

# Prosodic Boundaries Delay the Processing of Upcoming Lexical Information During Silent Sentence Reading

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Prosodic boundaries can be used to guide syntactic parsing in both spoken and written sentence comprehension, but it is unknown whether the processing of prosodic boundaries affects the processing of upcoming lexical information. In 3 eye-tracking experiments, participants read silently sentences that allow for 2 possible syntactic interpretations when there is no comma or other cue specifying which interpretation should be taken. In Experiments 1 and 2, participants heard a low-pass filtered auditory version of the sentence, which provided a prosodic boundary cue prior to each sentence. In Experiment 1, we found that the boundary cue helped syntactic disambiguation after the cue and led to longer fixation durations on regions right before the cue than on identical regions without prosodic boundary information. In Experiments 2 and 3, we used a gaze-contingent display-change paradigm to manipulate the parafoveal visibility of the first constituent character of the target word after the disambiguating position. Results of Experiment 2 showed that previewing the first character significantly reduced the reading time of the target word, but this preview benefit was greatly reduced when the prosodic boundary cue was introduced at this position. In Experiment 3, instead of the acoustic cues, a visually presented comma was inserted at the disambiguating position in each sentence. Results showed that the comma effect on lexical processing was essentially the same as the effect of prosodic boundary cue. These findings demonstrate that processing a prosodic boundary could impair the processing of parafoveal information during sentence reading.

*Keywords:* prosodic boundary, sentence reading, eye movements, parafoveal processing, wrap-up process

To understand a spoken sentence, a hearer needs to know the meaning of its constituent words, to analyze its syntactic structure, and to attend to its prosodic structure. For instance, the sentence “The reporter interviewed the squatter and the policeman” may describe an event with two objects. But if a break is heard between

*squatter* and *and*, the listener may expect a second event with the policeman as its agent or patient and may feel that the sentence is incomplete after hearing only *the policeman*. In this case, prosodic information is used to guide the syntactic parser (Snedeker & Yuan, 2008) and to help predict upcoming information with respect to the syntactic structure (Kerkhofs, Vonk, Schriefers, & Chwilla, 2007), and hence to facilitate sentence comprehension. However, although there is ample evidence showing that prosodic information can be immediately perceived and used to help syntactic parsing and semantic integration of phrases preceding the boundary, it is unknown whether and how this rapid process affects the processing of upcoming lexical information. The main purpose of the present study was therefore to explore how information about the prosodic structure of a sentence affects the processing of lexical items right after the occurrence of prosodic boundary.

In speech, a prosodic boundary is usually characterized by preboundary lengthening, pause and pitch declination, followed by pitch reset

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tion can keep listeners from entertaining unnecessary syntactic structures (e.g., Cutler, Dahan, & van Donselaar, 1997; Frazier, Carlson, & Clifton, 2006; Lu, 2003; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992) and provides them with the initial domains for semantic analysis (Schafer, 1997). In the case of reading, although there is no acoustic input during reading, readers may experience “inner speech” mirroring the intonation pattern of external speech (i.e., implicit prosody; Fodor, 2002). Behavioral evidence has shown that the implicit “intonational break” generated by readers is used to resolve syntactic ambiguity such as the attachment preference of relative clauses (Fodor, 2002; Jun, 2003)

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rather than speech melody, was used to induce a prosodic boundary. This experiment was expected to generally replicate the results of Experiment 2. Yet given that commas are explicitly, visually presented markers of prosodic boundaries, the specification of prosodic boundary would be easier for reading sentences with commas (in Experiment 3) than for reading sentences without visual boundary cues (in Experiment 2), and this could affect the specific pattern of effects for prosodic boundaries in Experiment 3, as compared with the pattern in Experiment 2. Thus this study would provide cross-method evidence regarding how prosodic processing affects parafoveal processing of lexical information during silent reading, a question that has not been addressed by the previous studies of prosody (e.g., Cohen et al., 2001; Hirotani et al., 2006).

### Experiment 1

Eye movements have been shown to be sensitive to implicit prosody during silent reading, including syllabic information (Ashby, 2006) and lexical stress (Ashby & Clifton, 2005; Breen & Clifton, 2011) at the word level as well as punctuation at the sentence level (Hirotani et al., 2006). For instance, Ashby and Clifton (2005) found that lexical stress affects eye movements such that readers had longer gaze durations and more fixations on words with two stressed syllables than on words with one stressed syllable. Breen and Clifton (2011) extended these results by showing that readers were slower to read words when their stress patterns do not conform to expectations.

In this experiment, we used ambiguous Chinese sentences that allow for two possible syntactic interpretations. These sentences were all structured as "NP1 + VP

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pated in Experiment 1. They all were native speakers of Chinese and had normal or corrected-to-normal vision.

**Materials and design.** Each ambiguous sentence was paired with three types of speech melody, forming three experimental conditions. For the condition with an early prosodic boundary, the speech melody provided a boundary cue at the offset of NP2. For the condition with a late prosodic boundary, the speech melody provided a cue at the offset of NP3. For the ambiguous condition, the speech melody did not provide cue at any of these positions (see below).

