This is a preprint of an article whose final and definite form will be published in:
Reading and Writing: An Interdisciplinary Journal (in press)
DOI 10.1007/s11145-010-9274-7; © Springer Science+Business Media B.V. 2010

Preview Fixation Duration Modulates Identical and Semantic Preview Benefit in Chinese Reading

Ming Yan (1, 2), Sarah Risse (2), Xiaolin Zhou (1), & Reinhold Kliegl (2),

(1) Department of Psychology, Peking University, P. R. China, and

(2) Department of Psychology, University of Potsdam, Germany

Running head: Parafoveal semantic processing in Chinese

Address for correspondence:

Ming Yan

Department of Psychology, Peking University

Yiheyuan Road 5th, 100871 Beijing, P.R. China

Email: mingyan@pku.edu.cn

Tel.: +86 010 62766211

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.

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.

Evidence for and against semantic preview benefit in alphabetic scripts

The boundary paradigm (Rayner, 1975) has been extensively used to investigate what type of information is obtained from a parafoveal preview. In this paradigm, preview of a target word is deprived by presenting an alternative word (or nonword) that parafoveally occupies the position during pretarget fixations. During a saccade that crosses an invisible boundary located at the end of the pretarget word, the preview word is replaced by the correct word. If correct preview of the target word is provided in parafoveal vision compared to if it is denied, fixation durations on the target word are reduced when it is subsequently fixated. This *preview benefit* is consistently interpreted as evidence for preprocessing a neighbouring word N+1 during prior fixations on word N, integrating the parafoveal information across saccades, and thus facilitating its later foveal processing.

With manipulations of the information overlap between the preview and the target word, it has been shown that in Western alphabetic languages orthographic (Balota, Pollatsek, & Rayner, 1985; Inhoff, 1989; Rayner, 1975) and phonological codes (Ashby, Treiman, Kessler, & Rayner, 2006; Miellet & Sparrow, 2004; Chace, Rayner, & Well, 2005) are extracted during preboundary fixations and facilitate word recognition of word N+1 when it is fixated. So far, there has been no such evidence of a benefit from a semantically related parafoveal preview (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Rayner, Balota, & Polatsek, 1986; see also Rayner, White, Kambe, Miller, & Liversedge, 2003, for a review). One possible explanation for this null effect 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, 2009). 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, Zhang, 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. It is explained as a consequence of mislocated fixations (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 ($F=1.0$, $p>.1$) 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.

■ TABLE 1

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 (1024 x 768 resolution; frame rate 100 Hz) for Data Set 1 and a 21-inch Dell Trinitron Monitor (1280 x 1024 resolution; frame rate 100 Hz) for Data Set 2. Therefore, it took at most 16ms 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 Figure 1. Full details concerning the material, apparatus and procedure are available in Yan et al. (2009) and Yan et al. (in press).

■ FIGURE 1

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). For the

five preview conditions in Data Set 1, there were 1052 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 4024 observations in the LMM model for FFD and GD analyses and 3385 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, Kliegl, Richter, Nuthmann, & Shu, 2009). We note that similar trends (not always significant) were also present for FFDs and GDs on the preboundary word N. We also test the critical results in post-hoc comparisons for short and long preview durations, using the mean of the log-transformed single fixation duration as cut-off point.

Preview benefit for word N+1

Identical preview benefit

The main effect of identical preview was highly significant (b = -0.16, SE = 0.03, t = -6.1; b = -0.17, SE = 0.03, t = -5.5; b = -0.27, SE = 0.04, t = -7.2; for FFD, SFD and GD analyses, respectively). In Figure 2, the identical preview benefit corresponds to the difference between the unrelated (bold solid) and identical (bold dotted) lines. It is 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).

FIGURE 2

With FFD as dependent variable (Figure 2A), the identical preview effect was remarkably large and also largely independent of preview duration for FFD analyses (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 (Figure 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 Figure 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 Figure 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) [1]. The dashed bold line (semantic preview) and the solid bold line (unrelated preview) in Figure 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 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).

