Liversedge, & Rayner, 2008). On the other hand, Deutsch, Frost, Peleg, Pollatsek, and Rayner (2003) demonstrated that preview of the root morpheme in Hebrew facilitated processing of targets but whether such effects can also be obtained in other languages needs to be established (Rayner, White, Kambe, Miller & Liversedge, 2003). In general, there obviously is a need for additional tests of semantic or morpho-semantic preview benefit. Here we report a study in which we systematically manipulated the semantic relatedness between root units (radicals) and the whole character and word and demonstrate reliable evidence for early parafoveal semantic information extraction from both lexical and sub-lexical levels for representative, compound characters in Chinese reading.

A Brief Introduction of Relevant Features of the Chinese Writing System

Chinese has been viewed as a logographic writing system with its basic writing

units, characters, written in a series of square-shaped objects of the same horizontal extent irrespective of visual complexity. Characters are formed according to a variety of principles and most modern Chinese characters are semantic-phonetic compound characters with two components (radicals), in many cases, one of which represents the meaning of the whole character and the other provides a rough clue to its pronunciation. For instance, the character “蝗” with pronunciation of /huang2/ and meaning of *locust* has a semantic radical “虫” which means *insect* and a phonetic radical “皇” which is pronounced as /huang2/. It is generally accepted that Chinese is more closely mapped to the meaning than to the sound if compared to alphabetic languages (Hoosain, 1991).

However, a semantic radical may not always provide a clear guide to the meaning of a character. Radical semantic *transparency* refers to the degree to which the constituent radicals are semantically related to the meaning of the whole character. As a result of the development of the Chinese writing system over centuries, there are characters whose meanings are unrelated, or only indirectly related to the meanings of their radicals. Characters such as “法” which means *law* with a semantic radical “氵” which means *water*, are semantically *opaque* from their radicals. Taken the above example “蝗” again, since its semantic radical “虫” represents the same meaning category as the whole character, this type of character is termed as being semantically *transparent* from radicals (see Shu & Anderson, 1997, for a review).

Parafoveal Preview Benefits in Chinese Sentence Reading

Similar to alphabetic reading, preview benefit from orthographically and

phonologically similar parafoveal previews relative to a dissimilar condition was also reported in Chinese sentence reading studies (Liu, Inhoff, Ye, & Wu, 2002; Tsai, Lee, Tzeng, Hung, & Yen, 2004). Reliable semantic preview benefit was also demonstrated in some recent studies but it was subject to certain constraints on the characters used. Yan et al. (2009) used neutral context and visually simple and frequent non-compound characters as previews. Whether their results can be generalized to Chinese language with compound character at large is not clear. In two experiments, Yang et al. (2011, p.17) examined whether parafoveal semantic information could affect preview benefit during Chinese reading with a more representative set of compound character stimuli. Their results indicated reliable semantic preview effects with contextually plausible preview words, as single fixation duration on the target word was shorter in the related and plausible condition than the unrelated and plausible condition (Experiment 2), but there was no significant evidence for semantic preprocessing when the previews were not plausible from prior sentence context (Experiment 1). Yang et al. (2011) suggested that “a semantic preview benefit was only apparent when the preview words were plausible”. Thus, whether semantic preview benefit “purely” from bottom-up processing without top-down contextual support can be observed for a representative set of preview words remains an open question.

Activation of Foveal and Parafoveal Sub-lexical Information

Underwood, Petley and Clews (1990) found that transparent compounds were read faster than opaque words. Similarly, Juhasz (2007) found a semantic transparency effect in English compound words independent of lexeme frequency in

gaze duration measure. When spaces were inserted between the two components of English compound words, Frisson, Niswander-Klement and Pollatsek (2008) found that the gaze duration for opaque compounds was significantly longer than that for the corresponding transparent controls (Experiment 2), although this transparency effect was absent with normally presented words (Experiment 1). However, Pollatsek and Hyönä (2005) failed to find transparency effects in Finnish compound word processing. In Chinese, Shu and Anderson (1997) instructed primary school students to complete a two-character word by choosing one among four candidate characters with the same phonetic radicals but with different semantic radicals and found that children performed better when the target characters were radically transparent. It has also been reported for adults that characters with transparent radicals were processed more efficiently than those with opaque radicals in semantic categorization and lexical decision tasks (Chen & Weekes, 2004; Hsiao, Shillock, & Lavidor, 2006). Using the primed lexical decision task, Feldman and Siok (1999) demonstrated the contribution of radical transparency in Chinese character recognition. Targets immediately following both transparent and opaque semantically related primes were equivalently facilitated (Experiment 1), but when 10 items separated primes and targets, facilitation was only evident after transparent primes (Experiment 2). These results indicated that sub-lexical semantic information was activated in the course of Chinese character recognition.

