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Preview fixation duration modulates identical and semantic preview benefit in Chinese reading

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Abstract Semantic preview benefit from parafoveal words is critical for proposals of distributed lexical processing during reading. Semantic preview benefit has been demonstrated for Chinese reading with the boundary paradigm in which unrelated or semantically related previews of a target word $N+1$ are replaced by the target word once the eyes cross an invisible boundary located after word N (Yan et al., 2009); for the target word in position $N+2$, only identical compared to unrelated-word preview led to shorter fixation times on the target word (Yan et al., in press). A reanalysis of these data reveals that identical and semantic preview benefits depend on preview duration (i.e., the fixation duration on the preboundary word). Identical preview benefit from word $N+1$ increased with preview duration. The identical preview benefit was also significant for $N+2$, but did not significantly interact with preview duration. The previously reported semantic preview benefit from word $N+1$ was mainly due to single- or first-fixation durations following short previews. We discuss implications for notions of serial attention shifts and parallel distributed processing of words during reading.

Keywords Eye movement · Parafoveal processing · Semantic · Chinese

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Introduction

The inspection time of each word during sentence reading strongly depends on the words' properties such as its length or frequency of occurrence in a certain language, suggesting that the duration of fixating a word reflects the time needed to process and lexically access its entry in the mental lexicon (for a review see Rayner, 2009). The spatial extent of visual processing during a fixation goes much further beyond the currently fixated word, extending at most up to 4 letters to the left and 14–15 letters to the right of fixation during reading of alphabetic languages (McConkie & Rayner, 1975; Rayner & Bertera, 1979) and 1 character to the left and 2–3 characters to the right of fixation during reading Chinese (C.-H. Tsai & McConkie, 1995; Inhoff & Liu, 1997, 1998). This area, which must be visible for a normal reading rate, is called the *perceptual span* (McConkie & Rayner, 1975). In principle, with a sufficiently short word to the right of a fixated word N, chances are that even the word beyond the next one (i.e., word $N+2$) may fall into the perceptual span. Whether information of word $N+2$ can be extracted during reading of alphabetic languages is currently a highly controversial discussion (Rayner, Juhasz, & Brown, 2007; Angele, Slattery, Yang, Kliegl, & Rayner, 2008; for positive results see Kliegl, Risse, & Laubrock, 2007; Risse, Engbert, & Kliegl, 2008; Risse & Kliegl, in press). Here we report a reanalysis of published data and demonstrate that semantic information extraction from words $N+1$ and $N+2$ during Chinese reading depends on preview duration. Preview duration of words $N+1$ or $N+2$ is defined as the time that the reader looks at word N before moving to words $N+1$ or $N+2$.

is that phonology plays an important mediating role leading to a word's meaning being activated relatively late (Van Orden, 1987; Van Orden, Pennington, & Stone, 1990; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), when compared to some other languages such as Chinese, which we will elaborate below.

In contrast to the view of late semantic activation, evidence from fast priming studies suggests that semantic information facilitates recognition of a foveal target word during a narrow time window at a very early stage with prime durations of about 30 ms (Sereno & Rayner, 1992). In a recent study using a combination of the fast priming and boundary paradigm, Hohenstein, Laubrock, and Kliegl (2010) extended this research to investigate parafoveal semantic priming. Hohenstein et al. varied the duration of parafoveal semantic primes for word $N + 1$. They obtained a semantic preview benefit with a parafoveal prime duration of 125 ms, but not for shorter ones (Experiment 1 and 2). When the saliency of the parafoveal prime word was increased, the semantic preview benefit was significant with an 80-ms but not with the 125-ms parafoveal prime duration (Experiment 3). Thus, in addition to providing evidence for parafoveally processing semantic information in alphabetic languages, the results suggest that semantic preview benefit is time dependent with facilitation due to semantic relatedness of parafoveal preview only during a specific, possibly only early, time window.