TABLE 2

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 Figure 3 for word N+2 and Figure 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 between preview duration and semantic preview benefit for GD analysis (b = -0.11, SE = 0.05, t = -2.0) [2]. Again, we observed a crossover pattern, but this time the semantic preview effect was negative for shorter than average preview durations and positive for longer than average ones (i.e., semantic preview benefit; see Figure 3B). This negative difference was not significant in the subgroup of short previews, but neither was the positive difference for long previews (see below). The interaction was not predicted. Therefore, the result is in need of independent replication before it is used for substantive interpretations.

Orthographic preview

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

FIGURE 3

Preview benefit for grouped short and long previews

Post-hoc breakdown of trials by mean log preview duration (i.e., 247ms 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.

TABLE 3

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 semantic facilitation effects were reported for an early time interval of parafoveal semantic priming (Hohenstein et al., 2010). Considering preview durations as a predictor for the size of different types of preview effects, the present study confirmed the notion of time-dependent parafoveal facilitation effects and extended it to sentence reading in Chinese. The most important results for previews of word N+1 were (a) that refixation rate increased with preview fixation duration in the unrelated condition, (b) that identical preview benefit in GDs increased with preview fixation duration, and (c) that semantic preview benefit in SFDs and FFDs occurred after short previews. The analyses of preview effects from word N+2 recovered the previously reported identical preview benefit. There was also a significant crossover interaction of semantic preview and preview duration. As the interaction was small and not expected, we will not attempt to interpret it.

Unrelated preview cost

During unrelated preview trials, GDs increased numerically, but not significantly across preview duration. There was, however, a significant increase in refixation rate. Such an increase with preview duration likely reflects interference with processing of the target word due to earlier or ongoing processing of the unrelated preview word. The unrelated preview condition usually serves as the baseline for the computation of preview benefit. Such preview benefit, however, may in part be due to processing cost induced by processing of unrelated words. The relation between gaze duration, refixation rate, and preview duration deserves to be followed up in detail.

Identical preview benefit

In the identical preview condition accumulation of information during preview is beneficial at all preview durations. For GDs on word N+1 identical preview benefit increased over preview duration. This increase in the difference between identical and unrelated previews was due to a numeric increase of unrelated GDs and numeric decrease of identical GDs; neither the identical nor the unrelated trends for preview duration was significant by itself. There was, however, a significant increase of refixation rate after unrelated previews. The fact that identical preview is facilitative for the entire duration of preview is in agreement with Inhoff, Radach and Eiter (2006) and Yen, Radach, Tzeng, Hung, and Tsai (2009) who reported reduction of durations on target words either if the target word was parafoveally visible only for the initial 140 ms of pretarget fixations or only during the end of the preboundary fixation (i.e., after 140 ms until a saccade to word N+1 terminated parafoveal processing). The absence of a significant modulation effect of the preview time on identical preview benefit in a boundary paradigm reported by White, Rayner, and 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 preview. Thus, a semantically related preview word changes from being functionally identical with the target word itself to being functionally unrelated to the target word.

Orthographic and phonologic preview benefit.

A time dependency analogous to the one observed for semantic preview benefit was also obtained for orthographic preview benefit with significant facilitation for short preview of word N+1. Finally, in line with a relatively late stage of phonology activation in Chinese sentence reading (Feng et al., 2001), the phonological preview benefit for word N+1 was mainly observed in trials with long previews.

Time course of parafoveal processing and attention

The time course of parafoveal processing has been discussed as an opportunity to test different assumptions on how attention relates to word processing during reading. Inhoff, Radach and Eiter (2006) postulated that SAS models predict parafoveal (lexical) information uptake during late periods of preboundary fixations that is after complete processing of the preboundary word N and the consequent shift of attention to the subsequent word N+1. In other words, SAS models may have difficulties to account for parafoveal effects during the beginning of the preboundary fixation.

There is another challenging result. The reduction of semantic preview benefit with long previews might be caused by a reduced perceptual span since long preboundary fixations could be an indicator of high processing difficulty (Henderson & Ferreira, 1990). However, given the fact that the identical preview benefit increased with preview duration, this perceptual span modulation assumption does not account for the current result. A more reasonable explanation is that the accumulated parafoveal semantic information eventually disrupted the processing of the target word. Yen, Tsai, Tzeng and Hung (2008) reported a similar finding in their Experiment 2: when the prior fixation duration was short (i.e., less than 220 ms), the semantic (or morphological) preview benefit amounted to 19 ms. This effect reduced to 4 ms when the prior fixation duration was long.

