Published in final edited form as:
J Exp Psychol Learn Mem Cogn. 2015 January ; 41(1): 254–261. doi:10.1037/xlm0000035.

Chinese Deaf Readers Have Early Access to Parafoveal Semantics

Ming Yan[1], **Jinger Pan**[1], **Nathalie N. Bélanger**[2], and **Hua Shu**[3]

[1]Department of Psychology, University of Potsdam, Potsdam, Germany

[2]Department of Psychology, University of California, San Diego, USA

[3]State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, People's Republic of China

Abstract

In the present study, we manipulated different types of information available in the parafovea during the reading of Chinese sentences and examined how deaf readers make use of the parafoveal information. Results clearly indicate that, although the reading-level matched hearing readers make greater use of orthographic information in the parafovea, parafoveal semantic information is obtained earlier among the deaf readers. In addition, a phonological PB effect was found for the better deaf readers (relative to less-skilled deaf readers) though we also provide an alternative explanation for this effect. Providing evidence that Chinese deaf readers have higher efficiency when processing parafoveal semantics, the study indicates flexibility across individuals in the mechanisms underlying word recognition adapting to the inputs available in the linguistic environment.

Keywords

parafoveal; sentence reading; Chinese; deaf readers

Reading is a complex task tightly linked to a spoken language foundation. When beginning to read, hearing children's awareness of the phonological structure of spoken words is of great importance for later reading ability across different writing systems (see Share, 2008 for a review) and phonological decoding consistently serves as mediation for lexical access (Doctor & Coltheart, 1980). For young deaf readers, this relationship is not as straightforward, but given the lack of (or limited) auditory input, and, crucially, an often less than adequate language exposure, reading acquisition turns out to be quite difficult (Mayberry, Del Giudice & Liberman, 2011). Though some deaf readers are very skilled, the median reading level of young deaf adults graduating from high school is equivalent to the average reading level of hearing children in the third grade, and 8 years below the average of their hearing peers (Kelly & Barac-Cikoja, 2007). Despite a generally low performance in reading, deaf readers have shown unique reading processes relative to hearing readers.

Address for correspondence: Ming Yan, Department of Psychology, University of Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam-Golm, Germany, mingyan@uni-potsdam.de, Tel.: +49 331 977 2127.

Recent results have shown that deaf readers have an advantage over hearing readers in parafoveal information processing. For hearing readers during the reading of both alphabetic and logographic scripts, useful information is not only obtained from the fixated foveal words but also from the upcoming parafoveal words (Schotter, Angele, & Rayner, 2012 for a review). The size of the perceptual span (the spatial extent within which useful visual information can be processed during a fixation) is smaller for hearing readers of English (extending 15 letters to the right; McConkie & Rayner, 1975) than it is for skilled deaf readers of English (extending 18 letters to the right; Bélanger, Slattery, Mayberry, & Rayner, 2012). Additionally, contrary to what is routinely found for hearing readers, Bélanger, Mayberry, and Rayner (2013) did not find evidence for parafoveal phonological processing for skilled and less-skilled adult deaf readers. They concluded that reading difficulties in deaf adults are not linked to the fact that they did not activate phonological codes during reading. Their results suggest that given the lack of auditory input, deaf readers may not need to use phonological cues as hearing readers would, but may instead develop a more direct access to semantics and bypass phonological mediation. The present study provides experimental evidence for this notion by demonstrating that Chinese deaf readers have earlier access to semantic information in the parafovea than reading-level matched hearing readers.

Chinese is fundamentally different from alphabetic scripts in the relationships between orthography, phonology, morphology, and semantics. The basic writing units, characters, are written in a series of square-shaped objects of identical horizontal size, irrespective of their visual complexity. In comparison to alphabetic scripts, information is more densely packed in Chinese. Most Chinese words are only one or two characters in length; as a consequence, upcoming words are on average in an area of comparatively higher visual acuity. In addition, the absence of inter-word spaces brings the upcoming parafoveal words into a much less eccentric position. These language-specific properties may enable Chinese readers to benefit from higher visual acuity in the near parafovea and facilitate parafoveal processing.

The boundary paradigm (Rayner, 1975) has been extensively used to investigate the type of information available for parafoveal processing. In this paradigm, parafoveal preview of a target word is either available, or deprived by presenting an alternative word (or nonword) that occupies the position of the target word before it is fixated. The preview is replaced by the correct target word during a saccade crossing an invisible boundary located between the pretarget and target words. Identical and related previews of the target word, as compared to an unrelated preview, reduce the fixation duration on the target word when it is subsequently fixated. This preview benefit (PB) has been consistently shown for orthographic and phonological information during the reading of alphabetic scripts (Schotter et al., 2012), suggesting that these types of information are obtained parafoveally.