Chinese script and semantic preview benefit

Eye-movement control during reading Chinese shares many basic characteristics of alphabetic writing systems (Yan, Kliegl, Richter, Nuthmann, & Shu, 2010). However, there are also important differences, especially with respect to parafoveal processing of semantic information. Chinese script uses square-shaped characters with different levels of visual complexity as the basic writing units; they all occupy the same amount of horizontal extent. There are two important features that make Chinese script particularly well-suited for the demonstration of parafoveal semantic processing. First, in comparison with alphabetic languages, it is generally accepted that Chinese characters are mapped more closely to meaning than to phonology (see Hoosain, 1991, for a summary) whereas the contribution of phonological activation during identification is comparatively small (see Feng, Miller, Shu, & Zhang, 2001, for a review). Second, most Chinese words are only one or two characters long (Yu et al., 1985). Given that a Chinese character typically occupies the space of 3 letters in alphabetic languages (i.e., J. L. Tsai & McConkie, 2003), on average, word $N + 1$ is closer to the point of fixation on word N in Chinese than in alphabetic languages.

Yan, Richter, Shu, and Kliegl (2009) investigated parafoveal processing of Chinese words in position $N + 1$ by manipulating the first character in two-character words and found a reliable preview benefit for characters semantically related to the target. Yan, Kliegl, Shu, Pan, and Zhou (in press) used the same material as Yan et al., but they moved the target word to the $N + 2$ position by inserting a high-frequency or low-frequency word in position $N + 1$. They reported an $N + 2$ preview benefit (see also Yang, Wang, Xu, & Rayner, 2009), but only when the preview character was identical to the target character; the effect was larger with a high-frequency word $N + 1$. Importantly, there was no significant preview benefit when the previewed character was semantically related to the target but there was a trend in this direction.

In the boundary paradigm the previews are always either available or denied for the entire duration of the fixation prior to the boundary. This raises the possibility that the failure to find a reliable semantic preview benefit for word $N + 2$ in Chinese could be due to a dependence of this effect on a specific time window. Hohenstein et al.'s (2010) results suggest that parafoveal semantic information may facilitate processing as early as 125 ms. As preboundary fixation durations are usually much longer than 125 ms (and under the readers' control), these long previews may have masked a semantic preview benefit during a specific time window in alphabetic scripts.

Sequential attention shift vs. processing gradient models

Statistically reliable evidence for semantic preprocessing of word $N + 2$ provides important constraints for theoretical accounts of serial attention shift (e.g., Engbert & Kliegl, 2001; Reichle, Liversedge, Pollatsek, & Rayner, 2009) and processing gradient models of eye-movement control (e.g., Engbert & Kliegl, 2010; Engbert, Nuthmann, Richter, & Kliegl, 2005; Reilly & Radach, 2003, 2006). Serial attention shift (SAS) models like E-Z Reader (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle et al., 2009; see Engbert & Kliegl, 2001, for a different variant) assume that lexical processing occurs only at the attended word and that attention shifts to the next word only after lexical access is completed. Thus, semantic preview benefit is problematic for serial attention shift models (e.g., Reichle et al., 2009, for a review). On the other hand, processing gradient (PG) models such as SWIFT (Engbert et al., 2005) or Glenmore (Reilly & Radach, 2003, 2006) assume distributed lexical processing in the perceptual span. As a consequence of this principle, PG models generally allow semantic preprocessing for words $N + 1$ and even for words $N + 2$ as long as they are in the perceptual span. However, due to the acuity-related decrease of processing efficiency with eccentricity from the current fixation location, semantic preprocessing for word $N + 2$ might be too weak to be detected in alphabetic languages. In Chinese, as a language in which the information is more densely packed, the semantic information extraction has been shown for word $N + 1$ and may even be visible for word $N + 2$ for an appropriate time window of preview.

The present study

The current study reports a reanalysis of Yan et al. (2009) and Yan et al. (in press). In the boundary paradigm, preview duration of word $N + 1$ and word $N + 2$ is 'controlled' by participants' fixations on the preboundary word N. When a saccade is executed that crosses the invisible boundary, the display change of word $N + 1$ and word $N + 2$ is triggered and terminates the parafoveal prime. Therefore, the variability of preview durations may act like different parafoveal prime durations and can be used as a covariate for the size and direction of various preview effects.

Using the data from the two prior studies, we focus on the size of various informative preview effects (i.e., identical, semantic, orthographic, and phonological relative to unrelated preview words) as a function of the preview single-fixation duration for parafoveal processing of word $N + 1$ and $N + 2$ in Chinese reading.

Method

Subjects

All participants of the experiments were native Chinese students from Beijing Normal University with normal or corrected to normal vision. For the eye-tracking experiments, 48 students were tested for Data Set 1 with a manipulation of word $N + 1$ (Yan et al., 2009) and an independent sample of 74 students contributed to Data Set 2 with a manipulation of word $N + 2$ (Yan et al., in press). Also, 51 students who did not participate in the two eye-tracking experiments were recruited for three norming studies of relatedness between previews and targets.

