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SEMANTIC PREVIEW BENEFIT DURING READING

Sven Hohenstein and Reinhold Kliegl

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ABSTRACT

Word features in parafoveal vision influence eye movements during reading. The question whether readers extract semantic information from parafoveal words was studied in 3 experiments by using a gaze-contingent display-change technique. Subjects read German sentences containing 1 of several preview words that were replaced by a target word during the saccade to the preview (boundary paradigm). In the 1st experiment the preview word was semantically related or unrelated to the target. Fixation durations on the target were shorter for semantically related than unrelated previews, consistent with a semantic preview benefit. In the 2nd experiment, half the sentences were presented following the rules of German spelling (i.e., previews and targets were printed with an initial capital letter), and the other half was presented completely in lowercase. A semantic preview benefit was obtained under both conditions. In the 3rd experiment, we introduced 2 further preview conditions, an identical word and a pronounceable nonword, while also manipulating the text contrast. Whereas the contrast had negligible effects, fixation durations on the target were reliably different for all 4 types of preview. Semantic preview benefits were greater for pretarget fixations closer to the boundary (large preview space) and, although not as consistently, for long pretarget fixation durations (long preview time). The results constrain theoretical proposals about eye-movement control in reading.

Keywords: eye movements, reading, semantic preview benefit, parafoveal processing, display-change awareness

During reading, eye movements (saccades) alternate with phases of relative stability (fixations). Properties of the fixated (or foveal) word, the preceding word, and the upcoming (or parafoveal) word all have a significant impact on when and where to move the eyes, but they vary in their degree of influence (see Heister, Würzner, & Kliegl, 2012, for a review). Whereas the parafoveal extraction of orthographic and phonological codes is well documented for various languages, the effect of semantic preprocessing in reading has been elusive at least for languages with alphabetic script (see Schotter, Angele, & Rayner, 2012, for a review).

Semantic parafoveal processing has been reported for reading of Finnish (White, Bertram, & Hyönä, 2008), Chinese (Cui et al., 2013; Tsai, Kliegl, & Yan, 2012; Yan, Richter, Shu, & Kliegl, 2009; Yan, Zhou, Shu, & Kliegl, 2012; Yang, Wang, Tong, & Rayner, 2012), Korean (Kim, Radach, & Vorstius, 2012), and German (Hohenstein, Laubrock, & Kliegl, 2010). None of these demonstrations, however, have been accepted as being conclusive because they depended on nonrepresentative targets (i.e., previews of the second constituent of Finnish compound words), non-Roman script (i.e., Chinese or Korean characters), or a nonstandard experimental paradigm (e.g., parafoveal fast priming in German, reviewed below).

Here we test the hypothesis of parafoveal preprocessing of semantic code in German sentences with the standard boundary paradigm (Rayner, 1975) in three experiments. Recent research also suggests that preview benefit depends on the duration and location of pretarget fixations (see Kliegl, Hohenstein, Yan, & McDonald, 2013, for a review). And there has also been concern about display change awareness in this paradigm (e.g., Slattery, Angele, & Rayner, 2011; White, Rayner, & Liversedge, 2005). Therefore, we also examine the relevance of these variables for semantic preview benefit in our experiments. Such evidence of a semantic preview benefit is of great interest to the further development of computational models of eye-movement control during reading. We will address this topic in the discussion.

Parafoveal preview benefits

Parafoveal preprocessing during reading has been extensively tested with the boundary paradigm (Rayner, 1975), in which the position of a critical target is at first occupied by a more or less valid preview word. When the reader's gaze crosses an invisible boundary located directly before the space preceding the preview, the target replaces the preview. Typically, fixation durations on the target are reduced if the preview is identical or related in some aspect to the target, compared to fixation durations with unrelated or nonwords as previews. A significant difference between uninformative and informative preview conditions, *preview benefit*, is interpreted as evidence of parafoveal preprocessing during the fixation on the word preceding the target.

There is considerable evidence of such a benefit arising from orthographic previews (Balota, Pollatsek, & Rayner, 1985; Inhoff, 1989a). Moreover, phonological and prosodic information can be processed in the parafovea and facilitate the processing of the target (Ashby & Rayner, 2004; Miellet & Sparrow, 2004; Pollatsek, Lesch, Morris, & Rayner, 1992). However, with the possible exception of a select set of morphological Hebrew codes (Deutsch, Frost, Pelleg, Pollatsek, & Rayner, 2003; Deutsch, Frost, Pollatsek, & Rayner, 2005), there have been no reliable findings indicating the effectiveness of morphological previews in alphabetic scripts (Bertram & Hyönä, 2007; Inhoff, 1989b; Kambe, 2004; Lima, 1987).

