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Use of phonological codes for Chinese characters: Evidence from processing of parafoveal preview when reading sentences☆

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Abstract

The role of phonological coding for character identification was examined with the benefit of processing parafoveal characters in eye fixations while reading Chinese sentences. In Experiment 1, the orthogonal manipulation of phonological and orthographic similarity can separate two types of phonological benefits for homophonic previews, according to whether these previews share the same phonetic radical with the targets or not. The significant phonological benefits indicate that phonological coding is activated early when the character is in the parafovea. Experiment 2 manipulated the character's consistency value and found that the phonological preview benefits are reliable only when the targets are high consistency characters. The results of two experiments suggest that phonological computation is rapid and early at both character and radical levels for Chinese character identification.

Keywords: Phonological coding; Chinese character; Eye movements; Parafoveal preview; Phonetic radicals

1. Introduction

When reading a sentence, the eyes execute a series of movements to fixate on different locations of text to recognize words and understand the passage. Much of the evidence suggests that processing of a word initiates early when the word is in the parafovea of the prior fixation. A central question is to know what information about words can be extracted in parafovea and integrated across saccades. Previous studies addressed this kind of question with a boundary paradigm (Rayner, 1975), which employs the eye-movement-contingent display during the silent reading of text. In this paradigm, a target location is identified in a sentence, and an invisible boundary is set just left of the target location. When the reader starts to read the sentence, the preview word is presented at the target location, but it is replaced with the target as soon as the reader's saccade crosses the boundary. If the preview word shares some properties with the target, the viewing durations on the target word are shortened. This facilitation in viewing time is termed "*preview benefit*." The present study aimed to explore the preview benefits of Chinese character and to address the use of phonological codes in the early stage of character identification.

The phonological preview benefit has been demonstrated in English (Pollatsek, Lesch, Morris, & Rayner, 1992). The preview word was identical, visually similar, homophonic, or visually and phonologically dissimilar to the target. Measurement is made of the first fixation duration, the viewing time of the initial fixation on the target word, and the gaze duration, the summed viewing time of fixations until the eyes leave the target

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word. The results showed the phonological benefit from homophonic previews compared to non-homophonic previews that were visually similar to the target. In addition, the preview benefit was a function of the visual and phonological similarities. Pollatsek et al. (1992) suggested that the visual and phonological codes can cooperate during the identification of a word. This view is compatible with automatic activation models, which assume that the phonological code of a word is activated automatically and obligatory (Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). However, it is contrary to the classical view of dual-route models, which assumes that the reader can access a word's meaning by identifying a whole word visually either with or without associating with its phonology (Coltheart, 1978; Paap & Noel, 1991).

In contrast to the alphabetic scripts, Chinese is characterized as an logographic writing system with deep orthography. Chinese characters map onto syllables rather than phonemes. The homophonic characters can be visually dissimilar and the orthographically similar characters can have different pronunciations. Since the correspondence of script to speech is less explicit than English, some researchers have suggested that the use of phonological codes is negligible for identifying a character or accessing its meaning (Baron & Strawson, 1976; Hoosain, 1991). However, this proposal has been challenged in many studies (see Feng, Miller, Shu, & Zhang, 2001; for a review). These studies showed that phonological processing takes place not only during reading Chinese sentences for comprehension (Tzeng, Hung, & Wang, 1977; Zhang & Perfetti, 1993) but also during identifying Chinese character in a lexical decision task (Cheng, 1992; Cheng & Shih, 1988; Perfetti & Tan, 1999) or a character naming task (Perfetti & Tan, 1998; Shen & Forster, 1999; Tan, Hoosain, & Peng, 1995; Tan & Perfetti, 1997).