Material

Forty-eight simple non-compound characters were selected as targets, which served as the first character of word $N + 1$ in Data Set 1 and the first character of word $N + 2$ in Data Set 2. Each target character was embedded into a two-character target word, only the identity condition provided legal word-level preview. For each target character, four types of preview characters were selected for orthographically related, phonologically related, semantically related, and unrelated preview conditions. As shown in Table 1, there were no differences between the five preview types with respect to visual complexity as indexed by number of strokes

Table 1 Means (standard deviations) of frequency (per million), number of strokes and relatedness ratings of target and preview characters

	Target	Preview				
		Identical	Orthographic	Phonological	Semantic	Unrelated
Example	永	永	水	用	久	向
Meaning	Forever	Forever	Water	Usage	Long	Towards
Pronunciation	yong3	yong3	shui3	yong4	jiu3	xiang4
Frequency	1,150 (1,728)	1,150 (1,728)	1,154 (1,435)	1,197 (1,757)	1,164 (1,721)	1,163 (1,573)
No. of strokes	5.0 (2.1)	5.0 (2.1)	4.8 (1.8)	5.1 (1.9)	5.5 (2.6)	4.9 (1.9)
Orthographic rating			**3.8 (0.8)**	1.6 (0.3)	1.5 (0.4)	1.6 (0.3)
Phonological rating			1.2 (0.3)	**4.3 (0.6)**	1.2 (0.2)	1.1 (0.2)
Semantic rating			1.2 (0.3)	1.2 (0.1)	**4.1 (0.6)**	1.2 (0.2)

Ratings set in bold signify that independent ratings matched the intended experimental manipulation

($F = 1.0$, $p > .1$) and frequency ($F < 1$). The three relatedness ratings nicely reflected the intended design. Due to non-significant phonological preview benefit for word $N + 1$ in the first fixation analysis reported in Yan et al. (2009), this condition was removed from Data Set 2.

The invisible boundary that triggered the display change was located just to the left of character $N + 1$, which is the first character of the target word (word $N + 1$) in Data Set 1, and a single-character word prior to the first character of the target word (word $N + 2$) in Data Set 2. Eye movements were recorded with an EyeLink II system (500 Hz). Single sentences were presented on the vertical position one-third from the top of the screen of a 19-inch ViewSonic G90f monitor (1,024 × 768 resolution; frame rate 100 Hz) for Data Set 1 and a 21-inch Dell Trinitron Monitor (1,280 × 1,024 resolution; frame rate 100 Hz) for Data Set 2. Therefore, it took at most 16 ms to complete the display change for both data sets. The words before the boundary (i.e., word N) were also always two-character words. Each sentence was only presented once to a participant with the different preview types. A set of example sentences is shown in Fig. 1. Full details concerning the material, apparatus and procedure are available in Yan et al. (2009) and Yan et al. (in press).

(A)

Identical preview:

Orthographical preview:

Phonological preview:

Semantic preview:

Unrelated preview:

Target sentence:

Data analysis

Data were reduced to a fixation format using an algorithm for the binocular detection of saccades (Engbert & Kliegl, 2003). Sentences containing a blink or loss of measurement were deleted (i.e., 18% in Data Set 1 and 5% in Data Set 2). Analyses were based on right-eye fixations during first-pass reading. We distinguish between first fixation durations (FFDs; the first fixation on a word, irrespective of the number of fixations), single fixation durations (SFDs; cases in which a word was inspected with exactly one fixation), and gaze durations (GDs; the sum of fixations during the first reading of the word). Cases with FFDs shorter than 60 ms or longer than 600 ms were excluded (1% of all fixations in Data Set 1 and 2% in Data Set 2). Further, trials with regressions from word N or $N + 1$ for Data Set 1 as well as from word N, $N + 1$ or $N + 2$ for Data Set 2 were excluded (10% trials in Data Set 1 and 11% trials in Data Set 2). For the five preview conditions in Data Set 1, there were 1,052 observations in the LMM model for FFD and GD analyses and 769 observations for SFD analysis; for the four preview conditions in Data Set 2, there were 4,024 observations in the LMM model for FFD and GD analyses and 3,385 observations for SFD analysis.