Underwood, Clews, and Everatt (1990) hypothesized eye movement guidance due to parafoveal semantic processing, as they observed that readers' saccades took

their eyes further into the word if informative information was located in the second half, as compared to those words with informative information located in the first half of the word. Apparently, the eye guidance system had knowledge of the information density of the to-be-fixated-word prior to their fixation (see also Hyönä, Niemi, & Underwood, 1989). Although this parafoveal semantic processing hypothesis was challenged in later studies (Rayner et al., 1986) and Underwood et al.'s (1990) critical finding was not replicated (e.g., Rayner & Morris, 1992), Hyönä (1995) reported that irregular letter combinations at a word's beginning attracted a fixation closer toward the word beginning, indicating possible parafoveal partial word (sub-lexical) information extraction. On the other hand, Hyönä and Pollatsek (1998) found no effect of constituent length on initial landing position of 2-constituent compounds. It is perhaps worth noting that the parafoveal sub-lexical information in Hyönä (1995) mainly referred to orthography, and whether readers could make use of parafoveal sub-lexical semantic information to facilitate the later processing of the target word is not known yet.

The Present Experiment

The present experiment combined the design ideas reviewed above. Aside from identical and unrelated previews, the critical conditions were two semantically related conditions using characters that were either semantically transparent or opaque from their radicals. First of all, if semantic preview benefit can be generalized from non-compound character as reported in Yan et al. (2009) to Chinese language with compound characters at large, semantic preview benefits should be observed for both

semantically related previews in the present experiment. More importantly, if readers of Chinese are able to extract parafoveal sub-lexical semantic information from the previews, character with a transparent radical that provides information semantically related to the preview character and the whole target word should lead to stronger semantic preview benefits as compared to the preview character with an opaque radical.

METHOD

Subjects

Fifty¹ graduate and undergraduate students from the Beijing Normal University with normal or corrected-to-normal vision, who were native speakers of Chinese, effectively participated in the eye-tracking experiment. Also, four independent groups of 15, 16, 36 and 37 students participated in norming studies.

Material

Seventy two-character target words with their first characters as target characters were selected for the preview-type manipulation at word N+1 position. For each target character, four types of preview characters were chosen. Together with identical and unrelated previews serving as two baseline conditions, we also had two semantically related preview conditions: characters that were either semantically transparent or opaque from their semantic radicals. As in Yan et al. (2009), word-level preview was valid only for the identical condition, whereas the preview characters of the three non-identical conditions did not form words with the characters that followed them. As shown in Table 1, there were no differences between the four preview types with

respect to visual complexity as indexed by number of strokes and frequency (F -values <1). To avoid possible orthographic and phonological effects, the three non-identical previews did not share any radicals or syllables with the target.

Two sentence frames were constructed out of each target word. Sentences were 20 to 25 characters in length ($M=23.3$, $SD=1.6$). The target characters were never among the first three or the last three words. The invisible boundary that triggered the display change was located just to the left of the space before word $N+1$. Words before the boundary (word N) were always two-character words. Each sentence was only presented once to a subject with the four conditions counterbalanced over subjects. An example of sentences is shown in Figure 1.

-- FIGURE 1--

Norming Studies

We collected three types ratings with five-point scales. We had subjects judge radical transparency and semantic relatedness between the target characters and each type of the preview characters. In addition, the transparency of the semantic radical was rated with respect to the meaning of the entire two-character target word. This third rating is a further assurance of the contribution of the semantic radical to the whole target word. Cloze predictability of previews from prior sentence context was also collected.

There was a reliable radical transparency effect: a stronger association between the meanings of characters with transparent-radicals and the meanings of their semantic radicals ($M=3.8$, $SD=0.5$) was observed, as compared to the characters with opaque-radicals [$M=2.1$, $SD=0.4$; $F(1,139)=437.6$, $p<.001$]. Similarly, the

transparency of the semantic radicals with respect to the meaning of the entire two-character target word was also higher for characters with transparent-radicals ($M=3.2$, $SD=0.9$) than for those with opaque-radicals [$M=2.3$, $SD=0.5$; $F(1,69)=62.7$, $p<.001$].