Forty-two Chinese sentences with the structure “NP1 + VP1 + NP2 + *hé* + NP3 + VP2 + . . .” were created, with NP1 having two to four characters and VP1, NP2, and VP2 having two to three characters. NP3 comprised a modifier with two to five characters (one or two words) and a head noun with two to three characters. The purpose of using a modifier before the noun in NP3 was to increase the distance between NP2 and the noun in NP3 so that the reader could more precisely localize the prosodic boundary cue in speech melody to the position at the offset of NP2 (in the condition with an early prosodic boundary) or at the offset of NP3 (in the condition with a late prosodic boundary). Sentences were assessed for the functional ambiguity of the conjunction *hé*. Twenty participants who did not participate in the eye-tracking experiment were asked to read each sentence and to make a speeded forced choice between the two interpretations provided. These participants were instructed to respond to their preferred interpretation of the sentence. For the selected sentences, 50.1% (ranging between 40% and 65% for each sentence) responses had the interpretation that coincided with the sentence with an early prosodic boundary, and 49.9% (ranging between 35% and 60% for each sentence) had the

interpretation that coincided with the sentence with a late prosodic boundary, demonstrating that these sentences were not strongly biased toward either reading.

A professional male speaker with broadcast training read in a soundproof chamber the sentences with prosodic boundaries (cued by commas) at the offset of either NP2 or NP3. The speech was sampled at 16 bits/41.1 kHz. To create speech without boundary information, a cross-slicing procedure was applied to the recorded speech, combining the former part “NP1 + VP1 + NP2 + *hé*” from sentences with a late prosodic boundary and the latter part “NP3 + VP2 + . . .” from the sentences with an early prosodic boundary. This procedure ensured that phonetic variations other than those related to prosodic boundary in sentences of the ambiguity condition were the same as in those in sentences of the other two conditions and that no boundary was present in the ambiguous condition. The resulting three types of sentences were then low-pass filtered in the CoolEdit software package, via a Butterworth filter with a 200-Hz cutoff frequency (see Hesling, Clément, Bordessoules, & Allard, 2005, for a similar operation). Examples given in Figure 1 show the difference between normal sentences and their filtered versions. The signal generated from this filtering procedure consisted of an  $F_0$  contour and amplitude envelope, which represents speech melody, including information concerning distribution and type of pitch accents and prosodic boundary cues. However, most of the segmental information and therefore most of the lexico-semantic information was excluded through this procedure. Two Chinese native speakers, who did not participate in the eye-tracking experiments, were required to write down any words they heard from the low-pass filtered melody. Only a few words with high frequency were identified, and no more than three

words were recognized in any sentence. We also checked the durations of pauses, which are the most stable and salient phonetic markers for phrase boundaries in Chinese (Wang, Lü, & Yang, 2004). For each melody with an early prosodic boundary, a pause was detected at the offset of the original NP2, with a mean duration of 310 ms ( $SD = 66$ ). For each melody with a late prosodic boundary, the pause was at the offset of the original NP3, with a mean duration of 307 ms ( $SD = 74$ ). For the ambiguous melody, no obvious pause was detected at either the offset of NP2 or the offset of NP3.

Thirty-six sentences were added as fillers. They were structured similarly to those critical sentences except that they included a disambiguating adverbial after NP3. Take the sentence in 1) for an example. Adding a word, (*yiqi*, “together”), after NP3 would indicate that NP3 is the agent of VP2, that is, to indicate early closure of the first VP. This made the sentence unambiguous, although NP3 was still temporarily ambiguous as to whether it was an object of VP1 or a subject of the following VP2 before the disambiguating

from a linear mixed model for durations and landing positions and a generalized linear mixed model for percent regressions and skipping rates, with crossed random effects for participants and items, via the lmer program of the lme4 package (Bates, Maechler, & Dai, 2008) in the R environment for statistical computing (R Development Core Team, 2008). Analyses for untransformed and log-transformed durations yielded the same pattern of significance; thus statistics are reported for log-transformed durations. Estimates larger than 2 standard errors (i.e., absolute  $t$  values greater than 2) were interpreted as significant.

## Results

Participants correctly answered 91% ( $SD = 7\%$ ) of all the questions, indicating that they read sentences carefully. All but three of the participants reported that they realized the relationship between the melody and the sentence and that they used the prosodic cues in silent reading. The participants who did not overtly sense the use of melody displayed a similar data pattern as the others, and therefore their data were included in the eye

movement analysis. Measurements for the four regions are shown in Table 2.

**Region 1.** When sentences followed a speech melody with an early pause, the first-fixation duration on Region 1 was 253 ms, 14 ms longer than sentences preceded by speech melody with a late pause (i.e., no pause information was provided at this region) based on 1,017 observations. The difference was significant ( $b = 0.033$ ,  $SE = 0.011$ ,  $t = 2.9$ ). Similarly, gaze duration on Region 1 for sentences with an early pause (303 ms) was significantly longer by 16 ms than that for sentences with a late pause (287 ms;  $b = 0.033$ ,  $SE = 0.014$ ,  $t = 2.3$ ). Durations for sentences with no pauses were numerically in the middle and yielded no significant difference from the means of durations for sentences with a pause. No significant contrasts were found for other measurements.