Inferential statistics are based on planned comparisons for the related and the identity previews with the unrelated preview as reference. Estimates are based on a linear mixed model (LMM) with crossed random effects for subjects and items using the *lmer* program of the *lme4* package (Bates & Maechler, 2010) in the R environment for statistical computing and graphics (R-Core Development Team, 2010). Estimates larger than 2 SE (i.e., $t > 2$) are interpreted as significant. Analyses of residuals and inspection of duration distributions strongly suggested that log-transformation is required to meet LMM assumptions. Therefore, we used log-transformed durations for LMMs.

Results

The main goal of the present research was to test whether the duration of the fixation prior to the display change in cases when only a single fixation is made on the preboundary word modulates preview benefit from semantically related parafoveal words in positions $N + 1$ and $N + 2$ in reading of Chinese. FFDs, SFDs, and GDs on word $N + 1$ (Data Set 1) and $N + 2$ (Data Set 2) were used as dependent variables. In the LMMs, these effects of interest translate into interactions between the continuous predictor of single-fixation duration on preboundary word N and planned comparisons of semantic, orthographic, phonological (only in Data Set 1), and identical preview with an unrelated preview as baseline (i.e., treatment contrasts with unrelated preview as reference category). Main effects were evaluated at the mean of the log preview SFD (i.e., the covariate was centered). Thus, the intercept represents the mean log FFD, mean log SFD, or mean log GD on the target word for the unrelated condition. Analyses using preview SFD as covariate yielded the clearest dissociation of effects, possibly because single-fixation cases carry few mislocated fixations (Nuthmann, Engbert, & Kliegl, 2005) and are reliable indicators of successful parafoveal word segmentation (Yan et al., 2010).

We note that similar trends (not al a s signi cant) ere also present for FFDs and GDs on the preboundar ord N. We also test the critical results in post-hoc comparisons for short and long pre ie durations, using the mean of the log-transformed single ation duration as cut-off point.

Pre ie bene t for ord $N + 1$

shown for FFDs (panel A) and GDs (panel B). The vertical line indicates the mean log preview duration (i.e., the value at which main effects are evaluated).

With FFD as dependent variable (Fig. 2a), the identical preview effect was remarkably large and also largely independent of preview duration (i.e., distance between identical and unrelated conditions is large and the hypothesis that the two lines are parallel cannot be rejected; interaction t-values for FFDs, also SFD, <1).

On 17, 30, 25, 34 and 29% (for identical, orthographic, phonological, semantic and unrelated preview conditions, respectively) of all valid trials, first fixations on target word were followed by refixations. With GD as dependent variable (Fig. 2b), the identical preview benefit significantly increased with preview duration ($b = -0.28$, SE $= 0.14$, $t = -2.0$, for the interaction of identical vs. unrelated preview and preview duration).[1] The increase in the preview benefit resulted from the divergence in GD for unrelated and identical previews; neither the numeric GD increase for the unrelated preview ($t = 1.36$) nor the numeric GD decrease for the identical preview ($t = -1.37$) was significant by itself.

The similarity between FFDs and GDs in slopes for the identical conditions (bold dotted lines in Fig. 2) suggests that refixation rate did not depend on preview duration. The divergence in slopes for the unrelated conditions (negative for FFDs and positive for GDs; bold solid lines in Fig. 2) suggests that refixation rate increased during preview. This was confirmed in post-hoc analyses of refixation rate, using a binary measure of fixating the target once or more than once as dependent variable in a generalized linear mixed model (GLMM): Refixation rate increased significantly during preview in the unrelated preview condition ($b = 0.25$, SE $= 0.10$, $t = 2.5$), but refixation rate did not decrease significantly in the identical preview condition ($b = -0.07$, SE $= 0.11$, $t = -0.6$). Traditionally, the unrelated preview condition serves as the baseline for the computation of the preview benefit. The increase in refixation rate with preview duration in this condition may be interpreted as evidence for a preview cost. This is a very important result because it suggests that classical preview benefits may arise in part as a consequence of *preview cost* associated with long previews of unrelated words.