As a logographic writing system, Chinese orthography generally maps more closely to meaning than to sound and Chinese characters are known to be optimized for fast and direct semantic processing. Evidence for parafoveal processing of high-level information such as semantics has been consistently reported, although such effects are generally elusive in English or limited to synonym previews (Schotter, 2013). Yan, Richter, Shu, and Kliegl

(2009) first demonstrated a graded semantic PB of 17ms in first-fixation duration (FFD, duration of the first fixation on a word irrespective of the number of fixations), which increased to 27ms in gaze-duration (GD, cumulative duration of fixations during the first-pass reading of a word), among Chinese hearing adults using simple preview characters. Follow-up studies extended the semantic PB to visually more complex traditional characters (Tsai, Kliegl, & Yan, 2012), and compound characters (Yan, Zhou, Shu, & Kliegl, 2012a). In contrast, parafoveal phonological processing may not be as effective in Chinese: phonological PBs have been shown among adults only in GD and not in FFD (e.g., Liu, Inhoff, Ye, & Wu, 2002). Arguably, because GD very often includes refixations, if effects occur in GD and not in FFD, this is considered to indicate relatively late processing (Inhoff, 1984). Accordingly, it has been documented that semantic PB starts very early (Yan, Risse, Zhou, & Kliegl, 2012b; Zhou, Kliegl, & Yan, 2013) whereas reliable phonological PB requires both long parafoveal processing time and high parafoveal processing efficiency (i.e. high frequency pre-target words; Tsai et al., 2012).

As reviewed above, it is worth noting that most studies on parafoveal processing focused on skilled hearing readers and much less is known about how deaf readers process phonological and semantic information in the parafovea. The only study that tested parafoveal processing among deaf readers was reported by Bélanger et al. (2013). They found orthographic PBs among all three groups (i.e., skilled hearing, skilled deaf, and less-skilled deaf) of readers. Interestingly, phonological PB was found only among skilled hearing readers; neither skilled nor less-skilled deaf readers showed phonological PBs, suggesting that deaf readers do not rely on phonological decoding during word processing, and critically, that they probably have more direct access to semantics from orthography. However, due to the lack of a semantically related preview condition, this hypothesis could not be directly tested in the original study. We use the Chinese script in the present study because it is well-suited for testing this hypothesis with the deaf population given its language-specific properties: the predominant role of semantics and the possibility of lexical access without phonological mediation.

The amount of parafoveal information obtained can also be related to preview duration (i.e., fixation duration on pretarget word). This is because in the boundary paradigm, the amount of time within which the preview word is parafoveally processed is not under strict experimental control but time-controlled by subjects' fixations on the pretarget word and the display change during a saccade crossing the invisible boundary terminates the parafoveal prime. Therefore, the variability of preview durations acts like different parafoveal prime durations and can be used as a covariate to predict the size and direction of various PBs (Kliegl, Hohenstein, Yan, & McDonald, 2013; Yan et al., 2012b).

Previously, it has been debated whether phonological codes are used among deaf readers during lexical processing with evidence for both sides. Mayberry, Del Giudice and Lieberman (2011) pointed out that few studies on deaf readers have controlled for subjects' reading levels. This is important because for hearing readers Chace, Rayner and Well (2005) found phonological preview benefit only for undergraduate skilled readers but not for less-skilled readers. Analogously, it is possible that reading skill also plays a role for deaf readers though note that Bélanger, Baum and Mayberry (2012) and Bélanger et al. (2013) did not find an effect of reading skill on phonological activation during word processing. To address this question, in the present study we used a second covariate of readers' reading fluency as an index for their reading level and tested whether it interacts with phonological PB.

The present experiment combined the design ideas reviewed above. We tested whether deaf and hearing readers make use of parafoveal information differently during the silent reading of Chinese sentences. Our goal was to test the nature of parafoveal lexical processing of deaf readers given their reading ability[1]. Given the possibility of direct access to semantics among deaf readers and the existing evidence for fast processing of parafoveal semantic information in Chinese, we predict that deaf readers will have earlier access to parafoveal semantics, leading to stronger semantic PB in early eye-movement measures during the reading of Chinese sentences. In addition, if only skilled deaf readers activate phonological information, we should observe an interaction indicating that phonological PB is stronger for readers with higher reading fluency and increases with preview duration.

METHOD

Subjects

Thirty-six severely to profoundly deaf subjects, who were high-school students from the Beijing Experimental School for the Deaf, participated in the eye-tracking experiment. In addition, 38 grade-5 primary school students were recruited as a reading-level control group. An independent sample of 24 undergraduate subjects participated in a norming test for sentence predictability. All subjects had normal or corrected-to-normal vision and were native speakers of Chinese.

Background measures—The deaf and hearing readers were 18.6 (SD=1.8) and 10.7 (SD=0.3) years old on average. The deaf readers used Chinese Sign Language as their main language for communication for 8.65 years on average (SD=4.43). On average the deaf subjects had a hearing loss of 99dB (SD=15) in their better ear and none had received a cochlear implant. Based on a silent reading fluency test used in previous studies (e.g., Pan et al., 2011), the reading speed difference between the deaf readers [340 (SD=151) characters/min)] and the control group [343 (SD=86) characters/min] was not significant (F<1).

Materials

A total of 120 two-character target words were selected with their first characters under experimental manipulation. The target words were created from 40 target characters selected from Yan et al., (2009) and each target character was embedded into three two-character target words. Five types of preview characters were selected for identical, orthographically similar, phonologically similar, semantically similar, and unrelated preview conditions for each target character. Therefore, there were 24 target words from each condition for each subject. The reason for using the target character multiple times was the difficulty in creating preview and target character sets with overlapping information within only one dimension (orthography, phonology or semantics) while controlling a number of other

[1]Therefore it is more critical to include a reading-level rather than a chronological age-matched control group so that our results are not confounded by different reading skills.

factors. Word-level preview of word N+1 was only valid for the identical condition, whereas the other four non-identical preview characters did not form legal words with their following characters. As shown in Table 1, the preview characters were closely matched with respect to visual complexity as indexed by number of strokes [$F(4,195)=1.815$, $p=.128$] and character frequency [$F<1$].