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gaze duration: 308 and 310 ms; second-pass reading times: 423 and 432 ms, respectively). In contrast, the landing positions into this region for sentences with an early pause were numerically the shortest (0.91 character) among the three conditions.

**Region 3.** As shown in Table 2, sentences without pauses had longer gaze durations (316 ms) than sentences with a pause (298 ms for those with an early pause and 305 for those with a late pause;  $b = 0.020$ ,  $SE = 0.008$ ,  $t = 2.6$ ). The second-pass reading times were also longer for sentences without pauses (473 ms) than for the other two types of sentences (415 ms for sentences with an early pause, 402 ms for sentences with a late pause;  $b = 0.051$ ,  $SE = 0.022$ ,  $t = 2.3$ ). It is noted that although the difference of reading times between the two conditions with either an early or a late pause failed to reach significance ( $t = 1.3$  for first-fixation duration and  $t = 1.0$  for gaze duration), sentences with a late pause did have numerically longer reading times (first-fixation duration: 270 ms; gaze duration: 305 ms) than sentences with an early pause (first-fixation duration: 261 ms; gaze duration: 298 ms).

**Region 4.** Compared with sentences with an early pause (first-fixation duration: 261 ms; gaze duration: 281 ms), sentences with a late pause had longer first-fixation durations by 16 ms ( $b = 0.037$ ,  $SE = 0.015$ ,  $t = 2.5$ ) and longer gaze durations by 14 ms ( $b = 0.033$ ,  $SE = 0.016$ ,  $t = 2.1$ ). Sentences with no pauses had significantly longer second-pass reading times (432 ms) than sentences with a pause (309 and 347 ms for sentences with an early pause and those with a late pause, respectively;  $b = 0.065$ ,  $SE = 0.028$ ,  $t = 2.3$ ).

## Discussion

In line with our predictions, we found that compared with the ambiguous condition in which sentences were preceded by melody without pause, sentences preceded by melody with boundary information (for both early and late pauses) had shorter fixation durations on the disambiguating Region 3. The results of second-pass reading times further identified a more effortful rereading process in Regions 3 and 4 for sentences without prosodic boundary cues. These findings confirmed that the Chinese reader is able to project the melody just heard onto the reading material and to use prosodic boundary cues to chunk the sentence. The prosodic boundary information helps to resolve the ambiguity in syntactic parsing, and hence the disambiguated words can be easily integrated into the prior context. However, this ambiguity effect did not show at an earlier ambiguous region (i.e., Region 2). This absence of effect may be attributed to the role of the modifier in Region 2. This modifier acts as a local constraint on the head noun NP3 in Region 3, and it has no impact upon the interpretation of the ambiguous structure. Given that all the sentences had this “modifier + head noun” structure at this position, the reader may develop a reading strategy and wait for the head noun before committing to one interpretation.

More interestingly, comparing the two types of sentences preceded by speech melody with an early or a late pause, we observed longer first-fixation and gaze durations on the region immediately followed by an early prosodic boundary (Region 1). This finding is consistent with results showing that the reader tends to take longer to read sentence constituents followed by a punctuation mark (Hirotani et al., 2006). Together, these findings suggest that when coming across a prosodic (and syntactic) boundary cued by

punctuation or speech melody, the reader starts a wrap-up process for the preceding phrases, in which information from different sources is integrated.

Alternatively, the longer durations on Region 1 for sentences preceded by speech melody with the early pause may suggest a preparation process for postboundary regions. It is plausible that the prosodic boundary may function as a cue to prepare for the analysis of subsequent input (Steinhauer et al., 1999) or to redirect attention toward the upcoming information (Knösche et al., 2005). Either of these two processes needs additional processing resources, causing delays in moving eyes away from the fixated, preboundary region. However, the results of the present study do not appear to be consistent with this alternative. If the reader had prepared for the postboundary information even when his or her eyes still fixated on the preboundary region, then this preparation should have been able to reduce the fixation durations on the postboundary region once the eyes actually moved to that region. However, it is clear from Table 2 that durations on Region 2 and Region 4 were not shorter when the region was preceded by a local prosodic boundary than when it was not. In fact, the first-pass reading of Region 4 was even the longest for the condition with a late pause compared with other two conditions. Unlike Hirotani et al. (2006), we did not observe an effect of further landing positions for postboundary words, which can be taken as evidence for the preparation account; instead, we observed even numerically closer landing positions for postboundary words than for words following no boundary cues.

A perhaps surprising finding was that fixation durations on Region 3 did not differ significantly between the condition with an early prosodic boundary and that with a late one. One might expect to find longer durations for the condition with a late prosodic boundary, given that the prosodic boundary immediately following this region should induce the wrap-up process and hence prevent the eyes from moving to the next region. We suggest that the nonsignificant difference between the two conditions was due to the partial cancellation of two sorts of effects on eye movements. The prolonged durations on Region 3 (NP3; e.g., *wife* in Figure 2) in the late pause condition due to the wrap-up process could have been compensated by the faster integration of NP3 into the prior context. In the late pause condition, NP3, which had the same syntactic role (i.e., the direct object of VP1 “left”) as the preceding NP2 (*parents*), formed a short-distance dependency with NP2, and it should be relatively easy for the processing system to integrate NP3 into the prior context. In the early pause condition, however, NP3 was serving as a coagent with NP1 (*Wangwu*), forming a long-distance dependency between these two words. This would incur larger processing costs for reactivating the head of the dependency (i.e., NP1) when reading NP3, prolonging the durations on NP3 (Gibson, 1998; Phillips, Kazanina, & Abada, 2005). Thus it is possible that the effect due to the wrap-up process and the effect based on syntactic role partially canceled each other, reducing the difference between the two conditions.