As McDonald (2005) pointed out, if several words are processed in parallel, cumulative preview benefit could be expected to increase with the time a target word resides in the perceptual span. This argument, however, can only be applied to identical preview benefit because it assumes that integration across saccades is

restricted to correct parafoveal information. In the boundary paradigm using non-identical previews, various kinds of "incorrect" parafoveal previews overlap with the later foveal target. We consider it as plausible that during preboundary fixations we accumulate not only positive evidence (which may later facilitate identification of the replaced target word) but also diverging evidence (which may interfere with target word identification). Therefore, as preview durations increase, facilitation of parafoveal preview may cancel and even result in disruptions.

We very much doubt that any of the currently available computational models, such as the E-Z Reader SAS model (Reichle et al., 1998; Reichle et al., 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.

REFERENCES

Altarriba, J., Kambe, G., Pollatsek, A., & Rayner, K. (2001). Semantic codes are not used in integrating information across eye fixations in reading: Evidence from fluent Spanish-English bilinguals. *Perception & Psychophysics, 63*, 875-890.

Angele, B., Slattery, T., Yang, J., Kliegl, R., & Rayner, K. (2008). Parafoveal processing in reading: Manipulating n+1 and n+2 previews simultaneously. *Visual Cognition*, *16*, 697-707.

Ashby, J., Treiman, R., Kessler, B., & Rayner, K. (2006). Vowel processing in silent reading: Evidence from eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 416-42.

Baayen, R. H. (2008) *Practical data analysis for the language sciences with R*. Cambridge, MA: Cambridge University Press.

Balota, D. A., Pollatsek, A., & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. *Cognitive Psychology, 17*, 364-390.

Bates, D. & Maechler, (2010). *lme4: Linear mixed-effects models using S4 classes*. R package version 0.999375-32. [Computer software]

Chace, K. H., Rayner, K., & Well, A. D. (2005). Eye movements and phonological parafoveal preview benefit: Effects of reading skill. *Canadian Journal of Experimental Psychology*, *59*, 209-217.

Chen, H.-C., & Shu, H. (2001). Lexical activation during the recognition of Chinese characters: evidence against early phonological activation. *Psychonomic Bulletin*

& Review, 8 (3), 511-518.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204-256. doi:10.1037//0033-295X.108.1.204

Engbert, R. & Kliegl, R. (2001). Mathematical models of eye movements in reading: a possible role for autonomous saccades. *Biological Cybernetics*, *85*, 77-87.

Engbert, R., & Kliegl, R. (2003). Microsaccades uncover the orientation of covert attention. *Vision Research, 43(9)*, 1035-1045. doi:10.1016/S0042-6989(03)00084-1

Engbert, R., & Kliegl, R. (2010). *Parallel graded attention models of reading.* Manuscript submitted for publication.

Engbert, R., Nuthmann, A., Richter, E., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112,* 777-813. doi:10.1037/0033-295X.112.4.777

Feng, G., Miller, K., Shu, H., & Zhang, H. (2001). Rowed to recovery: The use of phonological and orthographic information in reading Chinese and English. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27(4)*, 1079–1100.

Henderson, J. M., & Ferreira, F. (1990). Effects of foveal processing difficulty on the perceptual span in reading: Implications for attention and eye movement control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 417-429.

Hohenstein, S., Laubrock, J., & Kliegl, R. (2010). Semantic preview benefit in eye movements during reading: A parafoveal fast-priming study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36,* 1150-1170.

Hoosain, R. (1991). *Psycholinguistic implications for linguistic relativity: A case study of Chinese*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Inhoff, A.W. (1989). Parafoveal processing of words and saccade computation during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 544-555.

Inhoff, A.W., Radach, R., & Eiter, B. (2006). Temporal overlap in the processing of successive words in reading. A reply to Pollatsek, Reichle, and Rayner (2006). *Journal of Experimental Psychology: Human Perception and Performance, 32*, 1490-1495.

Inhoff, A. W., & Liu, W. (1997). The perceptual span during the reading of Chinese text. In H. C. Chen (Ed.), *Cognitive processing of Chinese and related Asian Languages* (pp. 243-266): The Chinese University of Hong Kong Press.