Using the eye-movement-contingent display technique, recent researches have shown the use of phonological information from parafoveal Chinese character (Liu, Inhoff, Ye, & Wu, 2002; Pollatsek, Tan, & Rayner, 2000). In a character naming task, similar to the boundary paradigm, readers were asked to move their eyes to a target location in the parafovea and then name the target character (Pollatsek et al., 2000). Compared with unrelated preview, they found that target naming latencies were shorter for the homophonic previews, no matter whether they were visually similar or dissimilar to the targets. The orthographic preview benefit was also robust when the non-homophonic previews shared the same phonetic radical with the target. Liu et al. (2002) reported a similar phonological preview benefit in a silent sentence reading task, where the gaze durations were shorter than the dissimilar control when the homophonic previews were visually dissimilar to the targets. They also found that the orthographic benefit was significant only when the orthographic similarity included sharing the same phonetic radicals, rather than semantic radicals or stroke overlap. Liu et al. (2002) concluded that the orthography of phonetic radicals has a privileged role in the early stage of character identification.

The phonological preview benefit has been shown for the visually dissimilar homophones compared with unrelated control. However, there was no clear evidence for the phonological benefit of the visually similar homophones compared with the visually similar non-homophones. Using English text, Pollatsek et al. (1992) reported that the phonological benefit was unreliable when homophonic previews were at high level of visual similarity to targets. This finding reflects the characteristic of English words that phonological similarity usually confounds with orthographic similarity. That is, the visually similar non-homophones which are the matched controls of homophonic previews also activate a set of phonological neighbors of the target, in addition to the activation of visually similar neighbors. Some of these phonological neighbors can be homophones of the target. Therefore, both homophonic previews and their visually matched controls activate the homophonic neighbors of the target. The phonological benefit will be small or unreliable when comparing these two conditions. For the case of Chinese, Pollatsek et al. (2000) showed no phonological benefit in the naming latencies and error rates when the previews were visually similar homophones compared to the matched non-homophones. In this study, the visual or orthographic similarity was defined according to whether characters shared the phonetic radicals or not. It has been demonstrated that the orthographic information of phonetic radicals can be peculiarly extracted from parafoveal character (Liu et al., 2002). However, the phonetic radicals convey some useful phonological information in addition to the orthographic information. The null homophonic effect from visually similar previews could be the result of the character-level phonology confounded with the radical-level phonology. Pollatsek et al. (2000) noted that whether the sound of a character is identical with that of its phonetic radical, the so-called character regularity, might confound the phonological preview benefit. When the target is an irregular character and the sound of its phonetic radical is activated, the competition between radical and character pronunciation could obscure the phonological preview benefit. They manipulated the regularity and showed the naming latency was longer for irregular targets than for regular targets. It indicates the activation of phonetic radicals' phonology in identifying foveal character. None the less, the interaction between the regularity and the phonological preview benefit was not found. The null interaction effect suggests two conclusions. First, the phonetic radical's sound is unable to be accessed in the parafovea. Second, the regularity fails to account for the lack of phonological preview benefit when the previews shared the phonetic radicals.

In fact, there are concerns for effectiveness of regularity in describing the mapping between orthography and phonology for Chinese characters. Analysis of Chinese corpora indicates that less than 30% of Chinese phonograms have pronunciation identical to their phonetic radicals; this may prevent readers from using the phonetic radical as a cue in retrieving a character's phonology (Tan & Perfetti, 1998). Moreover, not all the phonetic radicals are legitimate characters. It is noteworthy that the notion of regularity effects can only be applied to phonograms whose phonetic radicals are legitimate characters. On the other hand, the validity of phonetic radical in representing the whole character's phonology can be described by the statistical concept of consistency. A character is consistent if all its orthographic neighbors, which share the same phonetic radical, have the same pronunciation; otherwise, it was inconsistent. The degree of consistency can be expressed by the relative ratio of homophonic characters within a given set of characters sharing the phonetic radical. It has been demonstrated that the high consistent characters were named faster than low consistent characters, no matter whether the characters can be described by regularity or not (Lee, 2000).