One may argue that the reader would use a particular strategy for parsing the ambiguous regions. If the reader completely ignored prosodic information and used a particular strategy for parsing, then there should be no difference in reading times between the conditions. If the reader did take into account the prosodic information conveyed by speech melody but nevertheless used a particular parsing strategy, then there would be a conflict



between prosody and parsing strategy in a particular experimental condition (depending on the strategy used). For instance, if the reader used a minimal attachment strategy (Frazier, 1978; Frazier & Rayner, 1982), the postboundary Region 2 and Region 3 (modifier + NP3) would be taken as a copatient by the strategy. Then on both Region 1 and the postboundary regions the conflict between parsing strategy and prosody would engender longer reading times. It is clear from Table 2 that although this was the case for Region 1, it was not for Region 2 and Region 3. On the other hand, if the reader used an early closure strategy, then the reading times on Region 1 should be longer for the sentences with a late pause than for the sentences with an early pause because of the conflict in the former condition. Again, the data in Table 2 speak against this suggestion.

## Experiment 2

Experiment 1 showed that prosodic boundary information in a speech melody can be projected onto visually presented sentences and gives rise to longer durations on preboundary regions, possibly because of a wrap-up process. Moreover, inconsistent with the preparation account, Experiment 1 showed that reading times on the postboundary regions were not shorter or were even longer than reading times on the words without a boundary preceding them. In Experiment 2, we focused more on postboundary regions and sought to examine whether the processing of prosodic boundary information would facilitate or interfere with the processing of the upcoming, postboundary lexical information. To this end, we adopted the gaze-contingent boundary paradigm (Rayner, 1975) and examined how prosodic boundaries and parafoveal preview would jointly influence the processing of the words right after and before the prosodic boundary.

In the gaze-contingent boundary paradigm, a target word is initially either visible or replaced with a preview mask (e.g., a random letter string). When a reader's eyes cross a predefined, invisible vertical boundary located between the pretarget and the target words, the initially displayed mask is replaced by the target word. The logic behind this paradigm is that if the reader obtains parafoveal information concerning the target before the eyes cross the vertical boundary, shorter fixations on the target word (preview benefits) should be found for the identical than for the masked preview.

Indeed, such a preview benefit for parafoveal word  $n + 1$  (i.e., when the vertical boundary immediately precedes the target) has been reported not only for previews with identical words (see Rayner, 1998, for a review), but also for previews with words that are orthographically (Inhoff, 1990; Inhoff & Tousman, 1990; Rayner, 1975) or phonologically (e.g., Pollatsek, Lesch, Morris, & Rayner, 1992) related to the target in alphabetic scripts. This  $n + 1$  preview benefit has also been observed for the logographic Chinese script (e.g., W. Liu, Inhoff, Ye, & Wu, 2002; Tsai, Kliegl, & Yan, 2012; Tsai, Lee, Tzeng, Hung, & Yen, 2004; Yan, Richter, Shu, & Kliegl, 2009; Yan, Zhou, Shu, & Kliegl, 2012; Yen, Radach, Tzeng, Hung, & Tsai, 2009). Moreover, preprocessing of word  $n + 2$  has also been observed in some German and Chinese studies (Kliegl, Risse, & Laubrock, 2007; Yan, Kliegl, Shu, Pan, & Zhou, 2010; Yan, Risse, Zhou, & Kliegl, 2012; Yang, Wang, Xu, & Rayner, 2009; but see Angele & Rayner, 2011; Angele, Slattery, Yang, Kliegl, & Rayner, 2008; Rayner, Juhasz, & Brown, 2007,

for contradictory evidence in English), showing that the area from which useful visual information can be obtained, namely the perceptual span, may extend to word  $n + 2$  in Chinese when the fixation is on word  $n$ .

Parafoveal processing has been shown to be modulated by foveal processing load (Henderson & Ferreira, 1990; Inhoff & Rayner, 1986; Schroyens, Vitu, Brysbaert, & d'Ydevalle, 1999; White, Rayner, & Liversedge, 2005), perhaps through the dynamic adjustment of the size of perceptual span. For instance, Henderson and Ferreira (1990) found that less parafoveal information is acquired when foveal processing is difficult due to either lower lexical frequency or higher syntactic complexity. A recent study by Yan et al. (2010) demonstrated that whether or not the preview benefit is obtained on word  $n + 2$  depends crucially on properties of word  $n + 1$  such as word frequency; perceptual span covers

the full width of the preview region (Yan, Zhou, Shu, & Kliegl, 2012; Yen, Radach, Tzeng, Hung, & Tsai, 2009).