Inhoff, A. W., & Liu, W. (1998). The perceptual span and oculomotor activity during the reading of Chinese sentences. *Journal of Experimental Psychology: Human Perception and Performance, 24(1)*, 20-34.

Kliegl, R., Risse, S., & Laubrock, J. (2007). Preview benefit and parafoveal-on-foveal effects from word n+2. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1250-1255. doi:10.1037/0096-1523.33.5.1250

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a

fixation in reading. *Perception & Psychophysics, 17*, 578-586.

McDonald, S. A. (2005). Parafoveal preview benefit in reading is not cumulative across multiple saccades. *Vision Research, 45*, 1829-1834.

Meng, X., Jian, J., Shu, H., Tian, X., & Zhou, X. (2008). ERP correlates of the development of orthographical and phonological processing during Chinese sentence reading. *Brain research, 1219*, 91-102. doi:10.1016/j.brainres.2008.04.052

Miellet S. & Sparrow L. (2004). Phonological codes are assembled before word fixation: Evidence from boundary paradigm in sentence reading. *Brain & Language, 90*, 299-310.

Nuthmann, A., Engbert, R., & Kliegl, R. (2005). Mislocated fixations during reading and the inverted optimal viewing position effect. *Vision Research*, *45*, 2201-2217.

R Development Core Team (2010). *R: A language and environment for statistical computing*. Wien: R Foundation for Statistical Computing. [Computer software]

Rayner, K. (1975). The perceptual span and peripheral cues during reading. *Cognitive Psychology, 7*, 65-81.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *The Quarterly Journal of Experimental Psychology, 62*, 1457–1506.

Rayner, K., Balota, D. A., & Pollatsek, A. (1986). Against parafoveal semantic preprocessing during eye fixations in reading. *Canadian Journal of Psychology,*

40, 473-483.

Rayner, K., & Bertera, J. H. (1979). Reading without a fovea, *Science, 206,* 468-469.

Rayner, K., Juhasz, B.J., & Brown, S.J. (2007). Do readers obtain preview benefit from word n+2? A test of serial attention shift versus distributed lexical processing models of eye movement control in reading. *Journal of Experimental Psychology: Human Perception & Performance, 33,* 230-245. doi:10.1037/0096-1523.33.1.230

Rayner, K., Li, X., & Pollatsek, A. (2007). Extending the E-Z Reader model of eye-movement control to Chinese readers. *Cognitive Science*, *31*, 1021-1034.

Rayner, K., White, S. J., Kambe, G., Miller, B., & Liversedge, S. P. (2003). On the processing of meaning from parafoveal vision during eye fixation in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movements* (pp.213-234). Amsterdam: Elsevier Science.

Reichle, E.D., Liversdege, S.P., Pollatsek, A., & Rayner, K. (2009). Encoding multiple words simultaneously in reading is implausible. *Trends in Cognitive Science, 13*, 115-119.

Reichle, E.D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, *105*, 125-157.

Reilly, R., & Radach, R. (2003). Glenmore: An interactive activation model of eye movement control in reading. In J. Hyönä, R. Radach, and H. Deubel (Eds.), *The mind's eye: Cognition and applied aspects of eye movement research* (pp. 429–456). Oxford, England: Elsevier.

Reilly, R., & Radach, R. (2006). Some empirical tests of an interactive activation model of eye movement control in reading. *Cognitive Systems Research*, *7*, 34–55.

Risse, S., Engbert, R., & Kliegl, R. (2008) Eye-movement control in reading: Experimental and corpus-analytic challenges for a computational model. In Rayner, K., Shen, D., Bai, X., & Yan, G. (Eds.), *Cognitive and cultural influences on eye movements* (pp.65-91). Tianjin People's Publishing House.

Risse, S., & Kliegl, R. (in press). Investigating age differences in the perceptual span with the N+2-boundary paradigm. *Psychology and Aging.*

Sereno, S. C., & Rayner, K. (1992). Fast priming during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 173-184.

Schiepers, C. (1980). Response latency and accuracy in visual word recognition. *Perception, & Psychophysics, 27*, 71-81.

Schroyens, W., Vitu, F., Brysbaert, M., & d'Ydewalle, G. (1999). Eye movement control during reading: Foveal load and parafoveal processing. *Quarterly Journal of Experimental Psychology*, *52A*, 1021-1046.