In present study, similar to Liu et al. (2002) experiments, the preview benefits of characters were examined in a boundary paradigm during the reading of sentences. In Experiment 1, the phonological and orthographic similarities between preview and target characters were manipulated orthogonally according to whether they were homophones and whether they shared the same phonetic radical. The manipulation of preview type allows us to separate two types of phonological preview benefits by orthographic similarity. Consistent with the previous studies, the phonological benefit is expected in the orthographic dissimilar previews. For the phonological benefit in orthographically similar previews, the benefit is expected if phonological coding is as important as orthographic coding for the process of character identification. This effect can also suggest a role of phonological coding at the sublexical level since the orthographic similarity was manipulated by sharing the same phonetic radical.

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

Twenty undergraduate students with normal or corrected vision participated for credits of psychology courses. They are all native Chinese speakers.

2.1.2. Material and design

Ninety-six target characters were selected for the experiment. The average character frequency of occurrence for the target was 75 per million characters, as estimated from the Academia Sinica balanced corpus (1998). For each target character, four preview characters were possible: (a) homophonic and orthographically similar character (sharing the same phonetic radical); (b) homophonic and orthographically dissimilar character; (c) non-homophonic and orthographically similar character (sharing the same phonetic radical); and (d) non-homophonic and orthographically dissimilar character. The character frequency and number of strokes were not significantly different among the four types of previews. These properties and the example of a target and the matched previews are shown in Table 1. Each target character was embedded in a two-character word. All the target characters were the first character of the words except two targets. The average word frequency was 3 per million words. The use of low frequency words was to minimize the likelihood that readers would skip the word containing the target character. Sentences were written in the length of 24 or 25 characters and the target character was at the 11th to 16th character position. Participants read 96 sentences with only one of the conditions presented for each target. The four types of preview were counterbalanced over participants.

2.1.3. Apparatus

The eye movements were recorded by an EYELINK I eye-tracking system manufactured by SR Research, sampling eye position at 250 samples/s. The sentences were displayed on a ViewSonic PT795 monitor. In the experiment program, a set of VGA routines from a PCTSCOPE library (Tsai, 2001) was used. These routines increased the vertical refresh rate of the display to 167 Hz in the resolution of 800×600 and preloaded all

Table 1
Experiment 1: Examples of characters, mean frequency, and number of strokes of targets and previews

	Target	Preview type			
		Orthographically similar homophone	Orthographically dissimilar homophone	Orthographically similar non-homophone	Orthographically dissimilar non-homophone
Character	罐 /guan4/	灌 /guan4/	貫 /guan4/	權 /quan2/	翁 /weng1/
Mean frequency	75	128	164	112	104
Mean No. strokes	12.3	12.5	11.7	12.0	11.7

images into VGA memory before each trial. The timing error of changing displays in the program was less than 6 ms. Eye-movement-contingent display was accomplished by combining the PCTSCOPE library for fast display change and the EYELINK software for detecting eye positions on line. The duration from acquiring the current eye position to displaying an image was less than 12 ms. The size of a character presented on the screen was 24×24 pixels, and there was a space of 8 pixels between characters. The viewing distance was 70 cm and the width of a character and the space before it subtended 0.9° of visual angle.

2.1.4. Procedure

Prior to the experiment, a nine-point calibration procedure was used for each participant. This procedure is to determine the correspondence between pupil position and gaze position. After the initial calibration, ten practice trails were presented and followed by 96 experimental sentences. A validation procedure was performed every three trials to check the accuracy in predicting gaze position from pupil position. The calibration procedure was performed again if the eye position had drifted in the validation procedure. At the beginning of each trail, a small circle was shown at the left-most position of the sentence on the center of the monitor. The subject was asked to fixate on the circle first. Once the eyes had fixated on that location, the circle disappeared and the sentence was shown. An invisible boundary located just to the left of the space before the target location was established for each sentence. One of the preview characters occupied the target location until the eyes moved across the boundary. When this occurred, the preview was immediately replaced with the target character. Subjects pressed a button when they understood the meaning of the sentence. A comprehension question followed one-third of the sentences. The experiment took about 45 min to be completed.