For each target word, a sentence frame was created; therefore, there were a total of 120 experimental sentences. Given that the experimental sentences were 14 to 22 characters in length ($M=20$, $SD=2.0$) and the repeated used target characters were embedded into three different target words, subjects were unlikely to notice the three target characters out of a total of 2400 (i.e., 120×20) characters. The invisible boundary that triggered the display change was located between the pretarget and target words. Pretarget words were also always two-character words. The target characters never appeared among the first three or the last three words. Each sentence was presented only once to a subject, and the conditions were counterbalanced across subjects. According to teachers' evaluations, all sentences were appropriate given the reading level of the subjects. An example set of sentences is shown in Figure 1.

The sentence contexts were always neutral. We presented sentence frames up to the target words to the norming subjects and asked them to complete the sentence. Each subject completed 60 sentences. To reduce the likelihood of skipping, the preview characters were of very low predictabilities. From 1,440 predictions, the target character was guessed 3.6% of the time, and the non-identical preview characters were guessed 0.1%, 0.1%, 0.7% and 0.0% of the time, respectively, for orthographically, phonologically, semantically related and unrelated conditions, respectively.

Apparatus

Eye movements were recorded with an EyeLink 1000 desktop system with a 35mm lens running at 1000Hz. Sentences were presented in single lines on the vertical position one third from the top of the screen of a 21-inch ViewSonic G220f monitor (resolution, 1024-by-768 pixels; frame rate, 120Hz). Given these parameters, the display change should complete within 12ms after the eyes crossed the invisible boundary. Subjects were seated comfortably with a chin rest and a forehead rest at a distance of 65cm from the monitor. The font Song 40 was used with one character equal to 1.4°of visual angle. All recordings and calibrations were done monocularly based on the right eye and viewing was binocular.

Procedure

Subjects were calibrated with a 5-point grid. Before every trial started, a fixation point appeared on the left side of the monitor for drift check. The experimenter carried out an extra calibration if the eye-tracker did not detect subjects' eyes within a pre-defined window around the initial fixation point (<.5deg). Fixation on the fixation point initiated presentation of the next sentence with its first character occupying the position of the fixation point.

The subjects 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 the readers' eyes crossed the invisible boundary located between words N and N+1, they got to see one of the five previews at the position of word N+1. The preview word was replaced by the target word immediately after the eyes crossed this boundary. A total of 40 randomly selected sentences were followed by an easy yes-no comprehension question. All subjects correctly answered at least 65% of all questions and the hearing reader (*M*=93% and *SD*=5%) had better comprehension rate than the deaf readers [*M*=78% and *SD*=11%; $F(1,72)=61.2$, $p<.001$].

Data Analysis

Fixations were determined using an algorithm for binocular saccade detection (Engbert & Kliegl, 2003; Yan et al., 2010). Together with first-pass reading measures of FFD and GD, we also analyzed go-past time (GPT; the accumulated fixation durations from when a reader first fixated on the target word until the first fixation to the right of it) and total reading time (TRT; sum of all fixation durations on the target word) as measures for second-pass reading because regressive re-reading time is included in these two measures. There were four levels of data screening: First, a total of 113 (i.e., 1%) trials were removed due to subjects' blinking or excessive movement. Second, FFDs shorter than 60ms or longer than 800ms and GDs longer than 1000ms were removed for first-pass duration analyses, excluding 7% and 8% of data in the target region for deaf and hearing readers, respectively. For second-pass measures, GPT and TRT shorter than 60ms or longer than 1600ms were removed, excluding 6% and 4% of data for deaf and hearing readers, respectively. Third, we discarded trials with regressions from pretarget words for all analyses because they may reflect incomplete parafoveal processing of preview words during fixations on pretarget words (1% and 2% of data for deaf and hearing readers, respectively); trials with regression from target words were removed for FFD and GD analyses because of possibly incomplete first-pass foveal processing of target words (3% and 3% of data for deaf and hearing readers, respectively). Finally, we excluded the trials with early or late display change (i.e., display changes were triggered during fixations) because readers are more likely to perceive a display change at this time (19% trials). Taken together, the final dataset excluded 28% and 25% data from the deaf and the hearing readers, respectively, and the remaining data were evenly distributed across conditions.

Inferential statistics are based on planned comparisons for the related and the identical previews with the unrelated preview as a reference condition. We estimated model parameters of variance components for subjects and for items (at both levels of target-character and target-word) as well as variance components for subjects, and subject-related experimental main effects (i.e., varying intercepts and slopes), using the *lmer* program of the *lme4* package (Bates & Maechler, 2013) in the R environment for statistical computing and graphics (R Core Development Team, 2013). In LMMs, estimates 1.96 times larger than their standard errors are interpreted as significant at the 5% level, this is because given the number of subjects and the large number of observations for each subject, the *t*-statistic in LMMs (i.e., M/SE) effectively corresponds to the *z*-statistic. We report log-transformed dependent variables of fixation times in the models because analyses of residuals and inspection of duration distributions strongly suggested that log-transformation is required to meet LMM assumptions (Kliegl, Masson, & Richter, 2010). Analyses for untransformed and log-transformed durations yielded the same pattern of significance.