Past attempts to establish a semantic preview benefit

Initial studies, which failed to demonstrate semantic preview benefit

There has been much debate whether *semantic* codes facilitate parafoveal preprocessing. In the first experiment on this topic, subjects had to fixate a parafoveal word and name it (Rayner, McConkie, & Zola, 1980). Reaction times were the same for related (*chair*) or unrelated (*chore*) previews to the target (*table*). This experiment did not involve reading sentences, and the preview benefit was not measured in terms of the difference between fixation durations following unrelated and semantically related previews. However, for the standard version of the boundary paradigm, Rayner, Balota, & Pollatsek (1986) subsequently did not find evidence for a semantic preview benefit in sentence reading. The seeming absence of evidence of semantic preview benefit has been supported by three further boundary-paradigm experiments (Altarriba, Kambe, Pollatsek, & Rayner, 2001; Dimigen, Kliegl, & Sommer, 2012; Hyönä & Häikiö, 2005). In these cases, however, there are other factors that may have worked against finding the effect. Altarriba et al. (2001) used preview words in a second language, possibly entailing disadvantages arising from the switch between two languages (e.g., Meuter & Allport, 1999; Soares & Grosjean, 1984). Hyönä and Häikiö (2005) used unrelated emotional and unrelated neutral previews rather than related ones. Therefore, in this case, it is not clear whether this qualifies as a semantic preview. Finally, Dimigen et al. (2012) used semantically related and unrelated previews, but relied on a word list reading task in which subjects were asked to report whether an animal was included. Hence, one should note that strictly speaking, this list of experiments includes only one that used the standard boundary paradigm for reading sentences and an explicit manipulation of semantic relatedness (Rayner et al., 1986).

Finnish compounds

White et al. (2008) used the boundary paradigm *within* words and found parafoveal semantic information extraction. The preview for the second constituent of a Finnish compound noun (*vaniljakastike*; translation: vanilla sauce) was either semantically related (*sinappi*; mustard) or unrelated (*rovasti*; priest) to the second constituent (*kastike*; sauce). When the reader's gaze crossed the boundary between the two constituents, the target replaced the preview. Fixation times on the target indicated that related previews facilitated the extraction of semantic information from the parafoveal part of the fixated word.

Chinese

Two differences between Chinese and alphabetic script facilitate the detection of a semantic preview benefit in Chinese. Firstly, Chinese characters are more directly connected to meaning (Hoosain, 1991) than alphabetic characters. Secondly, and more importantly, most Chinese words are only one or two characters long (Yu et al., 1985). Therefore, the mean distance between the current fixation position and the next word is smaller than in alphabetic script, and the next word occupies less space within the parafoveal field. Relying on the boundary paradigm with noncompound (i.e., very simple) characters, Yan et al. (2009) established significant semantic preview benefit with simplified Chinese, the orthography used in mainland China. Recently, Tsai et al. (2012) replicated these results with traditional Chinese characters used in Taiwan. Furthermore, semantic preview benefit in Chinese also exists when using compound characters (Cui et al., 2013; Yan, Zhou, et al., 2012; Yang, Wang, et al., 2012).

Korean

Korean combines features of both alphabetic and syllabic writing. The orthography is based on phonology and represented in syllable blocks. Case markers are used to indicate syntactic functions of words and thereby provide semantic information about thematic roles. Kim et al. (2012) used correct and incorrect syntactic case markers as parafoveal previews. Incorrect previews led to a syntactic and semantic mismatch between the initially visible case marker and the one following the display change. Target fixation durations were longer in the incorrect preview condition, indicating that processing of parafoveal syntactic and semantic information does occur while a person is reading Korean.

Parafoveal fast priming

For alphabetic scripts, there is evidence of a semantic preview benefit from a nonstandard boundary paradigm. Hohenstein et al. (2010) used German sentences and a *parafoveal fast-priming* technique, in which the temporal availability of the preview was determined by a timer (for foveal fast-priming, see Sereno & Rayner, 1992). For a critical target n + 1 (*Knochen*; bones), a nonword string (*Nzwrfgt*) initially occupied the target location. It was then replaced by a semantically related (*Schädel*; skulls) or an unrelated preview (*Stiefel*; boots) as soon as the reader fixated the pretarget n. This preview was available for a variable prime duration (i.e., 35, 80, or 125 ms) before being replaced by the target. Thus, information extraction from the preview was limited to an experimentally determined duration, and the target became available while the reader was still fixating the preceding word. Semantic preview benefit was present for prime durations of 125 ms. When the saliency of the preview was increased with bold font in another experiment, the effect was found for prime durations of 80 ms (but no longer for 125 ms). So, in addition to providing first evidence of semantic preview benefit from the upcoming word in an alphabetic script, the results also suggested a relationship between semantic preview benefit and preview time.

In summary, the question whether semantic relatedness of preview and target affects processing of the target appears to depend on several factors pertaining to script (alphabetic vs. character script), task (natural reading vs. reading of word lists), and methodology (boundary paradigm vs. parafoveal fast priming). In addition, as we will review in the following two sections, semantic preview benefit may also depend on factors that are intrinsic to the boundary paradigm.

Preview space and preview time

Preview space

If the fixation on the pretarget is close to the boundary, there is much preview space, because more of the preview falls into the perceptual span (McConkie & Rayner, 1975; Rayner & Bertera, 1979) than for a far-away fixation position. Indeed, McDonald (2006) reported evidence of a greater identity preview benefit if the launch site distance (the distance between the position of the pretarget fixation and the beginning of the target) is small. Preview benefit was highly significant for launch sites of four characters or less, but despite increasing constraints on visual acuity, it was still significant for saccades launched 9 or 10 letters before the target. In their reanalysis of McDonald's data, Kliegl et al. (2013) analysed saccade amplitude not as a categorical but continuous variable. Their results also corroborate a positive relationship between preview space and preview benefit, thereby replicating results from studies in which the distance to the preview word was used as categorical covariate (e.g., Pollatsek, Rayner, & Balota, 1986; Rayner, 1975).