2.1.5. Data selection

We computed three first-pass measures, first fixation duration, gaze duration, and skipping rate within a target area. The target area was defined as the region occupied by the two-character words which include the target characters. There were three main criteria for trials excluded in the analysis. First, trials were excluded if the eyes blinked or drifted just before moving into the target area. In this case, it would increase the possibility that display change occurred in a fixation rather than in a saccade. Participants would notice the display change and the fixation durations in the target area could be contaminated. Second, trials were excluded if the first fixation duration was less than 100 ms or more than 800 ms. Third, trials were excluded if the prior fixation location was more than two characters away from the target area. This is to assure that participants could actually perceive the preview character for those selected trials, for it has been shown that the perceptual span of reading Chinese, the number of characters that readers could obtain from a fixation, is three characters to the right and one to the left of a fixation (Inhoff & Liu, 1998). The data remaining in the analysis was 73% of the trials on average. There was no significant difference for the number of valid trials among the four preview conditions.

2.2. Results

The means and standard errors of first fixation duration, gaze duration, and skipping rate for each preview condition are shown in Table 2. ANOVAs with the two factors of phonological similarity (homophone vs non-homophone) and orthographic similarity (sharing vs non-sharing phonetic radical) were performed on the three dependent variables. The skipping rate for target area was approximately 7% of the trials, neither the main effects nor interaction approached significance (Fs < 1.78, ps $> .18$). In contrast to the skipping rate, both duration measures revealed the significant main effect of orthographic similarity: the benefit of 11 ms in first fixation duration ($F1(1, 19) = 6.37$, $p < .05$; $F2(1, 95) = 9.65$, $p < .01$) and of 18 ms in gaze duration ($F1(1, 19) = 4.53$, $p < .05$; $F2(1, 95) = 10.39$, $p < .01$). For the main effect of phonological similarity, the benefit of 11 ms in first fixation duration was significant by

Table 2
Experiment 1: Mean viewing durations and skipping rate (in milliseconds; with standard error) as a function of preview type

	Preview type	Orthographically similar	Orthographically dissimilar	Mean
First fixation duration	Homophone	253.84 (9.17)	268.66 (8.94)	261.25
	Non-homophone	268.51 (7.89)	276.17 (8.77)	272.34
	Mean	261.17	272.42	
Gaze duration	Homophone	318.78 (13.08)	330.45 (13.13)	324.62
	Non-homophone	328.72 (13.35)	352.69 (16.59)	340.71
	Mean	323.75	341.57	
Skipping rate (%)	Homophone	7.08 (1.42)	5.63 (1.10)	6.35
	Non-homophone	6.04 (1.19)	7.71 (1.55)	6.88
	Mean	6.56	6.67	

participants and was marginally significant by items ($F1(1,19) = 5.40$, $p < .05$; $F2(1,95) = 3.53$, $p < .06$); of 16 ms in gaze duration was significant by participants but not significant by items ($F1(1,19) = 5.12$, $p < .05$; $F2(1,95) = 2.79$, $p < .12$). The interaction of orthographic and phonological similarity in both duration measures did not approach significance (Fs < 1).

Although the interaction was not statistically significant, planned pair comparisons were performed to examine the reliability of the preview benefits under different conditions. Because of the orthogonal manipulation of phonological and orthographic similarity, different baselines can be used to evaluate the contribution of phonological benefit with or without visually similar previews and the contribution of orthographical benefit with or without homophonic previews. For example, the phonological benefit from visually similar previews was obtained from the comparison of the homophonic and non-homophonic previews which shared the same phonetic radical with the target. The phonological benefit from visually dissimilar preview was obtained from the comparison of the homophonic and non-homophonic previews which did not share the same phonetic radical with the target. The orthographic benefits were also examined separately for homophone and non-homophone previews.

2.2.1. Phonological preview benefits

When the previews were orthographically similar to the target, the data revealed a significant phonological benefit of 15 ms in first fixation duration ($t1(19) = 1.83$, $p < .05$; $t2(95) = 1.87$, $p < .05$); a benefit of 10 ms in gazed duration was not significant ($t1(19) = 0.75$, $p > .10$; $t2(95) = 0.76$, $p > .10$). When the previews were orthographically dissimilar to the target, the phonological benefit of 8 ms in the first fixation duration was failed to approach significance ($t1(19) = 1.49$, $p > .05$; $t2(95) = 0.89$, $p > .10$); a benefit of 22 ms in gaze duration was significant ($t1(19) = 2.03$, $p < .05$; $t2(95) = 1.66$, $p < .05$).