RESULTS

A total of 6297, 6297, 8021 and 8070 observations contributed to the following FFD, GD, GPT and TRT analyses. As shown in Table 2 and Figure 2, the two groups of readers did not differ in their FFDs (b=.003, SE=.044, t=0.07), but the hearing readers had longer GDs, GPTs and TRTs than the deaf readers (63ms, b=.128, SE=.047, t=2.70; 78ms, b=.144, SE=.053, t=2.74 and 73ms, b=.141, SE=.051, t=2.77). The identical PB (i.e., a contrast between the identical and the unrelated conditions) significantly interacted with the subject group in all four measures (FFD: b=−.092, SE=.031, t=−2.99; GD: b=−.132, SE=.035, t=−3.79; GPT: b=−.134, SE=.036, t=−3.73 and TRT: b=−.119, SE=.036, t=−3.30), indicating that the identical PB was larger for the hearing readers (FFD: 68ms, b=−.189, SE=.019, t=−10.08; GD: 103ms, b=−.233, SE=.022, t=−10.50; GPT: 135ms, b=−.269, SE=.021, t=−12.50 and TRT: 127ms, b=−.260, SE=.021, t=−12.44) than for the deaf readers (FFD: 35ms, b=−.096, SE=.019, t=−5.14; GD: 49ms, b=−.102, SE=.023, t=−4.38; GPT: 71ms, b=−.134, SE=.023, t=−5.77 and TRT: 77ms, b=−.139, SE=.023, t=−6.16). There was also a marginally significant interaction between orthographic PB (i.e., a contrast between the orthographic and the unrelated conditions) and subject group in FFD (b=−.051, SE=.028, t=−1.82) with similar numerical but not statistically reliable trends in GD (b=−.022, SE=.032, t=−0.66), GPT (b=−.034, SE=.031, t=−1.07) and TRT (b=−.024, SE=.031, t=−0.79), indicating that the hearing readers had larger orthographic PB (FFD: 34ms, b=−.096, SE=.019, t=−5.01; GD: 33 ms, b=−.071, SE=.023, t=−3.12; GPT: 49ms, b=−.093, SE=.022, t=−4.31 and TRT: 48ms, b=−.094, SE=.021, t=−4.49) than the deaf readers did though the effect was significant for both groups (FFD: 18ms, b=−.046, SE=.019, t=−2.51; GD: 26ms, b=−.049, SE=.023, t=−2.12; GPT: 36ms, b=−.061, SE=.023, t=−2.56 and TRT: 43ms, b=−.071, SE=.022, t=−3.15).

Crucially, the interactions between semantic PB (i.e., a contrast between the semantic and the unrelated conditions) and subject group were reliable in FFD (b=.062, SE=.028, t=2.25), GPT (b=−.062, SE=.032, t=−1.96) and TRT (b=−.062, SE=.031, t=−1.99). Interestingly, these interactions appeared in different directions in first-pass and second-pass measures. There was a highly reliable and early semantic PB in FFD among the deaf readers (21ms, b=−.056, SE=.019, t=−2.98), but not among the hearing readers (4ms, b=.004, SE=.019, t=0.22). On the other hand, the effect emerged in late measures for the hearing readers (GPT: 22ms, b=−.042, SE=.022, t=−1.96 and TRT: 18ms, b=−.037, SE=.021, t=−1.75) and the deaf readers even showed a numerical semantic *preview cost* effect (GPT: 14ms, b=.021, SE=.023, t=0.88 and TRT: 13ms, b=.027, SE=.023, t=1.18). The semantic PB effects in GD, as well as phonological PB effects in all duration measures, were far from significance in both groups [abs(t)-values<1.7].

Another question we asked in the present study is whether readers with different levels of reading fluency make different use of parafoveal information. Although the phonological PB was not significant when averaged across all subjects with different levels of reading fluency and across all trials with different preview durations, it is of theoretical interest to test whether it depends on reading ability and preview duration, because results from previous studies indicate an dependence of PB upon these factors (e.g., Chace et al., 2005; Kliegl et al., 2013; Yan et al., 2012b). Therefore, with these two additional covariates the extended LMM for FFD totally included four fixed factors: (a) identical and related PBs, (b) subject group, (c) individual reading fluency and (d) a continuous predictor of log-transformed GD on the pretarget word. There were no four-way interactions for identical and semantic PBs (t-values<1.7). The four-way interactions concerning phonological (b=1.110e-3, SE=5.469e-4, t=2.03) and orthographic PBs (b=1.086e-3, SE=5.355e-4, t=2.03) were both significant and illustrated in Figure 2. The phonological PB was significant among the deaf readers when they had high reading fluency and when they had longer GDs on pretarget words. On the other hand, there was no evidence for phonological PB depending on these factors for the hearing readers. The orthographic PB increased with increasing preview duration for the hearing young readers but not for the deaf readers.