Preview time

In the standard boundary paradigm, preview time is identical with the pretarget fixation duration. Preview time is not fixed but terminated by the reader's eye movement. Therefore, semantic preview benefit may depend on the pretarget fixation duration. Indeed, for a reanalysis of Yan et al.'s (2009) data on semantic preview benefit during reading Chinese, Yan, Risse, Zhou, and Kliegl (2012) reported time-dependent parafoveal facilitation effects: Semantic preview benefit was smaller for long pretarget fixation durations than for short ones. In another study (Yan, Zhou, et al., 2012), the effect was different: The preview benefit was significantly greater when the subjects were given a longer preview duration. These opposite effects need to be followed up, but they may be related to differences in processing demand of the targets in two studies (i.e., noncompound vs. compound characters)

The present study

Here we report three experiments that establish parafoveal semantic preprocessing for subjects reading German sentences with the classic boundary paradigm. In the first experiment, we used nouns as previews and targets. In regular German spelling, nouns are capitalized. The capitalization of nouns in German, combined with the use of highly frequent pretargets, may facilitate parafoveal processing. To test this hypothesis, we presented sentences with either capitalized or lowercase target nouns in the second experiment. In the third experiment, we used four preview conditions, that is, an identical and a nonword preview in addition to the semantically related and unrelated conditions. This extension of the design allowed us to compute semantic preview benefit relative to alternative baselines. In this experiment, we also presented sentences at two levels of text contrast. For each of the three experiments, we also tested whether semantic preview benefit depends on preview space and preview time and carried out detailed analyses of correlations between self-reported awareness of the fact that words were exchanged during reading and semantic preview benefit.

Experiment 1

Method

Subjects

Thirty students (19 women, 11 men) from Potsdam, Germany, participated in the experiment. They were between 19 and 30 years of age (*M* = 22, *SD* = 3.1). They were paid €7 or received course credit. All were native speakers of German with normal or corrected-to-normal vision.

Apparatus

Subjects were seated 60 cm [24 in.] in front of an Iiyama Vision Master Pro 514 monitor (Iiyama Seiki Co., Nagano, Japan; 1024 × 768 pixels; 53 cm [21 in.]; vertical refresh rate 150 Hz; 20-pt Courier New bold font). One character covered 12 pixels horizontally (0.45° of visual angle). All sentences were presented in black on a white background. We measured the luminance with a PR-650 SpectraScan Colorimeter (Photo Research, Inc., Chatsworth, CA) at the center of the screen: The luminance of the background was 92.3 cd/m^2; the luminance of the text was below 3.4 cd/m^2. The text luminance was too dark to be measured, and the reported value is an upper limit based on manufacturer's data on the sensitivity of the instrument.

The experiment was run in MATLAB (The MathWorks, Natick, MA) with the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) and the Eyelink Toolbox (Cornelissen, Peters, & Palmer, 2002). The eyes were monitored with an EyeLink II system (SR Research Ltd., Osgoode, ON, Canada) with a sampling rate of 500 Hz, an instrumental spatial resolution of 0.01°, and an average accuracy better than 0.5°. The recording was binocular, and the heuristic filter was set to level 1. Heads were positioned on a chin rest to minimize head movements.

Material

We used Hohenstein et al.'s (2010) sentences, including semantically related and unrelated previews for targets. The 102 experimental sentences were constructed around the target region of the foveal pretarget n and the parafoveal target $n + 1$ and ranged from six to 13 words. All frequency variables were extracted from the lexical database dlexDB (version 0.2.5; Heister et al., 2011) based on the DWDS corpus (Geyken, 2007).

The pretargets were unique, between four and eight characters long (*M* = 5.4), and of high frequency (range: 8−6718 per million).[1] Words were selected to increase the possibility for a broad perceptual span and facilitate the pickup of information from the parafoveal target or to induce faster attention shifts, respectively (e.g., Henderson & Ferreira, 1990). The mean of the base-10 logarithmic frequency was 2.5. Pretargets covered different word classes (e.g., verbs, adjectives), but no nouns (which were used as targets), and were at positions 3−7 in the sentences.

The targets were unique, between four and eight characters long (*M* = 5.3), and their frequency ranged from 0.13 to 212 per million; the related previews were of the same length, and their frequency ranged from 0.28 to 248 per million. Table 1 provides details on the lemma frequencies of targets as well as related and unrelated previews. All the targets and previews were nouns and thus—according to German spelling—capitalized. One major constraint in generating the stimuli, given the display changes in the study, was that the previews had to be of the same length as the targets.

The unrelated previews were constructed to have the same length as the target, an overlap of characters with the target identical to the related preview (at the same spatial position), and minimal frequency differences between the related and the unrelated preview. The unrelated previews ranged in frequency from 0.06 to 177 per million. The two lists of preview types were matched in terms of their lemma frequency. The unrelated previews had been constructed with regard to orthography (i.e., character overlap with the target), frequency, and length, but 47% of them did not fit into the sentence syntactically. Finally, the targets, related previews, and unrelated previews were used only once, with the exception of one unrelated preview that was used twice, leading to a total of 305 words. See Table 2 for sample sentences with translations.