2.2.2. Orthographic preview benefits

The orthographic effect for homophonic previews revealed a robust benefit of 15 ms in first fixation duration ($t1(19) = 2.49$, $p = .01$; $t2(95) = 2.42$, $p < .01$); the benefit of 12 ms in gazed duration approached significance only in the item analysis ($t1(19) = 0.94$, $p > .10$; $t2(95) = 2.02$, $p < .05$). For non-homophonic previews, the orthographic benefit of 8 ms in first fixation duration was unreliable ($t1(19) = 1.10$, $p > .10$; $t2(95) = 1.86$, $p < .05$); the benefit of 24 ms in gazed duration was significant ($t1(19) = 1.79$, $p < .05$; $t2(95) = 2.61$, $p < .01$).

2.3. Discussion

In summary, analyses of fixation durations within the target area revealed both phonological and orthographic preview benefits. The planned tests of individual preview benefits showed that the phonological benefit from visually similar previews was reliable in first fixation duration; the benefit from visually dissimilar previews was reliable in gaze duration. The orthographic benefits showed a similar pattern as the phonological benefits.

The present data showed both orthographic and phonological benefits from the preview characters. The results indicate that both orthographic and phonological codes of a Chinese character are extracted in the parafovea and facilitate the processing of that character when it is later fixated. This is consistent with the previous finding of English words (Balota, Pollatsek, & Rayner, 1985; Pollatsek et al., 1992) and Chinese characters (Liu et al., 2002; Pollatsek et al., 2000). The phonological benefit from visually dissimilar previews supports the involvement of phonological computation at the character level. Moreover, for first fixation duration, the previews of visually similar homophones showed a 15 ms phonological benefit over visually similar non-homophones. These previews also showed a 15 ms orthographic benefit over visually dissimilar homophones. The findings support that the activation of both phonological and orthographic codes can contribute to character processing jointly.

Furthermore, the phonological benefit from orthographically similar previews was more reliable in first fixation duration and the phonological benefit from orthographically dissimilar previews was more reliable in gaze duration. Whether or not the discrepancies of effects revealed in different measures can indicate the influence of different linguistic properties is controversial (Inhoff & Radach, 1998; Rayner, 1998). However, it has been suggested that an early or fast cognitive process can affect the first fixation duration and a late or slow process can affect the gaze duration (Inhoff, 1984; Pollatsek, Rayner, & Balota, 1986; Rayner & Pollatsek, 1987). In our results, the two phonological benefits appeared in different measures can help to disentangle the phonological coding at different levels. The phonological benefit from orthographically dissimilar previews in gaze duration clearly is at the character level. The phonological benefit from orthographically similar previews in first fixation duration could be at the sublexical level.

Phonetic radical can provide pronunciation clue for phonograms. That means, the preview characters which share the same phonetic radical with target not only could provide the orthographic information, but also the phonological clues at sublexical level. It would be interesting to know, whether the phonological benefit can be affected by the validity of phonetic radical in representing the whole character's phonology or not. There are two ways which can be used to express the validity of phonetic radical, one is regularity, and the other is consistency. The post hoc examination of the materials in Experiment 1 showed that 68% of targets were irregular characters. If the phonetic radicals' phonology is aroused in the preview, the conflict between the sounds of phonetic radical and character in the target will dilute the phonological preview benefit. However, the significant phonological benefit found in Experiment 1 suggests that it is not the case. On the other hand, 74% of targets in this experiment were high consistency characters. The advantage of dominant pronunciation for homophonic preview might be responsible for the phonological benefit. To clarify whether the extent of character consistency affects the phonological preview benefit, Experiment 2 directly manipulated the consistency of target characters.