DISCUSSION

In the present study, we manipulated different types of information (orthographic, phonological and semantic) available in the parafovea during the reading of Chinese sentences and examined whether deaf and hearing readers make use of these different types of parafoveal information differently. Previously, Bélanger et al. (2013) reported no evidence for phonological PB for English deaf readers, strongly suggesting direct access to semantics from orthography. The results from the present study demonstrate that Chinese deaf readers process parafoveal semantic information more efficiently than hearing readers matched on reading fluency and suggest that readers' lexical processing can be flexibly adjusted across individuals utilizing information available in their linguistic environment.

Presumably due to direct access to semantics in Chinese (Chen & Shu, 2001), parafoveal processing of high-level information such as (morpho-)semantics have been consistently reported among skilled hearing readers (Pan, Laubrock, & Yan, 2014; Tsai et al., 2012; Yan et al., 2009; Yan et al., 2012a; Yang, Wang, Tong, & Rayner, 2012; Yen, Tsai, Tzeng, & Hung, 2008). However, it is an open question whether such effects can be transferred to typically developing readers of Chinese. No evidence was found for early parafoveal semantic processing among primary school readers, suggesting that fast extraction of semantic information from the parafovea has not yet become an automatic process by grade-5 and effective semantic preprocessing may require more reading experience. As predicted for the deaf readers, however, we observed early and strong semantic activation from information in the parafovea. We interpret this result as direct evidence for higher parafoveal semantic processing efficiency among deaf readers compared to reading-level matched controls. The marginally smaller orthographic PB among the deaf readers may also suggest that they process graphemic information faster and thus make connections to semantics faster than the hearing readers.

Comparison across different measures indicates strikingly different time course of semantic information usage between the two groups. Semantic PB effects appeared only in late measures for the young hearing readers, indicating that semantic information requires a relatively long time to express its effect. For the deaf readers, the semantic PB effect was positively significant in FFD and started to disappear in refixations (as shown in GD). It is also worth noting that both the young hearing readers in the present study and hearing adults in previous studies investigating effects of semantic PB (Tsai et al., 2012; Yan et al., 2009; 2012a) showed a different pattern from our deaf readers: Indeed, the semantic PB was larger in GD than in FFD for hearing readers. In addition, the semantic PBs in FFD for hearing adults were of smaller magnitude (in the range of 10ms to 17ms across experiments) than that of the deaf readers in the present study (24ms). These comparisons suggest that the semantic effect among Chinese hearing readers, even adults, may need time to develop and emerge slightly later than what was found here for the deaf adult readers of Chinese, who, crucially, read at a lower level than the adult readers in previous studies. Therefore, the different pattern of semantic activation observed in the present study is unlikely linked to chronological age difference. Although the target characters were the same as in Yan et al. (2009), the sentence frames used in the present experiment were different (due to different reading proficiency of the subjects); thus a direct comparison is not possible. It will be of great interest for future research to further explore the influence of chronological age on parafoveal processing.

Interestingly, the semantic PB effect for the deaf readers turned out to be a numerical interference in late second-pass measures, suggesting early benefits for semantic previews were cancelled by subsequent processing costs. We suggest that due to the high semantic processing rate, the deaf readers were able to pick up the non-overlapping semantic representations between the preview and the target and thus the accumulated diverging semantic information eventually disrupted the processing of the target word in late processing stage. The semantic ‘preview cost’ effect is in principle in agreement with a recent report by Pan et al. (2014) who showed that semantic previews lead to longer durations on target words in oral reading. These results strongly suggest different efficiency in semantic parafoveal processing between the two groups. The Chinese deaf readers may also benefit from language-specific features such as optimization for semantics and high information density; whether such effects can be generalized to deaf readers of alphabetic languages remains of great theoretical importance.

Phonological PB was not significant when averaged across all subjects with different reading fluency and all trials with different preview durations. This is possibly due to their overall low reading level, as was found for the less-skilled readers in (Chace et al., 2005), and to the fact that Chinese script is less optimized for phonological activation than alphabetical scripts are (see Tsang & Chen, 2012, for a review). However, interestingly, we found that for deaf readers, under certain conditions (higher reading level and longer preview durations), a phonological PB was apparent. In the present study, we used reading fluency as a continuous predictor because it is known that more detailed information is kept when using a continuous rather than a dichotomized predictor (Baayen, 2008), as was used in Bélanger et al., 2013 (and may have obscured effects of phonological PBs). The results support the notion that parafoveal phonological extraction in Chinese requires both long preview duration and high parafoveal processing efficiency (Tsai et al., 2012). Thus, results from the present study appear to be in agreement with the notion that the use of phonological information correlates with reading level among deaf readers (Harris & Moreno, 2006; Wang, Trezek, Luckner & Paul, 2008). However, whether the phonological

PB in the present study can be solely interpreted as phonological processing should be considered tentatively. Deaf individuals are known to access some levels of phonological information developed via nonauditory channels (Kelly & Barac-Cikoja, 2007). In mainland China, students on school entry are taught pinyin, which is a shallow, alphabetic-based orthography that provides a way to represent the sound of Chinese characters and helps acquisition of new vocabulary among first and second graders. Experimental evidence suggests that beginning hearing readers do not rely on pinyin when they encounter familiar characters (Yan, Miller, Li, & Shu, 2008). In the present study, given the relatively rich vocabulary knowledge of the young hearing readers, pinyin probably has minimal activation during reading. On the other hand, pinyin is also used as a standard input method for entering Chinese characters/words on computer and cellphone systems. Critically, using pinyin for typing is likely more often employed for the deaf as compared to the hearing readers given their age difference. Therefore, an alternative explanation to the phonological PB might be a non-auditory representation of the character associated with character-typing (see McQuarrie & Parrila, 2009 for a similar argument). Follow-up studies are needed to further investigate phonological processing among Chinese deaf readers, for example, by testing deaf readers from Hong Kong who have mastered Chinese without pinyin.