[1] Note that some measures differ from the ones reported in Hohenstein et al. (2010), which were based on the November 2007 (prerelease) version of the lexical database.

Table 1

Means and Standard Deviations of the Untransformed and the Log_{10} Lemma Frequencies of Targets, Related Previews, and Unrelated Previews Together With the Absolute Differences Between Both Preview Types

	Target		Related preview		Unrelated preview		Difference[a]	
Frequency	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Untransformed	44.2	77.6	38.3	64.7	38.4	62.2	5.9	15.1
Log_{10}	1.2	0.6	1.2	0.6	1.2	0.6	0.11	0.22

Note. Frequency values are scaled to counts per million.

[a] Absolute difference between related and unrelated preview on sentence level.

We measured the cloze task predictability for the target position in a study with 23 native speakers of German (14 women, nine men, mean age = 21 years), who did not participate in Experiments 1−3. Participants were given a sentence up to, but not including, the target and were asked to generate the next word. The mean predictability of targets, related previews, and unrelated previews was .03, .02, and 0, respectively. Up to the 8th decile, the predictability values are 0 for all three word groups. Hence, the target was not constrained by sentence context.

In addition to the experimental sentences, there were 12 training and 24 filler sentences with targets as well as related and unrelated previews. In the filler sentences, targets were selected from different word classes (adjectives, adverbs, verbs, but not nouns). Training sentences also contained targets of different word classes. See Hohenstein et al. (2010) for further details.

Table 2

Example Sentences With Related and Unrelated Previews

Sentence	Preview: Related	Preview: Unrelated
Beim Ausgraben waren *Knochen* zum Vorschein gekommen. (With the excavation *bones* came to light.)	Schädel (skulls)	Stiefel (boots)
Für manche Zwecke war die kleine *Trage* viel praktischer. (For some purposes the small *stretcher* was much more useful.)	Bahre (bier)	Roste (gratings)
Am späten Abend konnte kein *Riese* im Land gesehen werden. (Late in the evening no *giant* could be seen in the country.)	Zwerg (dwarf)	Trend (trend)
Diese Frauen brauchen noch *Wolle* zum Fertigstellen der Kleidung. (These women need more *wool* to finish the clothes.)	Seide (silk)	Seife (soap)

Note. The target is in italics; translations are in parentheses.

Design

The experimental design implemented two conditions (related vs. unrelated preview) with 102 trials per subject. There were 51 experimental sentences per condition and subject. Each sentence occurred the same number of times in each of the two conditions. As 30 subjects were tested, each sentence was read 15 times in each condition. The mapping of the experimental condition to sentences was counterbalanced; the order of presentation of sentences, and hence of experimental conditions, was randomized.

Procedure

Subjects were naive concerning the purpose of the experiment. They were instructed to read single sentences for comprehension. Their field of vision was calibrated with a standard 9-point grid. If the eye tracker identified a fixation, the fixation point disappeared and a sentence was presented such that the centre of the first word replaced the initial fixation point. Participants ended presentation of a sentence by looking into the lower right corner of the screen. A three-alternative multiple-choice question followed a random sample of one third of the sentences. It was answered by clicking on one of the response alternatives. Ninety-six percent of all questions were answered correctly, indicating no serious problems of comprehension.

Subjects read six practice sentences (a random subset of all 12 training sentences), followed by the experimental and filler sentences. When a sentence was presented initially, the preview (related or unrelated) occupied the target location. An invisible boundary located directly after the last letter of pretarget *n* was present in each sentence. When either eye crossed the boundary, the preview word on position *n* + 1 was replaced by the target. The sentence remained in this final form until the end of the trial. In total, each person read 132 sentences including 102 experimental ones.

We measured the delay between eye movement and display change with the Black Box ToolKit (Plant, Hammond, & Turner, 2004). After either eye crossed the boundary, display changes were accomplished within approximately 10 ms. This delay does not only include the time required to technically make the display change after the information of boundary crossing has been transferred to the system, but rather comprises the entire delay measured from an actual eye movement (physically, not in the eye tracker software) to the moment the changed display appears on the screen. Since saccades in reading typically last about 30 ms (Rayner, 1998, 2009), the display change should occur during the saccade to the target.

Following the last sentence of the experiment, subjects were asked to answer a paper-and-pencil questionnaire consisting of three questions: Did you notice anything unusual concerning the presentation? (yes/no); were words exchanged during reading? (yes/no); in how many sentences were words exchanged during reading (%)? Twenty-nine out of thirty subjects completed the questionnaire.

Eye-movement measures and selection criteria

Data from sentences with a blink or loss of measurement were only used until the point in time preceding the first loss and only if the loss occurred after the target region. Saccades were detected with a binocular velocity-based algorithm (Engbert & Kliegl, 2003; Engbert & Mergenthaler, 2006). Small saccades were considered part of a fixation if they covered a distance less than the width of two characters. Analyses are based on right-eye fixations.

We applied the following criteria to filter trials: Trials were included only if pretarget and targets were fixated in sequence on first pass. This filter left us with 79% of all trials. In addition, the change from the preview to the target had to occur during the saccade from the pretarget to the target (trials remaining: 70% from related and 72% from unrelated previews). Finally, we excluded all trials in which data loss occurred during target gaze.