The three non-identical preview conditions differed in their semantic relatedness to the target character [$F(2,138)=725.5$, $p<.001$], further paired t-tests indicated that characters with transparent- ($M=4.1$, $SD=0.5$) and opaque-radicals ($M=3.9$, $SD=0.5$) did not differ significantly in semantic relatedness to the target ($p=.12$) and were both more strongly related to the target than the unrelated control condition ($M=1.5$, $SD=0.3$; $ps<.001$). As shown in Table 1, the ratings reflected the validity of the intended design.

The sentence contexts were designed to be equally non-predictive for all previews. In the cloze test, we presented all words prior to the targets and participants completed the sentences. As expected, the target words were of low predictability (3.2%, 0.4%, 0.2% and 0.0% for identical, transparent, opaque and unrelated previews, respectively).

-- TABLE 1--

Apparatus

Eye movements were recorded with an EyeLink II system (500 Hz). Single sentences were presented on the vertical position one third from the top of the screen of a 19-in. ViewSonic G90f monitor (resolution, 1024 by 768 pixels; frame rate, 100 Hz). Therefore, it took at most 16ms to complete the display change. The font Song 40 was used with one character equal to 1.4 degrees of visual angle. The experiment

was controlled by a P4 computer, running at 2.8 GHz under Windows XP environment. Subjects read with the head positioned on a chin rest 60 cm from the monitor. All recordings and calibrations were binocular.

Procedure

Subjects were calibrated with a nine-point grid for both eyes. They were instructed to read the sentences for comprehension, then fixate a dot in the lower right corner of the monitor, and finally press a button to signal completion of the trial. As shown in Figure 1, before readers' eyes cross the invisible boundary located between word N and word N+1, they get any one of the four previews at the position of word N+1. The preview word is replaced by the target word immediately after the eyes cross this boundary. On 42 trials the sentence was followed by an easy yes-no question. Subjects correctly answered 93% of all questions ($SD=6\%$). 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 both eyes within a pre-defined window around the initial fixation point. All subjects read 140 sentences.

Data Analysis

Fixations were determined with an algorithm for binocular saccade detection (Engbert & Kliegl, 2003). Sentences containing a blink or loss of measurement were deleted (i.e., 0.4%). Analyses were based on right-eye fixations. We distinguish between first-fixation durations (FFDs; the first fixation on a word, irrespective of the number of fixations), single-fixation durations (SFDs; cases in which a word was inspected with exactly one fixation), and gaze durations (GDs; the sum of fixations

during the first reading of the word).

Inferential statistics are based on planned comparisons for the two semantically related previews and the identical previews, with the unrelated preview as reference. Estimates are based on a linear mixed model (LMM) for durations and a generalized linear mixed model (GLMM) for skipping with crossed random effects for subjects and items using the *lmer* program of the *lme4* package (Bates & Maechler, 2010) in the R environment for statistical computing and graphics (R-Core Development Team, 2010). Analyses for untransformed and log-transformed durations yielded the same pattern of significance. The significance of a given factor reported in the LMM was assessed with a likelihood ratio test between the full model and a nested model leaving out this factor; we report *p*-values for these tests.

RESULTS

Skipping and Regression Rate

The identical condition had significantly higher skipping rate ($M=8.7%$, $b=.445$, $SE=.109$, $z=4.1$, $p<.001$) and lower regression rate ($M=2.3%$, $b=.446$, $SE=.192$, $z=2.3$, $p=.020$) than the average of the three non-identical conditions (skipping rates: 5.7%, 6.0%, and 6.0%; regression rates: 3.2%, 3.8% and 3.2 %, for the unrelated, transparent, and opaque previews, respectively).

Semantic Preview Benefits

FFDs and SFDs as well as GDs with FFDs shorter than 60 ms or longer than 600 ms were excluded (i.e., 1.5%). Further, trials with regressions from word N or N+1 were excluded (i.e., 12.8%). Finally, we excluded the trials in which the saccade

crossed the boundary during the final 20% of the saccade duration because readers should be more likely to perceive a display change or a flash at this time (i.e., 14.9%). After the three levels of data screening, totally 4719, 3564 and 4719 observations on the target word contributed to the following FFD, SFD and GD analyses, respectively.