Tsai, C.-H., & McConkie, G. W. (1995). The perceptual span in reading Chinese text: A moving window study. Poster session presented at the Eighth European Conference on Eye Movements, Derby, UK.

Tsai, J. L., & McConkie, G. W. (2003). Where do Chinese readers send their eyes? In J. Hyönä, R. Radach & H. Deubel (Eds.), *The mind's eye: Cognitive and applied*

aspects of eye movement research (pp. 159-176). Oxford: Elsevier.

Van Orden, G. C. (1987). A rows is a rose: spelling, sound and reading. *Memory and Cognition, 15*, 181-198.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97*, 488-522.

White, S. J., Rayner, K., & Liversedge, S. P. (2005). The influence of parafoveal word length and contextual constraint on fixation durations and word skipping in reading. *Psychonomic Bulletin & Review* , *12*, 466-471.

Wickham, H. (2009). *ggplot2*. *Elegant graphics for data analysis.* Dordrecht: Springer.

Yan, M., Kliegl R., Richter, E. M., Nuthmann, A., & Shu, H. (2009). Flexible saccade-target selection in Chinese reading. *The Quarterly Journal of Experimental Psychology*. DOI: 10.1080/17470210903114858

Yan, M., Kliegl, R., Shu, H., Pan, J., & Zhou, X. (2010). Parafoveal load of word n+1 modulates preprocessing of word n+2. *Journal of Experimental Psychology: Human Perception and Performance*. doi: 10.1037/a0019329

Yan, M., Richter, E. M., Shu, H., & Kliegl, R. (2009). Chinese readers extract semantic information from parafoveal words during reading. *Psychonomic Bulletin & Review, 16,* 561-566.

Yang, J., Wang, S., Tong, X., & Rayner, K. (2010). Semantic and plausibility effects on preview benefit during eye fixations in Chinese reading. submitted.

Yang, J., Wang, S., Xu, Y., & Rayner, K. (2009). Do Chinese readers obtain preview benefit from word n+2? Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 1192-1204.

Yen, M.-H., Radach, R., Tzeng, O. J.-L., Hung, D. L., & Tsai, J.-L. (2009). Early parafoveal processing in reading Chinese sentences. *Acta Psychologica, 131,* 24-33.

Yen, M.-H., Tsai, J.-L., Tzeng, O. J.-L., & Hung, D. L. (2008). Eye movements and parafoveal word processing in reading Chinese sentences. *Memory and Cognition*, *36*, 1033-1045.

Yu, B., Zhang, W., Jing, Q., Peng, R., Zhang, G., & Simon, H. A. (1985). STM capacity for Chinese and English language materials. *Memory & Cognition, 13*, 202-207

Zhou, X., & Marslen-Wilson, W. (1999). Phonology, orthography, and lexical semantic activation in reading Chinese. *Journal of Memory and Language, 41*, 579-606.

Zhou, X., & Marslen-Wilson, W. (2000). The relative time course of semantic and phonological activation in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26(5)*, 1245-1265. doi:10.1037//0278-7393.26.5.1245

AUTHOR NOTE

This study was supported by Deutsche Forschungsgemeinschaft (KL 955/8, KL 955/15) to Reinhold Kliegl and Ralf Engbert and by the China Postdoctoral Science Foundation (20080440008, 200902025) to Ming Yan. We thank Sven Hohenstein, Kevin Miller, Keith Rayner, and an anonymous reviewer for helpful comments. Address for correspondence: Ming Yan, Department of Psychology, Peking University, 100871 Beijing, P.R. China, email: mingyan@pku.edu.cn. Reinhold Kliegl, Department of Psychology, University of Potsdam, 14476 Potsdam, Germany, email: kliegl@uni-potsdam.de.

FOOTNOTE

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).

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

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, N.obs = 1958, 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.