3. Experiment 2

The goal of Experiment 2 was to determine whether the phonological preview benefit can be affected by the consistency value of target characters. The consistency value of a character is defined as the ratio of phonograms with the same pronunciation within a set of phonograms sharing the same phonetic radical. For example, five characters have the same phonetic radical. Three of them are pronounced as "A" and the rest of them are pronounced as "B." The consistency value will be .6 (3/5) for "A" group and .4 (2/5) for "B" group. Two sets of target characters were introduced in Experiment 2: one set of targets with high consistency value and the other set of targets with low consistency value. For each set of targets, there are three possible previews: (a) a homophonic preview sharing the phonetic radical with targets, (b) a non-homophonic preview sharing the phonetic radical with targets, (c) an unrelated preview that is both phonologically and orthographically dissimilar with targets. Two types of preview benefit are computed to reveal the phonological processing of the homophonic previews which also share the same radical with the targets. One is the comparison of (a) and (b) to obtain the phonological benefit when the previews share the phonetic radicals. The other is the comparison of (a) and (c) to obtain the phonological benefit combined with the orthographic benefit. If the sublexical phonology can be extracted from parafoveal characters, the phonological preview benefit shall be obtained in high consistency condition but not in low consistency condition.

3.1. Materials and methods

3.1.1. Participants

Thirty-six undergraduate and graduate students with normal or corrected vision were paid for their participation. They are all native Chinese speakers and have not been in Experiment 1.

3.1.2. Material and design

Two sets of 72 phonograms were used as targets. One set were high consistency characters and the other set were low consistency characters. In each set, characters were selected according to whether the consistency value was higher than .5 or not. For the high and low consistency sets, the average consistency values were .68 and .30, respectively. The proportions of regular characters for each set were 44 and 26%; both were less than 50%. For each target character, three types of preview character were possible: a homophonic preview with the same phonetic radical as the target, a non-homophonic preview with the same phonetic radical as the target, and an unrelated preview which is non-homophonic and visually dissimilar to the target. The mean frequency and stroke numbers of targets and previews were matched. Table 3 illustrates the examples of the material and the major characteristics that were controlled or matched across conditions. Each target character was embedded in a two-character word. All the target

Table 3
Experiment 2: Examples of characters, mean frequency, and number of strokes of targets and previews

	Target	Preview type		
		Homophone sharing phonetic radical (O+)	Non-homophone sharing phonetic radical (O+)	Non-homophone non-sharing phonetic radical (O−)
High consistency target (CI = .68)				
Character	浴 /yu4/	裕 /yu4/	俗 /su2/	流 /liu2/
Mean frequency	15	74	109	33
Mean No. strokes	14.5	13.6	13.4	14.0
Low consistency target (CI = .30)				
Character	拘 /ju/	駒 /ju/	鉤 /gou/	莽 /mang3/
Mean frequency	14	66	83	73
Mean No. strokes	12.4	12.5	12.1	11.7

CI, consistency index; O+, orthographic similar; O−, orthographic dissimilar.

characters were the first character of the words. The average word frequency was 2 per million words. Sentences were written in the length of 24 or 25 characters and the target character was at the 11th to 16th character position. Participants read 144 sentences with only one of the preview conditions presented for each target. The three types of preview were counterbalanced over participants.

3.1.3. Apparatus, procedure, and data selection

The apparatus, procedure, and criteria for data selection were the same as Experiment 1. The data remaining in the analysis after the cut-off was 76% of the trials on average.

3.2. Results

The means and standard errors of first fixation duration, gaze duration, and skipping rate for each condition are shown in Table 4. The 2×3 ANOVAs with the factors of target consistency and preview type were carried out. The skipping rate of the target area was approximately 10% of the trials, neither the main effects nor the interaction approached significance ($F1\text{s} < 1.78$, $ps > .20$; $F2\text{s} < 2.52$, $ps > .12$). Both duration measures revealed significant main effects of preview type: in first fixation duration, $F1(2,70) = 3.58$, $p < .05$ and $F2(2, 284) = 10.15$, $p < .01$; in gaze duration, $F1(2,70) = 10.42$, $p < .01$ and $F2(2,284) = 12.45$, $p < .01$. The interaction of target consistency and preview type in first fixation duration was marginally significant by participants ($F1(2,70) = 2.42$, $p < .09$; $F2 < 1$). None of other main effects or interaction approached significance.