-- TABLE 2--

Characters with transparent radicals. Relative to unrelated previews, there were significant semantic preview benefits of 14 ms for FFDs, 16 ms for SFDs and 25 ms for GDs ($b=-.042$, $SE=.011$, $t=-3.9$, $\chi^2(1)=14.937$, $p<.001$; $b=-.049$, $SE=.013$, $t=-3.9$, $\chi^2(1)=14.833$, $p<.001$ and $b=-.070$, $SE=.015$, $t=-4.7$, $\chi^2(1)=21.795$, $p<.001$, for FFD, SFD and GD analyses, respectively). The preview benefit of compound preview characters in the present study is comparable to that reported in Yan et al. (2009).

Characters with opaque radicals. Fixation durations on target words were also significantly reduced from previewing characters with semantically opaque radicals: there were semantic preview benefits of 12 ms for FFDs, 13 ms for SFDs and 12 ms for GDs ($b=-.036$, $SE=.011$, $t=-3.3$, $\chi^2(1)=11.065$, $p=.001$; $b=-.040$, $SE=.013$, $t=-3.1$, $\chi^2(1)=9.861$, $p=.002$ and $b=-.038$, $SE=.015$, $t=-2.6$, $\chi^2(1)=6.598$, $p=.010$, for FFD, SFD and GD analyses, respectively). The semantic preview benefits in the opaque condition were all numerically smaller than those in the transparent condition.

Sub-lexical semantic extraction. In a planned comparison with the opaque condition as the reference category, fixations were estimated to be 13 ms shorter in the transparent condition for GD analysis ($b=-.032$, $SE=.015$, $t=-2.1$, $\chi^2(1)=4.506$, $p=.034$; Table 2). These differences were not significant for FFDs and SFDs (t -values <1). This important and reliable GD difference between the two semantically related preview

conditions may indicate that, together with parafoveal semantic information extraction from character/lexical level, readers of Chinese can also acquire additional semantic information from radicals of parafoveal characters.

DISCUSSION

So far there is no clear conclusion whether readers of alphabetic languages extract parafoveal semantic information in sentence reading (see Rayner et al., 2003, for a review; but Hohenstein & Kliegl, 2011 for opposite evidence). Presumably due to substantial cross-language difference, such semantic preview benefit has been consistently reported in Chinese reading (Yan et al., 2009; Yang et al., 2011). The main goals of present study were (a) to demonstrate a consolidation and generalizability of previous findings that readers of Chinese access semantic information from parafoveal characters or words, (b) to extend parafoveal semantic extraction from character/lexical to radical/sub-lexical level. To our knowledge, the present study is the first one that reported reliable facilitation of fixation duration due to parafoveal sub-lexical semantic overlap during prior fixations without contextual support.

The Generalizability of Semantic Preview Benefit

Chinese and English scripts differ in that the former is written without spaces between words. The absence of inter-word spaces likely entails differences in saccade-target selection: Chinese readers are assumed to parafoveally segment characters into word units and target word centers (Yan, Kliegl, Richter, Nuthmann & Shu, 2010). As a consequence, Chinese readers may have developed a higher

preprocessing efficiency which will obviously greatly increase the probability of successful parafoveal word segmentation. In the meanwhile, the absence of inter-word spaces brings the upcoming words into much less eccentric positions as compared with alphabetic scripts, which may enable Chinese readers benefit from the higher visual acuity in the near parafovea and further facilitate parafoveal processing.

There is strong evidence for direct access from orthography to semantics in Chinese with phonological mediation bypassed under some circumstances (Chen & Shu, 2001; Zhou & Marslen-Wilson, 2000). Against this background of research, we suspect that the well-known sequential activation “orthography-to-phonology-to-semantics” route to word recognition (Van Orden, 1987) with access to word meaning in a relatively late stage might be more dominant in English than Chinese, a writing system with a close association between graphic form and meaning. Indeed, recent studies of Chinese reading using the boundary paradigm demonstrated reliable semantic preview benefit from word N+1 (Yan et al., 2009; Yang et al., 2011).

In order to avoid activation from sub-lexical level during reading, Yan et al. (2009) selected simple and frequent characters as previews in the word N+1 position. Given that most characters in modern Chinese are compounds, we noted ourselves in Yan et al. (2009, p.564) that the “generalizability (of semantic preview benefit) to Chinese characters at large still remains to be established”. The present study not only consolidated the previous finding of reliable semantic preview benefit but also generalized it to a more representative set of characters of the Chinese script.