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

		Preview				
	Target	Identical	Ort.	Pho.	Sem.	Unrelated
Example	永	永	水	用	久	向
Meaning	forever	forever	water	usage	long	towards
Pronunciation	yong3	yong3	shui3	yong4	jiu3	xiang4
Frequency	1150 (1728)	1150 (1728)	1154 (1435)	1197 (1757)	1164 (1721)	1163 (1573)
N 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)
Ortho. rating			**3.8 (0.8)**	1.6 (0.3)	1.5 (0.4)	1.6 (0.3)
Phono. rating			1.2 (0.3)	**4.3 (0.6)**	1.2 (0.2)	1.1 (0.2)
Sem. rating			1.2 (0.3)	1.2 (0.1)	**4.1 (0.6)**	1.2 (0.2)

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.

		Short preview				
	N.Obs	Identical	Orthographic	Phonological	Semantic	Unrelated
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				
	N.Obs	Identical	Orthographic	Phonological	Semantic	Unrelated
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)

Note. Means and standard deviations are computed across grand means.

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.

		Short preview			
	N.Obs	Identical	Orthographic	Semantic	Unrelated
FFD	2222	248 (5)	257 (4)	266 (5)	263 (6)
SFD	1855	245 (5)	259 (5)	265 (5)	260 (6)
GD	2222	267 (8)	281 (8)	293 (8)	286 (9)
		Long preview			
	N.Obs	Identical	Orthographic	Semantic	Unrelated
FFD	1802	259 (6)	275 (6)	271 (6)	270 (6)
SFD	1530	259 (6)	274 (6)	273 (6)	272 (6)
GD	1802	285 (9)	298 (9)	298 (9)	312 (9)

Note. Means and standard deviations are computed across grand means.

Figure Captions

Figure 1. A set of example Chinese sentences using the boundary paradigm used in Data Set 1 (A) and Data Set 2 (B). The preview characters that were initially displayed in the target location were replaced by the target character as soon as the readers' eyes crossed the invisible boundary located between word N and word N+1.

Figure 2. Linear regression of first-fixation duration (panel A), and gaze duration (panel B) on word N+1 on single-fixation duration on word N for unrelated (bold-solid), semantic (bold-dashed), identical (bold-dotted), orthographic (simple dashed), phonological (simple dot-dashed) preview conditions using logarithmic scales for both axes. The vertical line indicates the mean log single-fixation duration on word N. Between-subject and between-item differences for dependent variable and covariance in the LMM were removed prior to regressions. Figure was generated with *ggplot2* (Wickham, 2009).

Figure 3. Linear regression of first-fixation duration (panel A) and gaze duration (panel B) on word N+2 on single-fixation duration on word N for unrelated (bold-solid), semantic (bold-dashed), identical (bold-dotted) and orthographic (simple dashed) preview conditions using logarithmic scales for both axes. The vertical line indicates the mean log single-fixation duration on word N. Between-subject and between-item differences for dependent variable and covariance in the LMM were removed prior to regressions. Figure was generated with *ggplot2* (Wickham, 2009).

Figure 1.

(A)

Identical preview:

许多人都认为爱情是人类永恒而经典的话题之一。

*

Orthographical preview:

许多人都认为爱情是人类水恒而经典的话题之一。

*

Phonological preview:

许多人都认为爱情是人类用恒而经典的话题之一。

*

Semantic preview:

许多人都认为爱情是人类久恒而经典的话题之一。

*

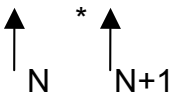
Unrelated preview:

许多人都认为爱情是人类向恒而经典的话题之一。

*

Target sentence:

许多人都认为爱情是人类永恒而经典的话题之一。



The target sentence is translated as *many people think that love is one of the most everlasting and classic topics*.

(B)

Identical preview:

雅典奥运会上刘翔冲过终点的永恒瞬间被人们铭记在心。

*

Orthographical preview:

雅典奥运会上刘翔冲过终点的水恒瞬间被人们铭记在心。

*

Semantic preview:

雅典奥运会上刘翔冲过终点的久恒瞬间被人们铭记在心。

*

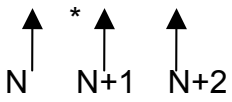
Unrelated preview:

雅典奥运会上刘翔冲过终点的向恒瞬间被人们铭记在心。

*

Target sentence:

雅典奥运会上刘翔冲过终点的永恒瞬间被人们铭记在心。



Target sentence is translated as *people will always remember the everlasting moment when Xiang Liu crossed the finishing line in the Athens Olympic Games*.

Figure 2.