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participants from extracting lexical information before fixating upon the target word. An invisible vertical boundary was located between NP2 and *hé*. When a saccade crossed this invisible boundary, the previewed character was replaced by the target character (see Figure 3C). The sentence remained in this final form until the end of the trial. After the eye-tracking system had detected the crossing of the boundary, display changes were accomplished with a mean time of 7.3 ms, ranging from 2 to 13 ms. Participants read 116 sentences, including 80 experimental sentences and 36 filler sentences. For half of the sentences in each category, a comprehension question was presented after the stimulus sentence, and the participant had to decide, by pressing a response button, whether the meaning of the question sentence was congruent or incongruent with a proposition encoded in the stimulus sentence. To detect whether participants used the prosodic boundary cue to parse the sentences, two of the 58 question sentences were directly related in meaning to the interpretation of the ambiguous sentences.

After the completion of the test, participants were asked to report whether and how often they had noticed anything unusual during sentence reading. Twenty-five out of 38 participants reported seeing “flashes” on the screen, and the number of flashes noticed ranged from one to four, with a mean of 1.6. However, they could not report anything specific for the flashes. In addition, all participants except three reported that they noticed the early and the late pauses in speech melodies. Those three participants showed similar patterns of eye movements as the other participants and were included in the data analysis.

**Data analysis.** Two regions were selected as regions of interest, as shown in Figure 3. Region 1 contained NP2 (i.e., word  $n$ ), composed of two to three characters. Region 2 (i.e., word  $n + 2$ ) contained part of the modifier for the head noun in NP3, composed of two to four characters (i.e., *newly married* in the figure). Trials with either first-fixation duration less than 60 ms or greater than 800 ms or gaze duration less than 60 ms or greater than 1,000 ms (2% of all fixations) were eliminated. Trials in which the display change was inappropriately initiated during

fixations on  $n + 1$  or  $n + 2$  were also excluded. Results from six participants were further discarded because the inappropriate display change occurred in more than 40% of the trials. For the remaining 32 participants, 77% of all the fixations were entered into the analyses of duration and landing position.

Similar to Experiment 1, estimates are from a linear mixed model for durations and landing positions and a generalized linear mixed model for percent regressions and skipping rates. Participants and stimulus items were treated as crossed random factors. The fixed factors included in the model were (a) prosodic boundary cue that could be either early or late, (b) preview type that could be mask or identical, and (c) the interaction of these two factors.

## Results

Participants correctly answered 85.6% ( $SD = 4.3\%$ ) of the poststimulus sentence questions, and there was no difference in the accuracy between the four experimental conditions ( $F < 1$ ). Measures for the two regions are shown in Table 3. The same patterns of effects were obtained for these measures when sentences that were incorrectly answered in the comprehension test were removed from the analysis. All participants correctly answered the two questions checking which interpretation was made except one, who responded incorrectly to one of the two questions. This result indicated that participants were able to use the prosodic boundary cue previously presented to help them parse the written sentences.

### Region 1.

**Prosodic boundary effect.** For the analysis of durations based on 1,704 observations, the interaction between preview type and prosodic boundary was marginally significant for first-fixation durations ( $b = 0.058$ ,  $SE = 0.030$ ,  $t = 1.9$ ). Further analyses showed that the difference between first-fixation duration in sentences with the early pause (288 ms) and those with the late pause (276 ms), that is, the prosodic boundary effect, was significant for the identical preview trials ( $b = 0.048$ ,  $SE = 0.022$ ,  $t = 2.2$ ). This effect replicated Experiment 1, with longer durations on the region

Table 3  
Grand Means and Standard Errors for Sentences of the Four Conditions in Experiment 2

Variable	Early pause, identical preview		Early pause, mask preview		Late pause, identical preview		Late pause, mask preview	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Region 1								
FFD	288	5.72	281	5.17	276	5.25	277	4.98
GD	340	8.20	327	7.68	323	7.11	328	7.73
LAND	1.00	0.03	1.00	0.03	1.08	0.03	1.01	0.03
REG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SKIP	0.13	0.01	0.14	0.01	0.15	0.01	0.16	0.01
Region 2								
FFD	296	4.98	301	5.26	282	4.59	300	5.11
GD	407	9.12	406	8.49	374	8.35	407	8.42
LAND	1.19	0.03	1.12	0.03	1.18	0.03	1.11	0.03
REG	0.01	0.004	0.02	0.007	0.03	0.008	0.02	0.006
SKIP	0.07	0.01	0.06	0.009	0.08	0.01	0.08	0.01

Note. FFD = first-fixation duration (ms); GD = gaze duration (ms); LAND = landing position (of character); REG = percent regressions; SKIP = skipping rate.

immediately before the prosodic boundary. But this effect was not significant when the previewed characters were masks (281 vs. 277 ms;  $t < 1$ ). As shown in Table 3, a similar pattern of interaction was observed for gaze durations, although the interaction failed to reach significance ( $t < 1.7$ ).

### Region 2.

**Parafoveal preview benefit.** For the analysis of durations based on 1,792 observations, the difference between sentences with mask preview and those with identical preview was significant for gaze durations (406 vs. 390 ms;  $b = 0.038$ ,  $SE = 0.017$ ,  $t = 2.2$ ) and marginally significant for first-fixation durations (300 ms vs. 289 ms;  $b = 0.027$ ,  $SE = 0.014$ ,  $t = 1.9$ ), showing increased reading times for conditions in which parafoveal information was not available as compared with conditions with normal preview (i.e., a preview benefit).