Semantic preview benefit

The main effect of semantic preview was also significant for FFDs and marginally significant for SFDs ($b = -0.07$, SE $= 0.03$, $t = -2.7$, and $b = 0.06$, SE $= 0.03$, $t = -1.8$, respectively) and there was a numeric trend for GDs ($b = -0.06$, SE $= 0.04$, $t = -1.6$). These (tendencies to) main effects were strongly qualified by interactions with preview duration (i.e., preview SFDs; $b = 0.16$, SE $= 0.10$, $t = 1.7$, and $b = 0.23$, SE $= 0.12$, $t = 2.0$, for FFDs and SFDs, respectively; see Footnote 1). The dashed bold line (semantic preview) and the solid bold line

[1] We also tested the interaction between preview duration and preview benefits in a LMM with subgroup as two-level factor replacing the covariate (i.e., logarithm preview single fixation duration), which is more compatible with the traditional ANOVA route. In this analysis we failed to replicate the significant interactions (identical preview benefit in GD analysis: $b = -0.09$, SE $= 0.07$, $t = -1.2$; semantic preview benefit: $b = 0.08$, SE $= 0.05$, $t = 1.5$; $b = 0.09$, SE $= 0.06$, $t = 1.5$; for FFD and SFD analyses, respectively). We present this also as evidence that not everything is significant in LMM (as is sometimes surmised).

(unrelated preview) in Fig. 2a shows that FFDs with semantic preview were as short as those for identical preview given a 150 ms preview duration, but were as long as those for unrelated preview with a preview duration of 400 ms. Thus, the semantic preview benefit differed from the identical preview benefit: the semantic preview benefit was large for short previews and vanished with increasing preview duration whereas identical preview benefit was present for all preview durations. The effects were not significant with GD as the dependent variable.

Orthographic and phonological preview benefits

There was a significant main effect for orthographic preview in FFDs ($b = -0.06$, $SE = 0.03$, $t = -2.1$; SFDs: $t = -1.7$, GDs: $t = -1.7$). There was no significant effect of the phonological preview condition (all t-values < 1.4).

None of the interactions between orthographic or phonological preview and preview duration was significant, that is the slopes for the orthographic (dot-dash) and phonological (dashed) previews did not differ significantly from the one for the unrelated-preview baseline. In a follow-up LMM with identical preview as reference conditions, these slopes were not significantly different from this condition either (all t-values < 1.4).

Preview effects for grouped short and long previews

Identical preview. As a further illustration of the significant interaction, we separated trials into two subgroups with a cutoff point of mean log preview SFD of 217 ms; the value at which the main effects in the above LMMs were evaluated (see Table 2). This criterion led to 572 observations for FFD and GD analyses as well as 420 observations for SFD analysis for the short preview group, and 480 observations for FFD and GD analyses as well as 349 observations for SFD analysis for the long preview group. Results indicated that identical preview benefit in GDs was significant in each of the subgroups and increased in effect size with

Table 2 Means (standard errors) of first-fixation duration (FFD), single-fixation duration (SFD) and gaze duration (GD) on word $N + 1$ from Data Set 1, broken down by mean log preview single-fixation durations

	No. obs	Identical	Orthographic	Phonological	Semantic	Unrelated
Short preview						
FFD	572	216 (9)	235 (10)	249 (9)	231 (9)	259 (7)
SFD	420	214 (10)	240 (12)	256 (11)	237 (11)	263 (8)
GD	572	260 (16)	307 (17)	322 (17)	308 (16)	332 (15)
Long preview						
FFD	480	219 (12)	255 (11)	254 (11)	254 (12)	262 (9)
SFD	349	218 (13)	246 (13)	257 (13)	259 (14)	259 (11)
GD	480	257 (23)	333 (23)	326 (23)	340 (23)	370 (20)

Means and standard deviations are computed across grand means increased preview duration ($b = 0.23$, SE $= 0.05$, $t = 4.7$ and $b = 0.31$, SE $= 0.06$, $t = 5.2$ for short and long previews, respectively).

Semantic preview. The semantic preview benefit was also modulated by preview duration: It was significant for short previews ($b = 0.10$, SE $= 0.03$, $t = 2.9$ and $b = 0.10$, SE $= 0.04$, $t = 2.3$; for FFD and SFD analyses, respectively) but not for long ones (both t-values $< .07$).

Orthographic and phonological preview. Orthographic preview benefit was significant for short previews, $b = 0.09$, SE $= 0.04$, $t = 2.3$ and $b = 0.09$, SE $= 0.04$, $t = 2.0$; for FFD and SFD analyses, respectively; both t-values were smaller than 1 for long previews. Note in the LMM this effect was significant as a main effect. The phonological preview benefit tended to be significant for long previews ($b = 0.10$, SE $= 0.06$, $t = 1.7$ and $b = 45$ ms, SE $= 23$ ms, $t = 1.9$; for analyses in log-transformed and original metrics, respectively) compared to short previews (both t-values < 0.7).