In two experiments Yang et al. (2011) reported that semantic preview benefit in SFDs was apparent only if the previews were plausible from contexts. Given that previews were not predicted and contexts were neutral in the present study as in Yan et al (2009), it is probably reasonable to argue that the present study demonstrated a “pure” semantic preview benefit without support from sentence context.

Activation of Parafoveal Sub-lexical Semantic Information and Its Implications for Chinese Character/Word Recognition

There is little evidence for integration of semantic or morpho-semantic information across saccades in English, but Deutsch et al. (2003) found reliable preview benefits from the root morpheme in Hebrew. As Rayner et al. (2003, p221) put it, “future research will have to determine if such effects are apparent in other languages”. In the present study, we addressed this question by testing whether readers of Chinese could make use of parafoveal sub-lexical semantic information to facilitate the later processing of the target word. Many existing models of Chinese character recognition assume an entire lexical route of accomplishment (e.g., Perfetti, Liu, & Tan, 2005). On the other hand, due to the special sub-lexical characteristics in Chinese language, Taft and Zhu (1997) adopted a multilevel interactive-activation model to account for Chinese character/word recognition, which assumes all units in the hierarchy have their own separate level of representation in the lexicon: from the lowest to the highest levels, the units are features and strokes, radicals, characters and finally words. They also suggested that characters/words are recognized via (and thus influenced by) the activation of their constituent radicals. If such a claim can be

transferred from foveal to parafoveal activation, targets in the present study should be pre-activated by both lexical and sub-lexical semantic information of the parafoveally presented preview character with transparent-radicals, but only by lexical level semantic information in the opaque condition. Indeed, semantic preview benefit was 13 ms larger for the transparent than the opaque condition. We explain this result as evidence supporting parafoveal semantic information extraction from radical or sub-lexical level.

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FOOTNOTE

- 1, Two subjects were excluded due to calibration failure.

Table 1

Means (standard deviations) of frequency (per million, Beijing Language Institute Publisher, 1986), number of strokes, transparencies of the semantic radicals with respect to the meaning of the character (radical-character semantic transparency rating, R-C Trans) and entire two-character word (radical-word semantic transparency rating, R-W Trans), rating of semantic relatedness to target of the previews.

	Identical	Transparent	Opaque	Unrelated
Example Char.	费	损	耗	笑
Char. meaning	cost	consume	spend	laugh
Sem. radical		扌	耒	
Rad. meaning		hand	plow	
Frequency	276 (307)	261 (441)	282 (415)	280 (326)
N. of strokes	9.3 (3.0)	9.2 (2.4)	9.2 (2.4)	9.6 (2.3)
R-C Trans.	--	3.8 (0.5)	2.1 (0.4)	--
R-W Trans.	--	3.2 (0.9)	2.3 (0.5)	--
Sem. Rating	--	4.1 (0.5)	3.9 (0.5)	1.5 (0.3)

Table 2

Means (standard errors) of first-fixation duration (FFD), single-fixation duration (SFD), gaze duration (GD) on target words.

	Type of Preview			
	Identical	Transparent	Opaque	Unrelated
FFD	252 (3)	279 (3)	281 (3)	293 (6)
SFD	252 (4)	280 (4)	284 (4)	298 (6)
GD	289 (6)	341 (6)	354 (6)	366 (9)

Figure Caption

Figure 1. A set of example Chinese sentences using the boundary paradigm. The target sentence is translated as: *These hard but unthankful works by the local city government were scolded.* The preview characters (损, 耗 or 笑) occupy the position of the first character of the target word N+1 and are replaced by the target character (费) as soon as the reader's eyes cross the invisible boundary located between words N (这些) and N+1 (费力).

Figure 1

Identical Preview

当地市政部门这些费力不讨好的举措招来了一片骂声。

*

Semantic Preview from Transparent Character

当地市政部门这些损力不讨好的举措招来了一片骂声。

*

Semantic Preview from Opaque Character

当地市政部门这些耗力不讨好的举措招来了一片骂声。

*

Unrelated Preview

当地市政部门这些笑力不讨好的举措招来了一片骂声。

*

Target

当地市政部门这些费力不讨好的举措招来了一片骂声。

N ↑ N+1 ↑

*