For these 71% of all trials, gaze durations (the sum of all first-pass fixations), first-fixation durations and single-fixation durations were computed for words *n* and *n* + 1 (for a definition of these measures, see Inhoff & Radach, 1998; Rayner, 1998). In addition, we computed the relative landing positions in the target (i.e., the position of the first fixation) and the target refixation probability. To determine the skipping probability of the target, we used trials in which word *n* was fixated before boundary crossing and was left with a right-directed saccade triggering the display change. Seventy-seven percent of all trials remained for this measure.

Statistical analysis

Inferential statistics for fixation durations are based on linear mixed models (LMMs), specifying subjects and sentences as crossed random factors (for a discussion of advantages of LMMs over F_1/F_2 analyses of variance, see Baayen, Davidson, & Bates, 2008; Kliegl, Masson, & Richter, 2010; Kliegl, Wei, Dambacher, Yan, & Zhou, 2011). Effects in models with continuous dependent variables were estimated with the lme4 package (Bates, Maechler, & Bolker, 2011) in the R environment for statistical computing (version 2.14.2, 64-bit build; R Development Core Team, 2012). LMMs were fitted with the restricted maximum likelihood statistic.

Binary dependent variables were analysed with the Automatic Differentiation Model Builder (ADMB; Fournier et al., 2012), with the R interface provided by the glmmADMB package (Skaug, Fournier, Nielsen, Magnusson, & Bolker, 2012). In a simulation study of generalized LMMs, ADMB-based confidence intervals were more accurate in terms of coverage probability than lme4-based ones (Bolker, Kliegl, & Fournier, 2011; Zhang et al., 2011).

To select the random-effects structure used for the analyses, we used a drop-one procedure starting with the full model including all varying intercepts and varying slopes of the main effects of the experimental design. Varying slopes not contributing significantly to the goodness of fit (as assessed through likelihood ratio tests) were removed from the model. This procedure was separately applied to each dependent variable.

Theoretically, the full model including variance components for all terms of the experimental design is the preferred model for statistical analyses (Schielzeth & Forstmeier, 2009; see also van de Pol & Wright, 2009). In our data, the variances between subjects and between sentences related to fixed effects ("varying slopes") is often very small. Therefore, corresponding variance components are estimated as close to 0 and the model is likely to be overparameterized; there simply is not enough information in the data to support a model of such complexity. On the other hand, coverage probability of confidence intervals associated with fixed effects is better for LMMs including random slopes than for models including intercepts only (Schielzeth & Forstmeier, 2009). It is our approach to include variance components if they contribute significantly to the model. It serves as a compromise between a full model and a model without any random slopes.

Continuous predictors were centered at their mean; factors (such as preview type) entered the analyses as sum contrasts (−0.5 vs. 0.5). Therefore, the intercept estimates the grand mean of the dependent variable; regression coefficients estimate the difference between factor levels. The base model for all dependent variables includes the fixed effect for preview type. For additional analyses, quasi-experimental and material-related covariates as well as their interactions with preview type were separately added to the base model's fixed-effects structure.

We report regression coefficients with t and z statistics. Degrees of freedom are not known for t statistics of LMMs, but for large numbers of subjects, sentences, and observartions, as in this experiment, the t statistic converges to the z statistic of the normal distribution. For all tests we apply the two-tailed criterion ($|t| \geq 1.96$; $|z| \geq 1.96$), corresponding to a 5% error criterion for significance. On the basis of the analyses of model residuals, we decided to use the (natural) logarithm of all fixation-duration measures. All graphics were created with ggplot2 (Wickham, 2009).

RESULTS

TARGET: SEMANTIC PREVIEW BENEFIT

Table 3 summarizes means and standard deviations for fixation durations, refixation probabilities, skipping probabilities, and landing positions by experimental condition for target *n* + 1. The analyses are based on 2,170 observations for gaze and first-fixation durations and 1,887 observations for single-fixation durations.

Table 3

Means and Standard Deviations of Target Reading (Experiment 1)

	Gaze duration [ms]		First fixation duration [ms]		Single fixation duration [ms]		Refixation probability		Skipping probability		Landing position	
Preview	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Related	306	182	280	163	283	166	.13	.34	.08	.27	.49	.25
Unrelated	337	185	309	173	319	177	.13	.34	.06	.24	.48	.24

Note. Refixation probability, skipping probability, and landing position ranged from 0 to 1.

Fixation times on the target were significantly longer for unrelated than for semantically related previews (b = 0.11, t = 5.5, for gaze durations; b = 0.10, t = 4.8, for first-fixation durations; b = 0.13, t = 5.8, for single-fixation durations). The regression coefficient b estimates the log fixation duration difference for unrelated compared to related previews. With respect to measures in milliseconds, the regression coefficients of the preview benefit correspond to differences of about 31 ms, 27 ms, and 35 ms for gaze duration, first-fixation duration, and single-fixation duration, respectively. Skipping rate, landing position, and refixation probability were not significantly influenced by the type of preview (t = 1.60, both $|z|$s = 1.67).

Pretarget

Table 4 summarizes results for the pretarget. There were no significant effects of type of preview present for the succeeding word on fixation durations (all $|t|$s < 1.24). Thus, there were no significant parafoveal-on-foveal effects.