In addition, a significant interaction was found between preview type and prosodic boundary for gaze durations ( $b = 0.066$ ,  $SE = 0.033$ ,  $t = 2.0$ ). Further analysis showed significantly shorter durations for the identical (374 ms) than for the mask preview condition (407 ms), that is, the preview benefit, in sentences with the late pause ( $b = 0.078$ ,  $SE = 0.025$ ,  $t = 3.1$ ) but not in sentences with the early pause (407 vs. 405 ms;  $t < 1$ ). These results indicated that less parafoveal information had been acquired about Region 2 during fixations on Region 1 when there was a prosodic boundary between the two regions than when there was no boundary.

The preview effect also manifested in landing positions, with fixation locations marginally closer to the beginning of the target words for sentences with mask preview than for sentences with identical preview (1.12 vs. 1.19 characters;  $b = 0.055$ ,  $SE = 0.029$ ,  $t = 1.9$ ).

**Prosodic boundary effect.** Another way to interpret the significant interaction between the preview type and prosodic boundary was to examine the prosodic boundary effect. Gaze durations on Region 2 were significantly longer for sentences with the early pause than for sentences with the late pause, but only in trials with identical preview (407 vs. 374 ms;  $b = 0.060$ ,  $SE = 0.025$ ,  $t = 2.4$ ), not in trials with mask preview (406 vs. 407 ms;  $t < 1$ ).

## Discussion

Experiment 2, like Experiment 1, showed that the first fixation durations on the Region 1 were longer when the region was immediately followed by a prosodic boundary. More importantly, measures at the postboundary region (Region 2) indicated that the preview benefit for word  $n + 2$ , which has been observed for Chinese (Yan et al., 2010; Yang et al., 2009), was obtained only when the target word was not preceded by a prosodic boundary, not when the target was preceded by a prosodic boundary. This finding, consistent with the wrap-up hypothesis, provides direct evidence that the processing of the normal and necessary prosodic boundary, despite its facilitatory role in syntactic structure building, may also hinder parafoveal processing and slow down the reading of postboundary word.

As can be seen from Table 3, the first-fixation and gaze durations in Region 2 were the shortest for the identical preview condition with the late pause, whereas they were essentially the same for the other three conditions. Thus, consistent with the wrap-up hypothesis, the existence of a prosodic boundary effectively hinders the reader from obtaining valid lexical information

from the preview, as does the existence of a mask (Rayner, 1998). It is possible that the prosodic boundary increases the processing load in integrating and packing up the perceived preboundary information when the eyes are fixating at the preboundary region, narrowing down the perceptual span. This finding also helps to rule out the possibility that the increased durations on the preboundary region (i.e., Region 1 in both experiments) are due to additional efforts devoted to parafoveal processing of postboundary information when the prosodic boundary is present.

On the basis of the above findings, one might suggest that the prosodic boundary processing, which includes a wrap-up process for the preboundary information, completely shuts down parafoveal processing. If it is the case, we should then expect to observe no parafoveal-on-foveal effect on Region 1. Although we indeed did not observe a main effect of parafoveal-on-foveal preview benefit, we did find an interaction between this effect and prosodic boundary: The prolonged readings upon the preboundary words disappeared when the information of the postboundary target word could not be accessed parafoveally due to a mask. This pattern suggests that readers did obtain information to the right of the early prosodic boundary to specify whether the postboundary character was a real one, and that the specification of prosodic boundary was more effective when the postboundary region contained meaningful or familiar characters than when it contained a pseudocharacter. Given that the orthographic information of the target word can be obtained from preview (Pynte, Kennedy, & Ducrot, 2004; Starr & Inhoff, 2004), it is possible that the parafoveal processing of the pseudocharacter in the mask conditions is harder to process and pulls the eyes toward the pseudocharacter (Kennedy, 1998). This shut down the normal wrap-up process induced by the prosodic boundary, resulting in a much reduced prosodic boundary effect at Region 1.

## Experiment 3

Experiment 2 showed that a prosodic boundary may lead to impaired parafoveal processing of words after it. This finding is in accordance with the prediction of the wrap-up account, which predicts that a wrap-up process for the preboundary information would weaken the parafoveal processing of the postboundary words. There exists a possibility, however, that the pattern of results observed in Experiment 2 was paradigm-specific. Compared with natural reading, projecting prosodic information from working memory onto the visually presented sentences may require more cognitive resources, particularly at positions where the prosodic boundary cues are present. This might lead to an inefficient preview of the postboundary words. To further establish that our results can be generalized to other paradigms, we conducted Experiment 3 in which a comma, the main device of conveying prosodic structure in written Chinese sentences (Zhang, 2003), was used to provide prosodic boundary information. In Chinese, commas indicate the hierarchical prosodic boundaries (breaks) within a sentence (China State Bureau of Technical Supervision, 1995) and have a considerable influence on interpreting ambiguous sentences (C. Liu, 1998). As shown in Figure 4, the ambiguous sentence is interpreted in one way when a comma was inserted at the position of an early prosodic boundary and in another way when a comma was inserted at the position of a late prosodic boundary.