Preview benefit for word $N + 2$

Skipping of word $N + 1$

In the second data set with target words in position $N + 2$, all of the words in position $N + 1$ were one character long. Consequently, there was a high skipping probability associated with this word (54%). It is well known that fixations after skipped words are longer than on average. In the present experiment skipping of $N + 1$ increased FFDs by 23 ms, SFDs by 23 ms and GDs by 58 ms on target word $N + 2$. These effects were highly significant in the LMM ($b = 0.09$, SE $= 0.01$, $t = 7.7$; $b = 0.08$, SE $= 0.01$, $t = 8.2$; $b = 0.18$, SE $= 0.01$, $t = 12.5$; for FFD, SFD and GD analyses, respectively). Skipping of word $N + 1$, however, did not interact with preview duration or preview conditions (all t-values < 1.4).

Identical preview

In general, preview effects were much weaker for word $N + 2$ than for word $N + 1$ (compare Fig. 3 for word $N + 2$ and Fig. 2 for $N + 1$). The largest effect in this data set was again the main effect of identical preview ($b = -0.05$, SE $= 0.01$, $t = -3.8$; $b = -0.05$, SE $= 0.01$, $t = -3.7$; $b = -0.07$, SE $= 0.02$, $t = -4.2$); for FFD, SFD and GD analyses, respectively, but none of the interactions with preview duration were significant (all $t < 1$). In a follow-up LMM, FFDs, SFDs, and GDs after identical preview were also significantly shorter compared to semantic or orthographic preview (all $t > 2.65$).

Semantic preview

Despite the strongly reduced preview modulation, the bold dashed line for semantic preview and bold solid line for unrelated preview represent a significant interaction

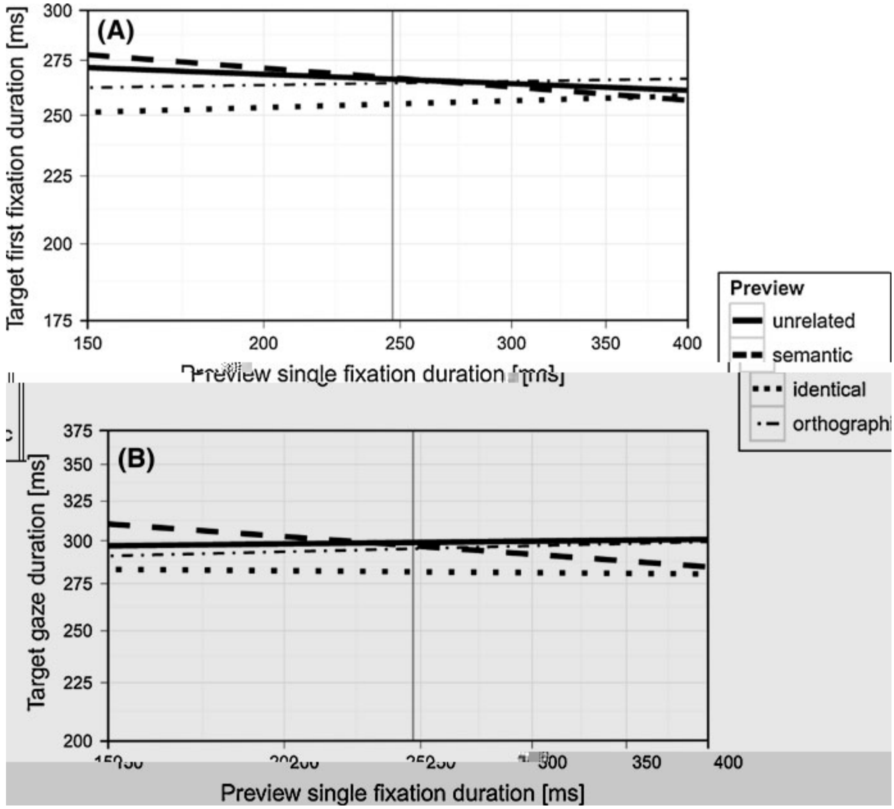

Fig. 3 Linear regression of rst- ation duration (**a**) and ga e duration (**b**) on ord $N+2$ on single- ation duration on ord N for unrelated (*bold-solid*), semantic (*bold-dashed*), identical (*bold-dotted*) and orthographic (*simple dashed*) preview conditions using logarithmic scales for both a es. The *vertical line* indicates the mean log single- ation duration on ord N. Bet een-subject and bet een-item differences for dependent variable and covariance in the LMM ere removed prior to regressions. Figure as generated ith *ggplot2* (Wickham, 2009)