Table 4

Means and Standard Deviations of Pretarget Reading (Experiment 1)

	Gaze duration [ms]		First fixation duration [ms]		Single fixation duration [ms]	
Preview	*M*	*SD*	*M*	*SD*	*M*	*SD*
Related	274	114	247	99	255	101
Unrelated	277	117	251	98	257	99

Modulation by pretarget fixation duration

Gaze duration, first-fixation duration, and single-fixation duration can be included in nine combinations in LMMs as dependent variable "log target viewing time" and covariate "log pretarget viewing time", along with preview type and the interaction between preview type and the covariate. None of the three pretarget viewing times had a reliable main effect on the three target viewing times. The magnitude of the preview benefit, however, was significantly modulated by pretarget gaze duration for target gaze duration (t = 2.0) and target single-fixation duration (t = 1.96). In the remaining combinations, the interaction did not reach significance (all $|t|$s < 1.20). The positive regression coefficients for the interactions indicated an increase of preview benefit with longer pretarget fixation duration.

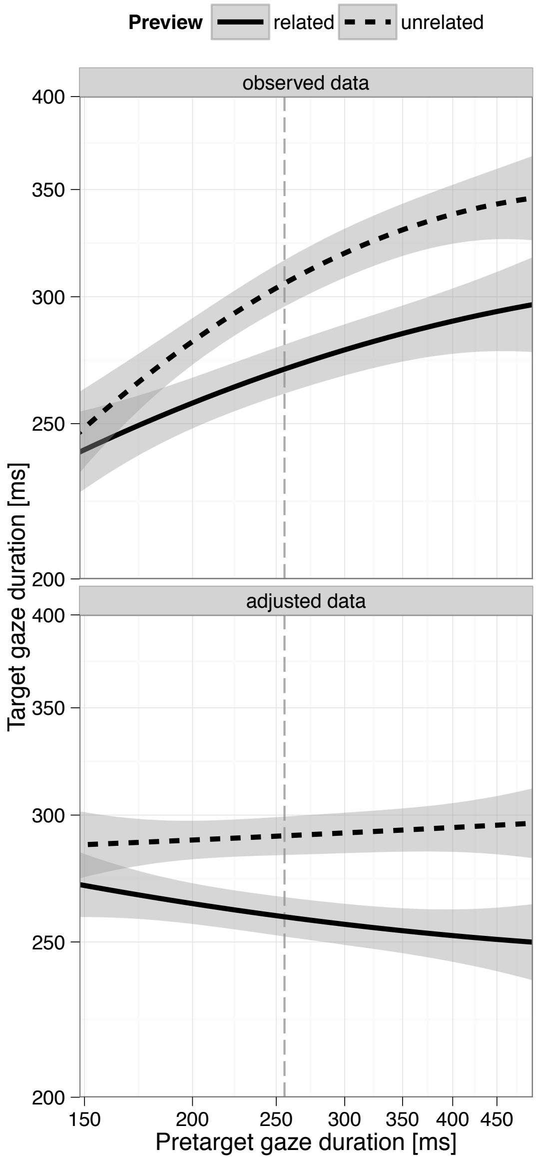

Figure 1. Top panel: Second-order polynomial trend of the regression of target gaze duration (on a log scale) on pretarget gaze duration (on a log scale) for related and unrelated previews (Experiment 1). Bottom panel: The same plot after removal of between-subject and between-sentence variance of the dependent variable. Shaded error bands represent 95% confidence interval. The horizontal axis covers roughly 90% of the data; minor differences are due to choosing the same *x*-axes limits for both panels; the mean is denoted by the vertical line.

To analyse the source of this modulation, we separately plotted pretarget and target fixation durations for observations (Figure 1, top panel) and for LMM estimates (i.e., after removing between-subject and between-sentence variance in the dependent variable;[2] Figure 1, bottom panel). Clearly, the overall increase in target fixation duration with pretarget gaze duration in the top panel of Figure 1 was mainly due to differences in the reading speed of subjects. With statistical control of individual differences in gaze durations, the semantic preview benefit (the difference between the two lines) emerged as a decrease in target gaze duration for related previews relative to fairly constant fixation durations for unrelated previews (bottom panel).

Modulation of preview benefit by pretarget gaze duration was independent of the frequency of the pretarget: Whereas the frequency of the pretarget had an impact on pretarget gaze ($b = -0.05$, $t = -2.2$; but not on first- and single-fixation duration, both $|t|$s < 1.24) and—as a spillover—on target viewing times (all ts < −2.5), a model including pretarget frequency and preview did not reveal an interaction between both variables for the prediction of target viewing times (all $|t|$s < 0.16). Thus, there was no evidence of a link between the preview benefit modulation by pretarget gaze and lexical difficulties in pretarget processing, but preview benefit increased with preview time.

Modulation by launch site distance and landing position

Figure 2 displays target gaze duration as a function of preview and launch site distance. Increasing distance from the last pretarget fixation to the target significantly reduced preview benefit in gaze duration ($b = -0.031$, $t = -2.4$) and marginally significantly in single-fixation duration ($t = -1.66$) and first-fixation duration ($t = -1.64$).