For each type of targets, planned comparisons were performed to test the reliability of the benefits from the homophonic preview when they were compared to the non-homophonic previews and the unrelated previews, respectively. An inspection of the first fixation duration in Table 4 suggested that the preview benefit was different for high consistency and low consistency targets. The benefit of homophonic previews over non-homophonic previews was significant for high consistency targets ($t1(35) = 1.77$, $p < .05$; $t2(142) = 1.57$, $p < .06$), but not for low consistency targets ($t1(35) = .74$, $p > .23$; $t2(142) = 1.04$, $p > .14$). The benefit of homophonic previews over unrelated previews was significant for high consistency targets ($t1(35) = 2.95$, $p < .01$; $t2(142) = 4.41$, $p < .01$), but not for low consistency targets ($t1(35) = 1.02$, $p > .15$; $t2(142) = 3.31$, $p < .01$). For gaze duration, both high and low consistency targets showed the similar pattern of the preview benefits. The benefit of homophonic previews over non-homophonic previews was not significant for both high and low consistency targets ($ts < 1.33$, $p > .09$). The benefit of homophonic previews over unrelated previews was significant for both high consistency targets ($t1(35) = 3.50$, $p < .01$; $t2(142) = 3.78$, $p < .01$) and low consistency targets ($t1(35) = 2.70$, $p < .01$; $t2(142) = 3.42$, $p < .01$).

To summarized, in first fixation duration, both types of preview benefit were robust for high consistency targets but not for low consistency targets. In gaze duration, only the preview benefit of homophonic previews compared with unrelated previews was robust regardless of targets' consistency. The benefits of homophonic preview compared with non-homophonic previews under different conditions for both experiments are presented in Table 5.

The data replicated the results of Experiment 1 and further indicated that processing of phonetic radicals can affect the phonological preview benefit. If only the phonetic radicals' orthography can be accessed in the parafovea, the phonological preview benefits should not be affected by the manipulation of target consistency. The evidence of phonological preview benefit for high consistency targets rather than low consistency targets indicates that, the character consistency play a role in

Table 4
Experiment 2: Mean viewing durations and skipping rate (in milliseconds; with standard error) as a function of preview type and target consistency

	Target type	Preview type			
		Homophone sharing phonetic radical (O+)	Non-homophone sharing phonetic radical (O+)	Non-homophone non-sharing phonetic radical (O−)	Mean
First fixation duration	HC	248.71 (6.55)	260.59 (8.92)	268.47 (9.04)	259.26
	LC	255.68 (6.80)	251.21 (7.75)	261.81 (8.43)	256.23
	Mean	252.19	255.90	265.14	
Gaze duration	HC	299.26 (13.90)	311.88 (13.22)	332.52 (15.89)	314.55
	LC	303.42 (13.17)	293.92 (13.88)	329.11 (16.07)	308.82
	Mean	301.34	302.90	330.81	
Skipping rate (%)	HC	10.42 (1.98)	9.95 (1.61)	8.10 (1.86)	9.49
	LC	9.84 (1.64)	10.76 (1.56)	11.11 (1.68)	10.57
	Mean	10.13	10.36	9.61	

HC, high consistency; LC, low consistency; O+, orthographic similar; O−, orthographic dissimilar.

Table 5
The preview benefits of homophonic preview contrasted to different types of non-homophonic previews in Experiment 1 and Experiment 2

	Target type	Preview benefit		
		Homophone (PR+) vs Non-homophone (PR+)	Homophone (PR−) vs Non-homophone (PR−)	Homophone (PR+) vs Non-homophone (PR−)
Experiment 1				
First fixation duration	—	14.66	7.51	22.33
Gaze duration	—	9.95	22.24	33.92
Experiment 2				
First fixation duration	HC	11.88	—	19.76
	LC	−4.46	—	6.14
Gaze duration	HC	12.62	—	33.26
	LC	−9.50	—	25.69

HC, high consistency; LC, low consistency; PR+, sharing the phonetic radical; PR, non-sharing the phonetic radical.

the phonological computation of characters and it is an early process of the character identification.