Acknowledgments

This research was funded by Deutsche Forschungsgemeinschaft Grant (KL 955/18 and LA 2884/2), by Major Project of National Social Science Foundation of China (13&ZD188) and by Grant #R03DC011352 from the National Institute On Deafness And Other Communication Disorders (NIDCD). We gratefully acknowledge comments by Keith Rayner, Dennis Drieghe, Sarah White and Elizabeth Schotter on earlier drafts. Data and R scripts are available at the Potsdam Mind Research Repository (http://read.psych.uni-potsdam.de/PMR2/).

REFERENCES

Baayen, RH. Practical data analysis for the language sciences with R. Cambridge, MA: Cambridge University Press; 2008.

Bates, D.; Maechler. lme4: Linear mixed-effects models using S4 classes (R package version 0.999999-4) [Computer software]. Vienna, Austria: R Foundation for Statistical Computing; 2013.

Beijing Language Institute Publisher. Modern Chinese Word Frequency Dictionary (in Chinese). Beijing: Beijing Language Institute Publisher; 1986.

Bélanger NN, Baum SR, Mayberry RI. Reading difficulties in adult deaf readers of French: Phonological codes, not guilty! Scientific Studies of Reading. 2012; 16(3):263–285.

Bélanger NN, Mayberry RI, Rayner K. Orthographic and phonological preview benefits: Parafoveal processing in skilled and less-skilled deaf readers. The Quarterly Journal of Experimental Psychology. 2013; 66(11):2237–2252. [PubMed: 23768045]

Bélanger NN, Slattery TJ, Mayberry RI, Rayner K. Skilled deaf readers have an enhanced perceptual span in reading. Psychological Science. 2012; 23(7):816–823. [PubMed: 22683830]

Chace KH, Rayner K, Well AD. Eye movements and phonological preview benefit: Effects of reading skill. Canadian Journal of Experimental Psychology. 2005; 59:209–217. [PubMed: 16248500]

Chen H-C, Shu H. Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. Psychonomic Bulletin & Review. 2001; 8(3):511–518. [PubMed: 11700902]

Doctor EA, Coltheart M. Children’s use of phonological encoding when reading for meaning. Memory & Cognition. 1980; 8(3):195–209. [PubMed: 7392946]

Engbert R, Kliegl R. Microsaccades uncover the orientation of covert attention. Vision Research. 2003; 43:1035–1045. [PubMed: 12676246]

Harris M, Moreno C. Speech reading and learning to read: A comparison of 8-year-old profoundly deaf children with good and poor reading ability. Journal of Deaf Studies and Deaf Education. 2006; 11(2):189–201. [PubMed: 16410610]

Inhoff AW. Two stages of word processing during eye fixations in the reading of prose. Journal of Verbal Learning and Verbal behavior. 1984; 23:612–624.

Kelly, L.; Barac-Cikoja, D. The comprehension of skilled deaf readers: The roles of word recognition and other potentially critical aspects of competence. In: Cain, K.; Oakhill, J., editors. Children's comprehension problems in oral and written language: A cognitive perspective. New York: Guilford Press; 2007. p. 244-279.

Kliegl R, Hohenstein S, Yan M, McDonald S. How preview space/time translate into preview cost/benefit for fixation durations during reading. The Quarterly Journal of Experimental Psychology. 2013; 66:581–600. [PubMed: 22515948]

Kliegl R, Masson MEJ, Richter EM. A linear mixed model analysis of masked repetition priming. Visual Cognition. 2010; 18:655–681.

Liu W, Inhoff AW, Ye Y, Wu C. Use of parafoveally visible characters during the reading of Chinese sentences. Journal of Experimental Psychology: Human Perception and Performance. 2002; 28:1213–1227. [PubMed: 12421066]

Mayberry RI, del Giudice AA, Lieberman AM. Reading achievement in relation to phonological coding and awareness in deaf readers: A meta-analysis. Journal of Deaf Studies and Deaf Education. 2011; 16:164–188. [PubMed: 21071623]

McQuarrie L, Parrila R. Phonological representations in deaf children: Rethinking the "Functional Equivalence" hypothesis. Journal of Deaf Studies and Deaf Education. 2009; 14:137–154. [PubMed: 18635579]

Pan J, Laubrock J, Yan M. Parafoveal processing in silent and oral Chinese reading. Manuscript submitted for publication. 2013

Pan J, McBride-Chang C, Shu H, Liu H, Zhang Y, Li H. What is in the naming? A 5-year longitudinal study of early rapid naming and phonological sensitivity in relation to subsequent reading skills in both native Chinese and English as a second language. Journal of Educational Psychology. 2011; 103:897–908.