Preview benefit also increased with the relative landing position on the target ($b = 0.19$, $t = 2.7$, for gaze durations; $b = 0.21$, $t = 3.0$, for first fixation durations); the effect was marginally significant for single fixations ($t = 1.68$). Launch site distance and target landing position correlated negatively ($r = -.49$, $p < .001$), but they accounted for unique amounts of variance in fixation durations.

[2] The adjustment of the dependent variable (target gaze duration) was achieved by subtracting random effects estimated in an LMM for subjects and sentences from the log raw data. For this analysis the predictor pretarget gaze duration was centered (indicated by the vertical line in Figure 1).

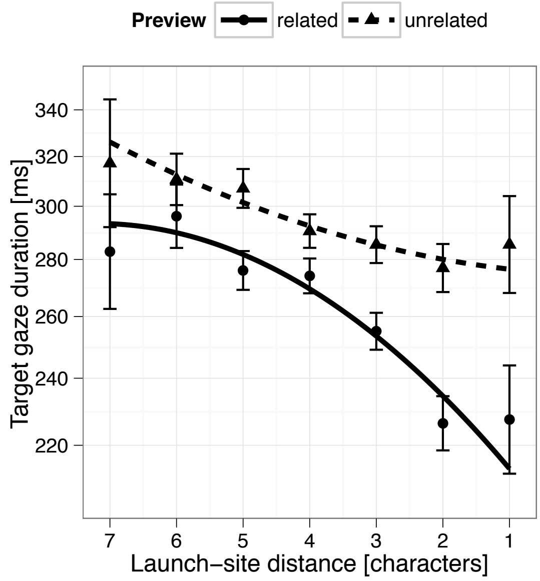

Figure 2. Second-order polynomial trend of the regression of target gaze duration (on a log scale) on launch site distance for related and unrelated previews (Experiment 1). Between-subject and between-sentence variance have been removed from the dependent variable. Error bars represent standard errors. The very infrequent trials with a launch site distance of eight characters were omitted (0.3%).

In addition, we analysed whether semantic preview benefit was related to length and frequency of pretargets and targets, and to the predictability of targets. The only notable result was a marginally greater preview benefit for predictable targets, in agreement with Balota et al. (1985). Thus, there was no evidence indicating that preview benefit depended on word characteristics, but it did depend on launch site and landing position. Finally, we tested whether high-level influences could explain the semantic preview benefit: Preview benefit remained significant for trials in which previews syntactically fit into the sentence and when we statistically controlled for preview predictability.

Awareness of display change

Twenty-six of 29 subjects (90%) who completed the questionnaire after the experiment noticed that display changes had taken place. Answers to the question concerning the amount of display change had a broad range (0%−95%). Display changes were used in all trials of the experiment. Mean of the self-reported detection rate was 40% (*SD* = 41%);

the median was 33%. Though almost all subjects reported that they had noticed display changes, they clearly were not aware that this had occurred in every trial.

The central question, of course, does not concern the relation of overall fixation duration to awareness of display change, but whether semantic preview benefit correlates with the awareness of display changes. A model including preview type and the continuous predictor display-change recognition rate (%) revealed a significant main effect of recognition rate ($b = 0.005$, $t = 4.0$, for gaze durations; $b = 0.005$, $t = 4.2$, for first-fixation durations; $b = 0.005$, $t = 4.0$, for single-fixation durations), but—most importantly—no interaction between preview benefit and display change recognition rate ($t = -0.18$, for gaze durations; $t = 0.10$, for first-fixation durations; $t = 0.06$, for single-fixation durations). Thus, subjects with longer fixation durations on targets reported a higher percentage of display changes, but there was no statistically reliable evidence that this measure relates differentially to related and unrelated previews.

Is the positive correlation between the self-reported detection rate of display change and target fixation duration due to individual differences in overall reading speed? With first-fixation duration as dependent variable and display-change detection rate as predictor, regression coefficients were positive for each word position relative to the target position (excluding first and last words); they were significant within a broad range of four words before the target to two words behind it (all *t*s > 2.2), indicating that subjects who were susceptible to display changes read slower in general. In an alternative analysis, we specified the position of the fixated word as 10 treatment contrasts (relative to the target; up to five positions before and five after the target), together with the self-reported display-change detection rate. All interactions were significantly negative (all *t*s < −2.6). Hence, the relationship between fixation duration and display-change awareness was strongest at the target.

Discussion

In the present study, we obtained shorter target fixation durations if the parafoveal preview was semantically related to the target, compared to unrelated previews. Moreover, we show that parafoveal semantic facilitation is (a) significantly moderated by launch site distance, (b) significantly moderated by pretarget gaze duration, and (c) not significantly related to the subjects' self-reported ability to detect display changes.

Semantic preview benefit

The interpretation of the general effect of preview is a straightforward matter: Readers were able to pick up semantic information. This result provides evidence that a semantic preview benefit can be obtained with the standard boundary paradigm for a language using alphabetic script, adding to evidence already available for Chinese and Korean. The magnitude of the semantic preview benefit, however, depends on several other factors.

Preview space

Semantic preview benefit was stronger when the eyes were close to the target. Several models for eye movements during reading predict this dependence (see General Discussion). Furthermore, our results are in agreement with a study on identity preview benefit by Kliegl et al. (2013; see also McDonald, 2006), who reported a decrease of the preview benefit with an increase in launch distance.