The aim of Experiment 3 was to investigate whether the presence of a prosodic boundary would elicit a prolonged reading of preboundary information and an impairment of parafoveal processing of post-

- A) 王博士告别了父母和新婚不久的丈夫到东海探查油田了。  
 B) 王博士告别了父母和新婚不久的丈夫,到东海探查油田了。

*Figure 4.* Exemplar sentences in Experiment 3. (A) A sentence with an early comma. Translation: “Dr. Wang bid farewell to her parents, and went to the East Sea to explore oil fields with her newly married husband.” (B) A sentence with a late comma. Translation: “Dr. Wang bid farewell to her parents and newly married husband, and went to the East Sea to explore oil fields.”

boundary words when the prosodic boundary is cued by comma, rather than by speech melody. The same materials and gaze-contingent boundary paradigm used in Experiment 2 were employed.

Chinese text is monospace; that is, a comma in a Chinese sentence usually takes up the same amount of space as a character in the printed form. This would increase the distance between the pre- and post-comma characters, in contrast with the absence of such space between the two characters when no comma is inserted at this position. Thus the difference between conditions in terms of the presence or absence of comma (space) could confound the effects we wanted to examine. To eliminate this confounding, we inserted the comma at the bottom of the spare space between the two characters while keeping the distance between these characters in the same way as the situation in which no comma was inserted (see Figure 4).

## Method

**Participants.** Forty-eight students (aged between 17 and 28 years) from Peking University and Beijing Normal University participated in Experiment 3. They were native speakers of Chinese and had normal or corrected-to-normal vision. They had not participated in Experiment 1 or Experiment 2. Forty participants were included in the final statistical analyses after data trimming.

**Material, design, and apparatus.** The materials and design were essentially the same as those in Experiment 2 except for the

manipulation of comma. Here, a comma was placed either at the early position (right after NP2) or at the late position (right after NP3). A comma subtended  $0.1^\circ$  of visual angle. Eye movements were recorded with an EyeLink 2K system and an EyeLink 1000 system at a sampling rate of 1,000 Hz. Other parameters were identical to those in Experiment 2.

**Procedure.** The experiment was conducted with the same procedure as that in Experiment 2. Display changes were accomplished with a mean time of 7 ms, ranging from 4 to 14 ms. Thirty of 48 participants reported seeing flashes on the screen after the completion of the test, and the number of flashes noticed ranged from one to four, with a mean of 1.5. However, they could not report anything specific for the flashes. We adopted the same criteria for trimming data as in Experiment 2, preserving 74% of the trials for further computation. Eight participants were excluded from data analysis because of excessive inappropriate display change (over 40%) in the trials.

## Results

Participants correctly answered 86.2% ( $SD = 3.3\%$ ) of the poststimulus questions, and there were no differences in the accuracy between the four experimental conditions ( $F < 1$ ). In Table 4, the mean first-fixation durations, gaze durations, landing positions, percent regressions, and skipping rates for the two regions were reported. The same patterns of effects were obtained for these measures when sentences that were incorrectly answered in the comprehension test were removed from the analysis.

### Region 1.

**Prosodic boundary effect.** For the analysis of durations based on 2,090 observations, the difference between sentences with an early comma and those with a late comma, that is, the prosodic boundary effect, was significant both for first-fixation durations (284 vs. 268 ms;  $b = 0.040$ ,  $SE = 0.013$ ,  $t = 2.9$ ) and for gaze durations (329 vs. 310 ms;  $b = 0.031$ ,  $SE = 0.015$ ,  $t = 2.0$ ). This effect demonstrated that a comma would induce longer rt

region. Although the interaction between preview type and prosodic boundary was not reliable ( $b = 0.049$ ,  $SE = 0.031$ ,  $t = 1.6$ ), the pattern was nevertheless similar to that in Experiment 2: The difference between gaze duration in sentences with the early pause (337 ms) and those with the late pause (308 ms) in identical preview was numerically larger than the difference in mask preview (322 vs. 313 ms).

### Region 2.

**Parafoveal preview benefit.** For the analysis of gaze durations based on 2,166 observations, the sentences with mask preview (399 ms) induced significantly longer reading times as compared with sentences with the original word (390 ms;  $b = 0.040$ ,  $SE = 0.017$ ,  $t = 2.4$ ). The interaction between preview type and prosodic boundary did not reach significance ( $t = 1.1$ ), although the preview benefit effect (3 ms) for sentences with an early comma was numerically smaller than that for sentences with a late comma (13 ms).

The preview effect was also observed on the measurement of landing position, as the eye fixations landed closer to the beginning of this region for sentences with mask preview than for sentences with identical preview (0.95 vs. 1.07 characters;  $b = 0.136$ ,  $SE = 0.026$ ,  $t = 5.2$ ). We also observed a significant interaction between prosodic boundary and preview type ( $b = 0.107$ ,  $SE = 0.052$ ,  $t = 2.0$ ). Detailed analysis showed that a mask preview induced significantly closer landing positions than an identical preview both in early-comma sentences (0.08 characters) and in late-comma sentences (0.18 characters;  $b = 0.081$ ,  $SE = 0.036$ ,  $t = 2.3$ , and  $b = 0.181$ ,  $SE = 0.038$ ,  $t = 4.8$ , respectively). The effect for early-comma sentences was much smaller than that for late-comma sentences as revealed by th

*b*

*S*

Experiment 3, the preview benefit for postcomma words was significant even when the comma was present.