bet een preview duration and semantic preview bene t for GD anal sis ($b = -0.11$, SE $= 0.05$, $t = -2.0$).[2] Again, e observed a crossover pattern, but this time the semantic preview effect as negative for shorter than average preview durations and positive for longer than average ones (i.e., semantic preview bene t; see Fig. 3b). This negative difference as not signi cant in the subgroup of short previe s, but neither as the positive difference for long previe s (see belo). The interaction as not predicted. Therefore, the result is in need of independent replication before it is used for substantive interpretations.

[2] This interaction also reached signi cance in a LMM using a logic grouping factor ($b = -0.06$, SE $= 0.03$, $t = -1.9$).

Table 3 Means (standard errors) of first-fixation duration (FFD), single-fixation duration (SFD) and gaze duration (GD) on word $N + 2$ from Data Set 2, broken down by mean log preview single-fixation durations

	No. obs	Identical	Orthographic	Semantic	Unrelated
Short preview					
FFD	2,222	248 (5)	257 (4)	266 (5)	263 (6)
SFD	1,855	245 (5)	259 (5)	265 (5)	260 (6)
GD	2,222	267 (8)	281 (8)	293 (8)	286 (9)
Long preview					
FFD	1,802	259 (6)	275 (6)	271 (6)	270 (6)
SFD	1,530	259 (6)	274 (6)	273 (6)	272 (6)
GD	1,802	285 (9)	298 (9)	298 (9)	312 (9)

Means and standard deviations are computed across grand means

Orthographic preview

The main effect of orthographic preview and its interaction with preview duration were not significant (all t-values < 1.2).

Preview benefit for grouped short and long previews

Post-hoc breakdown of trials by mean log preview duration (i.e., 247 ms in original metric) did not reveal significant semantic or orthographic preview benefits for any of the groups.[3] As shown in Table 3, there was only a numerical trend of a semantic and orthographic preview benefit with long previews for GD analyses (semantic preview benefit: $b = 0.04$, SE $= 0.02$, $t = 1.6$; $b = 0.02$, SE $= 0.02$, $t = 0.9$; for trials with long and short previews, respectively. For analyses of orthographic preview benefit: $b = 0.03$, SE $= 0.02$, $t = 1.4$; $b = 0.02$, SE $= 0.02$, $t = 0.7$; for trials with long and short previews, respectively). The lack of significance in the post-hoc analysis is a consequence of the loss of statistical power associated with using a dichotomized factor derived from a continuous covariate of preview duration (e.g., Baayen, 2008).

Finally, the identical preview benefit was significant for both groups ($M = 27$ ms, $b = 0.08$, SE $= 0.02$, $t = 3.2$ and $M = 19$ ms, $b = 0.06$, SE $= 0.02$, $t = 2.7$; for trials with long and short previews, respectively), with a numerically larger effect for long previews.

[3] Split of trials by preview single-fixation duration at 240 ms led to balanced groups in number of observations and more representatively demonstrative results: For semantic preview benefit with long previews, No. obs $= 1{,}958$, $b = 0.04$, SE $= 0.02$, $t = 1.8$ and $b = 17$ ms, SE $= 9$, $t = 2.0$; for analyses in log-transformed and original metrics, respectively; for orthographic preview benefit with long preview, $b = 0.03$, SE $= 0.02$, $t = 1.5$ and $b = 16$ ms, SE $= 9$, $t = 1.8$; for analyses in log-transformed and original metrics, respectively. Identical preview benefit was also numerically larger for long ($b = 0.08$, SE $= 0.02$, $t = 3.5$ and $b = 30$ ms, SE $= 9$, $t = 3.4$; for analyses in log-transformed and original metrics, respectively) than for short previews ($b = 0.06$, SE $= 0.02$, $t = 2.7$ and $b = 19$ ms, SE $= 8$, $t = 2.4$; for analyses in log-transformed and original metrics, respectively). All other t-values were smaller than 1.