R Development Core Team. R: A language and environment for statistical computing. Wien: R Foundation for Statistical Computing; 2013.

Rayner K. The perceptual span and peripheral cues during reading. Cognitive Psychology. 1975; 7:65–81.

Schotter ER. Synonyms provide semantic preview benefit in English. Journal of Memory and Language. 2013; 69:619–633.

Schotter ER, Angele B, Rayner K. Parafoveal processing in reading. Attention, Perception, & Psychophysics. 2012; 74:5–35.

Tsai J-L, Kliegl R, Yan M. Parafoveal semantic information extraction in Traditional Chinese reading. Acta Psychologica. 2012; 141:17–23. [PubMed: 22820455]

Tsang Y-K, Chen H-C. Eye movement control in reading: Logographic Chinese versus alphabetic scripts. PsyCh Journal. 2012; 1(2):128–142.

Wang Y, Trezek B, Luckner J, Paul PV. The role of phonology and phonologically related skills in reading instruction for students who are deaf or hard of hearing. American Annals of the Deaf. 2008; 153(4):396–407. [PubMed: 19146076]

Yan M, Kliegl R, Richter EM, Nuthmann A, Shu H. Flexible saccade-target selection in Chinese reading. The Quarterly Journal of Experimental Psychology. 2010; 63:705–725. [PubMed: 19742387]

Yan, M.; Miller, KF.; Li, H.; Shu, H. What is the place for pinyin in beginning Chinese reading? Evidence from eye movements. In: Rayner, K.; Shen, D.; Bai, X.; Yan, G., editors. Cognitive and cultural influences on eye movements. New York: Psychology Press; 2008.

Yan M, Richter EM, Shu H, Kliegl R. Chinese readers extract semantic information from parafoveal words during reading. Psychonomic Bulletin & Review. 2009; 16:561–566. [PubMed: 19451385]

Yan M, Risse S, Zhou X, Kliegl R. Preboundary duration modulates semantic preview benefit for word n+1 and n+2 in Chinese reading. Reading and Writing. 2012b; 25:1093–1111.

Yan M, Zhou W, Shu H, Kliegl R. Lexical and sub-lexical semantic preview benefits in Chinese reading. Journal of Experimental Psychology: Learning, Memory and Cognition. 2012a; 38:1069–1075.

Yang J, Wang S, Tong X, Rayner K. Semantic and plausibility effects on preview benefit during eye fixations in Chinese reading. Reading and Writing. 2012; 25:1079–1091. [PubMed: 22593625]

Yen M-H, Tsai J-L, Tzeng OJL, Hung DL. Eye movements and parafoveal word processing in reading Chinese sentences. Memory and Cognition. 2008; 36:1033–1045. [PubMed: 18630209]

Zhou W, Kliegl R, Yan M. A validation of parafoveal semantic information extraction in reading Chinese. Journal of Research in Reading. 2013; 36:S51–S63.

Orthographic preview:

心理咨询师认为子女成家后和父母在一起住利弊兼有。

*

Phonological preview:

心理咨询师认为子女承家后和父母在一起住利弊兼有。

*

Semantic preview:

心理咨询师认为子女立家后和父母在一起住利弊兼有。

*

Unrelated preview:

心理咨询师认为子女乡家后和父母在一起住利弊兼有。

*

Identical preview / Target sentence:

心理咨询师认为子女成家后和父母在一起住利弊兼有。

*

N N+1

The target sentence translates as: *Counselors believe that married children living with their parents can have both advantages and disadvantages.*

Figure 1.

A set of sample sentences. The preview characters occupy the position of the first character of the target word N+1 and are replaced by the target characters as soon as the reader's eyes (as indexed by the asterisks in the figure) cross the invisible vertical boundary located between words N and N+1.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