Previous research on the effect of prosodic boundary in sentence reading has commonly used punctuation to convey the (implicit) prosodic structures in the sentences. However, this kind of manipulation introduces at least two confounds: (a) the unbalanced visual complexity for the target regions between the conditions with and without a comma and (b) an increased distance between the pre- and postcomma words when a comma is present. Both confounding factors have been found to influence the pattern of eye movements during sentence reading (Drieghe, Brysbaert, & Desmet, 2005; Rayner, Fischer, & Pollatsek, 1998; White, 2008). To avoid this confound, we used speech melody to convey the prosodic boundary information and observed not only the effect of wrap-up process on the preboundary region that has been reported for sentences with punctuation (e.g., Hirotani et al., 2006), but more importantly, the impairment of parafoveal processing of postboundary words (Experiment 2). Moreover, when we did use the comma to cue the prosodic boundary but controlled the distance between the pre- and postboundary words, we obtained essentially the same pattern of impairment of lexical processing for postboundary words (Experiment 3). This cross-paradigm finding strongly supports the wrap-up account for interpreting the functions of prosodic boundary in sentence comprehension.

This finding also challenges the claim that the prolonged reading times on the preboundary (prepunctuation) region simply reflect a break of intonational phrases without specific cognitive functions (Hirotani et al., 2006). In Hirotani et al. (2006), both syntactically simple and complex sentences were used to examine to what extent adding a comma would affect the reading pattern on critical regions. Although longer durations for the with-comma condition were observed for the precomma region, as compared with the no-comma condition, this effect was of equal size for the simple and complex sentences. This lack of interaction between the comma effect and sentence complexity was taken as evidence that the wrap-up process elicited by a comma functions only at the intonational level. The impairment of the preview benefit on the postboundary words observed in this study, however, suggests that the prosodic boundary does not act only as an intonational break, but also involves semantic and syntactic processes.

Several other aspects of the study are worth discussion. First, although there exists the possibility that the melody-reading paradigm used in Experiments 1 and 2 introduces heavier demand on working memory during reading (for linking prosodic information conveyed through a speech melody with the visual input), this demand on working memory should not differ between conditions. Thus the difference in eye movements between sentences with the prosody cuing an early pause and those with the prosody cuing a late pause could not be attributed to the distinct perception of visual input, but should be due to the different processing induced by an early or a late prosodic boundary. In fact, we would like to suggest that the melody-reading paradigm could be used for studies that explore the processing of other prosodic features or emotional information during silent reading. Similar paradigms have already been used to examine phonological processing in silent reading (e.g., Eiter & Inhoff, 2010; Inhoff, Connine, Eiter, Radach, & Heller, 2004).

Second, although the wrap-up account successfully predicts the prolonged reading times on both the preboundary and postbound-

ary regions, our data may not allow us to completely exclude the initiation of a preparation process by the prosodic boundary information. It is possible that the direction of attention (saccade) toward the postboundary region initiated by a prosodic boundary (Knösche et al., 2005) is overshadowed by a stronger wrap-up process initiated also by this prosodic boundary and hence cannot be revealed through eye tracking. The potential facilitatory effect of the preparation process could be found in other paradigms. A study by Kjelgaard and Speer (1999) showed that listening to sentences with appropriate prosody, as compared with listening to sentences with inappropriate prosody or sentences without explicit prosody, could speed up cross-modal naming of constituent words used in the sentences, although unfortunately this study did not differentiate the positions of these words in relation to the prosodic boundary.

Third, the prosodic boundary cues in this study were also cues to the syntactic boundary. Indeed, prosodic boundaries and syntactic boundaries co-occur and cannot be easily separated in most situations (Steinhauer et al., 1999). Previous eye-tracking research has also shown an influence of syntactic parsing on the processing of prosodic boundary, as the pattern of eye movements varied between sentences with different syntactic structures (Hirotani et al., 2006). It is plausible that the impairment of postboundary lexical processing elicited by a prosodic boundary is partly based on or by means of the coincidental syntactic parsing. It would be interesting to examine how a “pure” prosodic boundary, which does not guide the syntactic parser, would affect the parafoveal processing of upcoming lexical information. We notice that the morphological boundary between constituents of a compound word, which does involve syntactic parsing, can abolish the parafoveal-on-foveal preview benefit (Drieghe, Pollatsek, Juhasz, & Rayner, 2010), suggesting that there could be something fundamental about the impact of boundary information upon lexical or sentence processing.

In summary, by providing prosodic information through speech melody or comma and by recording eye movements during silent sentence reading, we found that a prosodic boundary not only elicits a wrap-up process for the preboundary input, which delays the eyes from moving on to the next sentence constituents, but also blocks parafoveal processing of postboundary lexical information, possibly through increasing the preboundary processing load and narrowing the perceptual span.

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