4. General discussion

In present study, the phonological preview benefits provide the evidence of accessing phonological codes in Chinese characters identification, which is in chorus with the conclusion from studies with the naming task (Cheng & Shih, 1988) and the semantic judgment task (Perfetti & Zhang, 1995). Most important, the orthogonal manipulation of phonological and orthographic similarity in Experiment 1 showed that both the phonological preview benefit and the orthographic preview benefit can be additive. The suggestion of that only one code can have the benefit when the preview shares multiple linguistic codes (Pollatsek et al., 2000) is not supported. This finding is consistent with the conclusion of English words that the preview benefit is a function of both graphemic and phonological overlap (Pollatsek et al., 1992). It also can be explained by the current reading models, like the interactive-activation models (Plaut et al., 1996; Seidenberg & McClelland, 1989), which propose that both orthographic and phonological information can cooperate in word identification.

Liu et al. (2002) found the orthographic preview benefit showed in both first fixation duration and gaze duration but the phonological preview benefit showed only in gaze duration. They suggested that phonological coding might be slower or less important than orthographic coding in Chinese character. Similar to Liu et al. (2002) study, our Experiment 1 showed that the phonological benefit from orthographically dissimilar previews was more reliable in the gaze duration. However, the phonological preview benefit was found in first fixation duration when the previews share the phonetic radicals, indicating an early role of phonological processing. We suggest that the phonological preview benefit in the gaze duration reflects the character-level phonological processing, since it is not confounded with visual similarity. The phonological benefit in the first fixation duration reflects an early phonological processing at the sublexical level because the previews share the phonetic radicals.

Most of the target characters in Experiment 1 were irregular but high consistency characters. Experiment 2 replicated the phonological benefit when the previews shared the phonetic radical. Moreover, the phonological preview benefit was more reliable for high consistency targets than low consistency targets, no matter the previews shared the phonetic radicals or not. The manipulation of character consistency affected the phonological preview benefit in first fixation duration rather than gaze duration (Table 5). These extended findings have some implications for the role of phonetic radicals in character identification. First, the consistency value of characters reflects the sublexical processing of phonological computation. When a high consistency character is in the preview, more homophonic neighbors of the target are arousal, and then it facilitates the character identification when the target is later fixated. When a low consistency character is in preview, the number of the homophonic neighbors is small and many inconsistent neighbors compete for the correct character phonology. Thus, it reduces the possibility to obtain the phonological preview benefit. Second, the evidence of the phonological benefit affected by consistency value in first fixation duration rather than gaze duration indicates that, the sublexical processing of character consistency could be early for accomplishing the later access of a character's phonology. Gaze duration is insensitive to reflect the early sublexical processing because the variance is larger than first fixation duration or the early effect is hindered by other later processes.

The current study demonstrates that both orthographic and phonological information of characters are accessed in the parafovea and is used for integrating information across saccades. The conclusion of different linguistic codes contributing to character identification is compatible with an interactive activation model for Chinese (Perfetti & Tan, 1998). Furthermore, the two types of phonological benefits suggest the early activation of phonological codes at both character and sublexical levels. The manipulation of character's consistency affects the phonological preview benefit, indicating that the consistency of the pronunciation between characters and phonetic radicals has the initial and critical role in sublexical phonology. The participation of phonetic radicals for character identification is in line with a model assumed a functional role for radicals (Taft, Liu, & Zhu, 1999). However, different functions for types of radicals, especially for phonetic radicals, have not been addressed in this model. More research is needed to explore the nature of phonological coding at the sublexical level and to extend the current models incorporating the use of phonological coding at different levels for Chinese character identification.

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