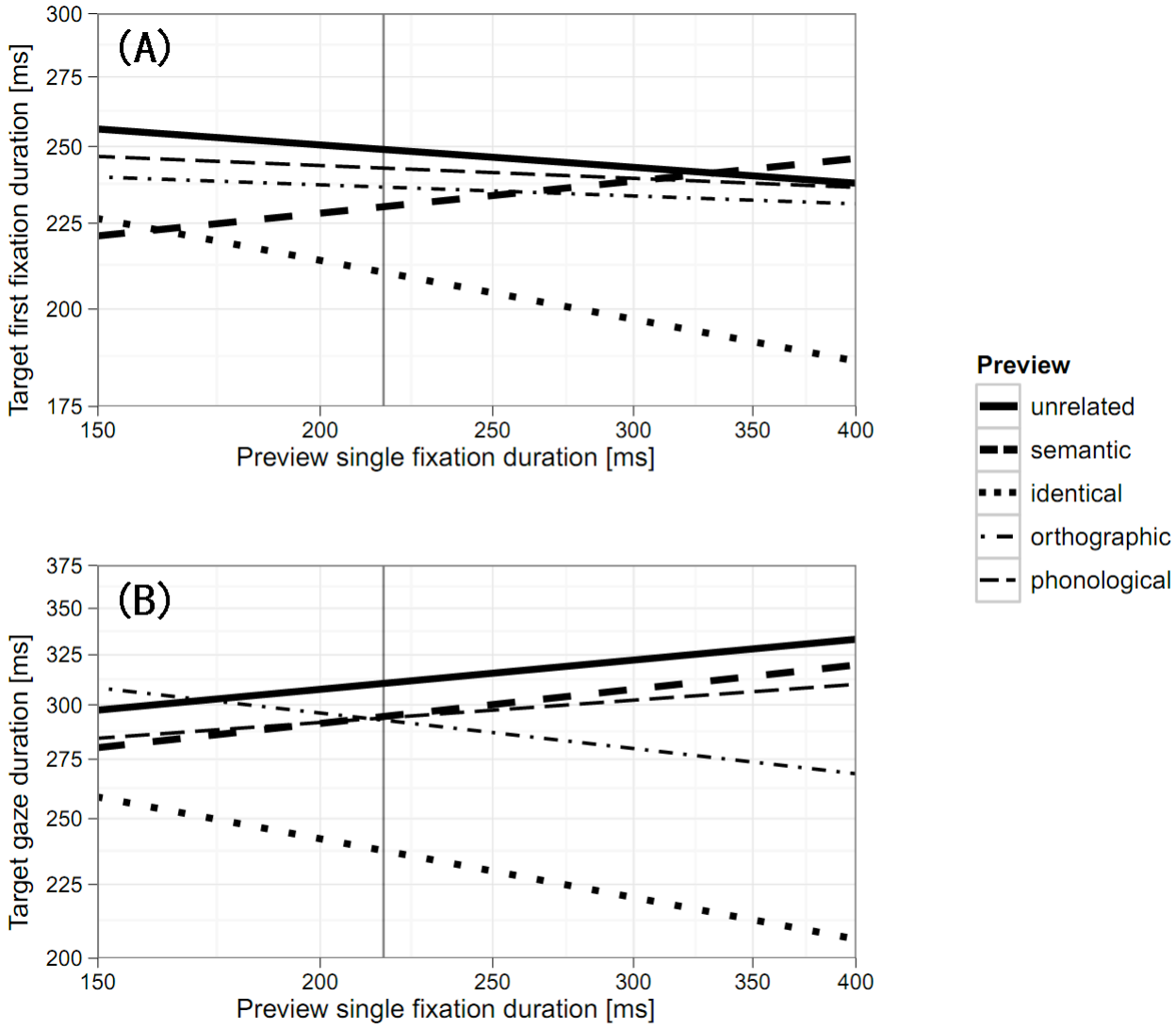
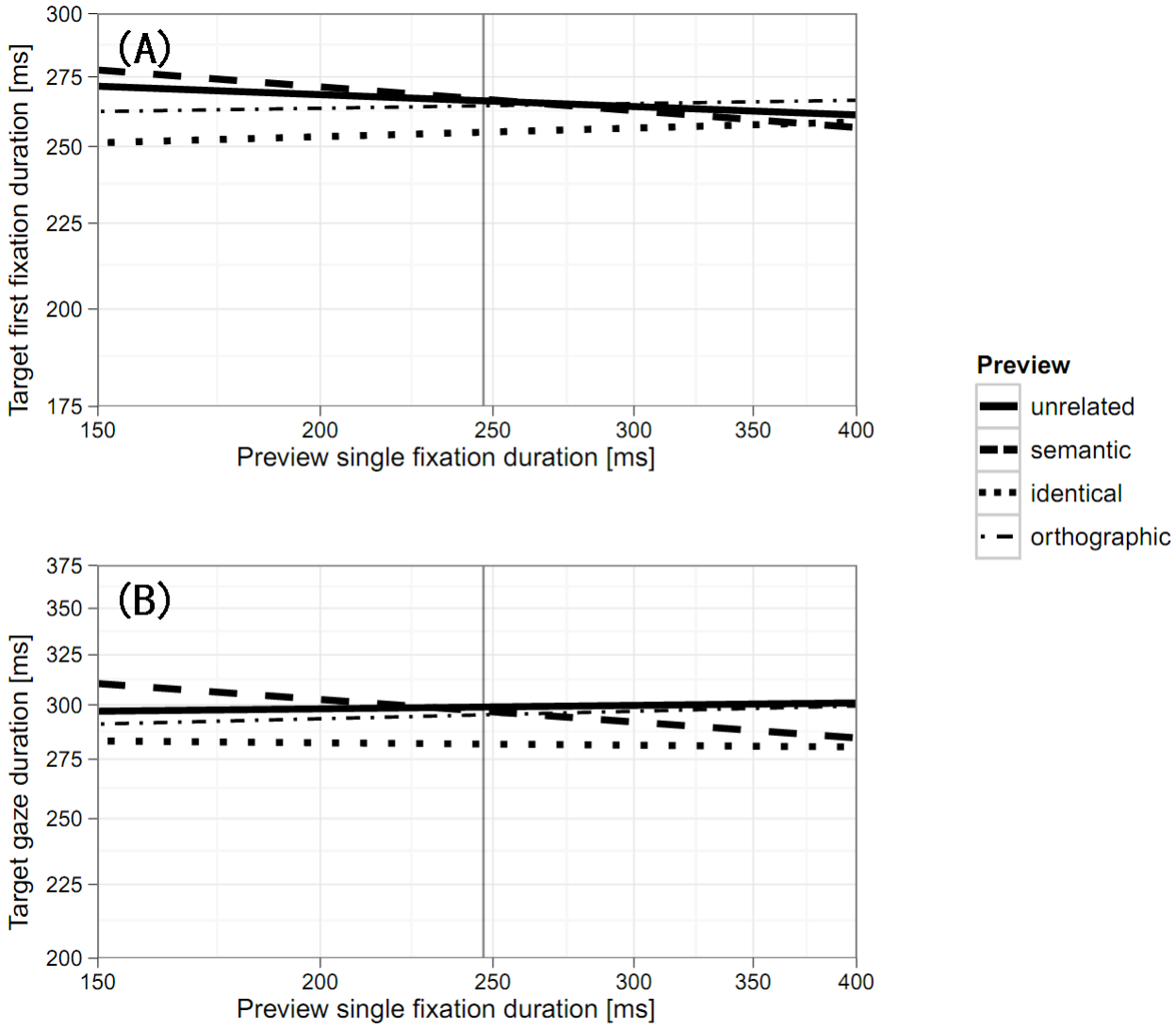

(A)
Target first fixation duration [ms]
300
275
250
225
200
175
150
200
250
300
350
400
Preview single fixation duration [ms]
(B)
Target gaze duration [ms]
375
350
325
300
275
250
225
200
150
200
250
300
350
400
Preview single fixation duration [ms]
Preview
unrelated
semantic
identical
orthographic
phonological

Figure 3.


(A)
Target first fixation duration [ms]
300
275
250
225
200
175
150
200
250
300
350
400
Preview single fixation duration [ms]
(B)
Target gaze duration [ms]
375
350
325
300
275
250
225
200
150
200
250
300
350
400
Preview single fixation duration [ms]
Preview
unrelated
semantic
identical
orthographic