Discussion

In alphabetic languages, studies using the boundary paradigm in a natural sentence reading task have so far failed to demonstrate preview benefit of semantically related parafoveal previews (see Rayner et al., 2003, for a review). Recently, such

Liversedge (2005) who partitioned their data on the median for participants and conditions could be due to reduced statistical power for dichotomized covariates.

The detection of the increase of preview benefit from word $N + 1$ across preview duration reported here probably requires the use of a continuous measure of preview duration and statistically more powerful techniques (such as LMM) than were used in the earlier studies. Our results that identical preview benefit increased with preview duration is in agreement with Schroyens, Vitu, Brysbaert, and d'Ydewalle (1999) who presented a sequence of three words with an invisible boundary between the first and second word of the triad, manipulating preview of word $N + 1$ during preboundary fixations on word N, and reported larger preview benefit on target word $N + 1$ with increasing pretarget durations.

Semantic preview benefit

The "orthography-to-phonology-to-semantics" route (Coltheart et al., 2001; Van Orden, 1987; Van Orden et al., 1990) assumes a sequential activation with access to word meaning in a relatively late stage. We suspect that this route to word recognition is more dominant in English than Chinese, which is known as a writing system with a close association between graphic form and meaning (see Hoosain, 1991, for a summary). For example, there is strong evidence for direct access from orthography to semantics with phonological mediation bypassed under some circumstances (Chen & Shu, 2001; Meng, Jian, Shu, Tian, & Zhou, 2008; Zhou & Marslen-Wilson, 1999, 2000). Against this background of research, it is not surprising that parafoveally previewing a semantically related character significantly reduces the subsequent fixation time on this target. Indeed, recent studies of Chinese reading using the boundary paradigm demonstrated reliable semantic preview benefit from word $N + 1$ for simple (Yan et al., 2009) and compound characters (Yang, Wang, Tong, & Rayner, 2010).

The failure to find evidence for a semantic preview benefit for word $N + 1$ in alphabetic scripts (Altarriba et al., 2001; Rayner et al., 1986) and for word $N + 2$ in Chinese (Yan et al., in press) may have been due to the fact that the preview was displayed throughout the whole fixation duration on word N. Hohenstein et al. (2010) controlled the duration of the parafoveal semantic preview and demonstrated that semantic preview benefit might be restricted to an early time window.

The present study is a reanalysis of data from Yan et al. (2009) and Yan et al. (in press). The dependence of semantic preview benefit on preview duration was tested with the interaction between preview duration and the contrast of semantic and unrelated preview. Facilitation due to semantic preview of word $N + 1$ was observed only for preview fixations shorter than 217 ms; semantic preview benefit was not significant for long preview fixations. The LMM results suggest that accumulation of information specific to the meaning of the semantically related preview word may interfere with lexical access of the target word. FFDs following a short semantic preview are similar to those following a short identical preview, but FFDs following a long semantic preview are similar to those following a long unrelated previe . Thus, a semanticall related previe ord changes from being functionall identical ith the target ord itself to being functionall unrelated to the target ord.

Orthographic and phonologic previe bene t

A time dependenc analogous to the one observed for semantic previe bene t as also obtained for orthographic previe bene t ith signi cant facilitation for short previe of ord $N + 1$. Finall , in line ith a relativel late stage of phonolog activation in Chinese sentence reading (Feng et al., 2001), the phonological previe bene t for ord $N + 1$ as mainl observed in trials ith long previe s.

Time course of parafoveal processing and attention

The time course of parafoveal processing has been discussed as an opportunit to at5en(Eiterat5e633d)]2i(1scn20.799015.6945001

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We very much doubt that any of the currently available computational models, such as the E-Z Reader SAS model (Reichle et al., 1998; 2009; see Rayner, Li, & Pollatsek, 2007, for an adaptation for reading Chinese) or models built around the assumption of processing gradients, such as the SWIFT model (Engbert et al., 2005) or Glenmore (Reilly & Radach, 2003, 2006) are ready to reproduce such competition of lexical activations. With its well-defined linguistic processing components, the Glenmore model might have the best chance to capture the time-dependent inhibition effects of parafoveally extracted incorrect information.

In general, the present results favor the notion of a 'sweet spot' in time at which parafoveal information is integrated across saccades (e.g., Schiepers, 1980). They are certainly compatible with the assumption of parallel distributed processing. Statistically reliable evidence for semantic information extraction (either facilitation or inhibition) from word $N + 1$ is in favor of parallel models.

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