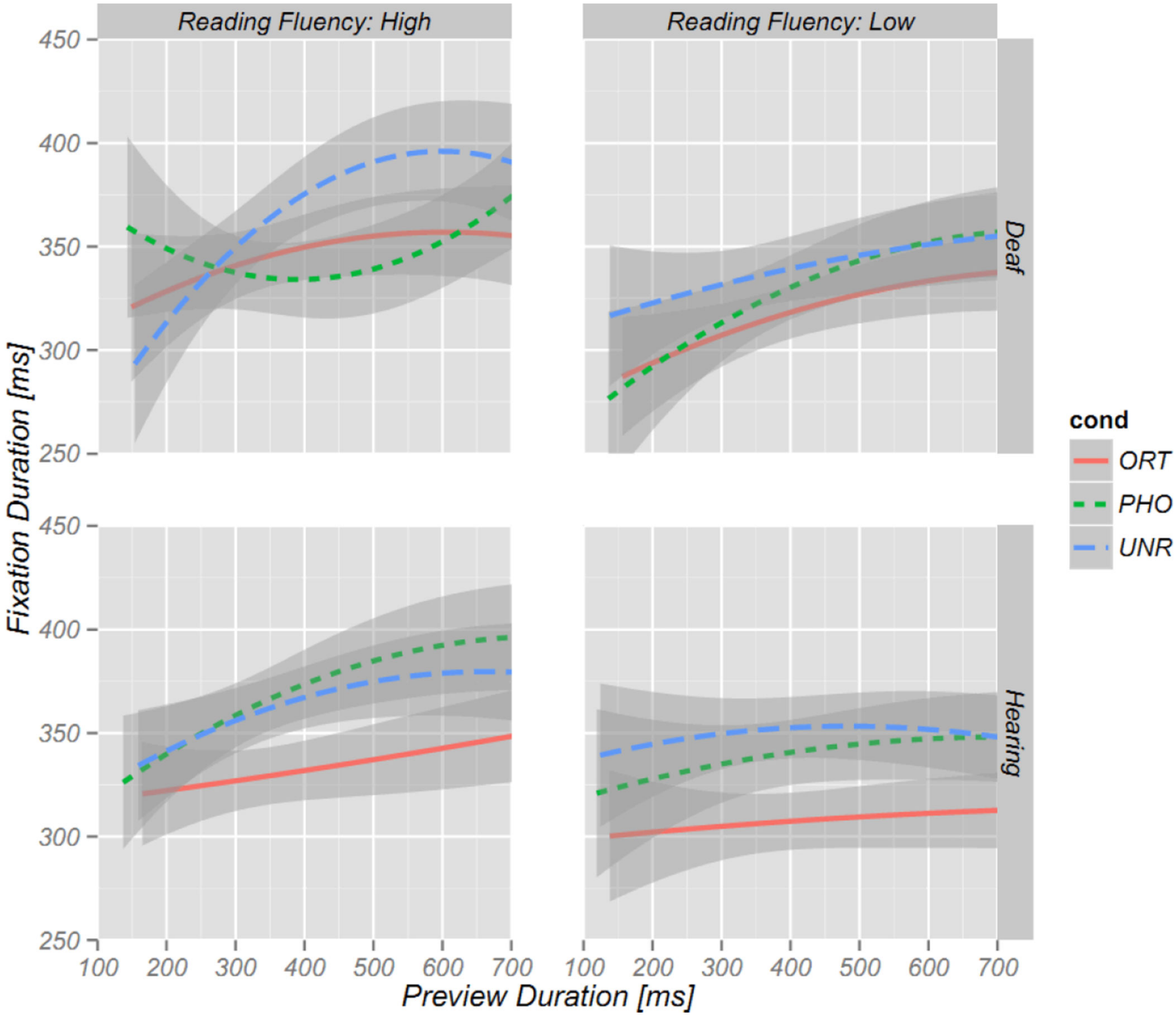

Figure 2.

Regression of first-fixation duration (FFD) on target word N+1 as a function of GD on word N, broken down by reading fluency and subject group. Solid lines stand for orthographic preview condition, dotted lines stand for phonological preview condition and dashed lines stand for unrelated preview condition. The x-axis is the GD on pretarget word N (in milliseconds). Between-subject and between-item differences for dependent variable and covariance in LMM were removed prior to regressions. Figure was generated with ggplot2 (Wickham, 2013). Error bands show 95% confidence intervals.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Character Properties

	Identical	Orthographic	Phonological	Semantic	Unrelated
Character	成	戍	承	立	乡
Translation	**complete**	**Garrison**	**have**	**found**	**village**
Pronunciation	**cheng2**	**shu4**	**cheng2**	**li4**	**xiang1**
Log Freq	2.6 (0.6)	2.5 (0.9)	2.5 (0.9)	2.6 (0.8)	2.6 (0.8)
N. Strokes	5.0 (2.1)	4.7 (1.8)	4.9 (1.7)	5.8 (2.8)	4.8 (1.9)
Ort. Rating		**3.8 (0.7)**	1.6 (0.3)	1.5 (0.3)	1.6 (0.3)
Pho. Rating		1.2 (0.3)	**4.3 (0.6)**	1.2 (0.2)	1.1 (0.2)
Sem. Rating		1.2 (0.4)	1.2 (0.2)	**4.1 (0.6)**	1.2 (0.2)

Note. Means (and standard deviations, in parentheses) of log frequency per million (Beijing Language Institute Publisher, 1986), number of strokes, and ratings of orthographic, phonological and semantic relatedness between target and non-identical previews are provided.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Fixation measures

	Identical	Orthographic	Phonological	Semantic	Unrelated
D-FFD	322 (66)	340 (67)	345 (67)	330 (63)	354 (61)
H-FFD	290 (38)	324 (54)	358 (66)	362 (67)	359 (70)
D-GD	431 (76)	459 (85)	468 (98)	471 (83)	479 (89)
H-GD	442 (88)	509 (97)	554 (109)	535 (104)	544 (101)
D-GPT	465 (82)	502 (100)	532 (115)	548 (101)	534 (108)
H-GPT	481 (117)	564 (120)	606 (131)	593 (130)	614 (130)
D-TRT	463 (83)	501 (100)	536 (116)	554 (97)	541 (108)
H-TRT	489 (119)	566 (122)	607 (132)	598 (129)	615 (127)

Note. Means (and standard deviations in parentheses) of first-fixation duration (FFD), gaze duration (GD), go-pass time (GPT) and total reading time (TRT) for the deaf (D) and the hearing (H) readers. Values are computed across subjects' means.