Preview time

The effects of preview time and display-change awareness are new, or not clearly predictable from the available literature. The magnitude of the semantic preview benefit covaried with gaze duration on the pretarget. When the pretarget was fixated longer, entailing longer availability of preview, the semantic preview benefit on the target was greater. This finding resembles results in Kliegl et al. (2013), who reported a positive relationship between pretarget fixation duration and identity preview benefit. However, in that study, the preview benefit depended on gaze duration; it did not vary with first- and single-fixation duration on the pretarget. Most likely, the effect is quite fragile and may depend on specific experimental conditions, or simply not be very reliable (e.g., White et al., 2005). At this point, evidence is simply not sufficient to draw definite conclusions on the influence of preview time on parafoveal preprocessing, but these issues should be resolved eventually because condition-specific timelines are important constraints for theoretical proposals about the time course of information integration during word recognition.

The positive relationship between pretarget gaze duration (and thus the temporal availability of the parafoveal preview) and the magnitude of the semantic preview benefit differs from results of an earlier study on semantic preprocessing using the parafoveal fast-priming paradigm (Hohenstein et al., 2010). Semantic preprocessing was demonstrated with a preview duration of 125 ms (Experiments 1 and 2). However, in Experiment 3, with increased preview saliency, the effect disappeared at 125 ms but was present at 80 ms of preview duration. This result was interpreted as a forward shift in visual processing of the highly salient parafoveal stimulus associated with larger interference between the semantic representations of preview and target. In the present study, a semantic preview benefit was present for much longer preview durations (i.e., pretarget fixation duration; see Figure 1). Obviously, then, different mechanisms are at work during parafoveal fast priming and the classical boundary paradigm: Preview and target are presented consecutively in fast priming, whereas the saccade from the pretarget to the target is in between the presentations of preview and target. Thus, interference should be less likely in the boundary paradigm. We submit that the two paradigms are likely to be useful for different questions and that more experimental work with parafoveal fast priming is needed to understand the underlying mechanisms.

1.1.1.1 Display change awareness

Most subjects reported awareness of display changes. Importantly, on average they thought that a change occurred in 40% of the trials, when in reality a change occurred on every trial. Thus, they did not notice display changes in 60% of the trials. In White et al.'s (2005) study, one third of all subjects reported having noticed display changes (the proportion was even lower in Rayner et al., 1986). What are the reasons for this discrepancy? There are three differences: First, we used an EyeLink II system, whereas White et al. and Rayner et al. used a Dual Purkinje eye tracker, which has a very high spatial accuracy leading to fewer incorrect display changes caused by a mismatch between actual and measured gaze position. Second, since in the present study pretargets were highly frequent, subjects' attention may have spread faster to the location of the preview word. After the boundary was crossed, differences between target and preview may have been more noticeable. Third, since White et al. ran an identity preview benefit condition, inherently, in half of the trials no display change occurred. This is to say there were cases in which the preview was identical with the target. Thus, the probability of noticing a display change was potentially half as high than in the present study in which words were exchanged in every trial. We also found a positive correlation between reading time and display-change awareness. Slow reading increased the chance of perceiving the difference between preview and target, presumably because of the longer preview time. White et al. (2005) did not report an effect of display-change awareness on reading speed, but fixation durations on pretarget and target were numerically longer for aware subjects.

In summary, the main result of Experiment 1 is a significant benefit of semantically related, as opposed to unrelated, parafoveal previews. This is the first demonstration of such an effect in the boundary paradigm for a language using alphabetic script. Most notably, such an effect has not been found in a boundary experiment for reading English sentences (Rayner et al., 1986). Besides methodological differences between studies, differences between English and German script may be responsible for the divergence of results. We followed up this possibility in Experiment 2.

EXPERIMENT 2

In Experiment 1 we obtained a semantic preview benefit for subjects reading German sentences. German script has the unusual characteristic that all nouns, not only proper names and first words of sentences, are spelled with an initial capital letter (capitalization). Since all targets in experimental sentences were nouns, it is plausible that capitalization had an impact on parafoveal preprocessing. A capitalized character of a preview in parafoveal vision may be salient and attract attention to the preview word. Furthermore, German capitalization possibly reduces the cost of lexical processing. From the first letter alone, readers of German script obtain the word class information (whether the next word is a noun or a nonnoun). Deeper lexical (semantic) processing of the word may start faster than in other languages because of the early availability of word class information. Therefore, we hypothesized that more remaining resources or faster processing triggers a deeper processing of semantic code in the parafovea and hence enhances semantic preview benefit.

There is research demonstrating the positive influence of capitalization on reading rate in German (Bock, 1989, 1990; Bock, Augst, & Wegner, 1985; Bock, Hagenschneider, & Schweer, 1989; Gfroerer, Günther, & Bock, 1989). Reading rate was lower if uppercase and lowercase letters were used improperly, compared to texts where the German capitalization rules were observed. On the basis of several experiments, Bock (1989) argued that the function of German capitalization rules for reading is independent of word shape and allows a reader to differentiate between nouns and nonnouns without analysing a word's meaning. Furthermore, there is more recent evidence of an influence of German capitalization rules on the missing-letter effect (Müsseler, Nisslein, & Koriat, 2005) and on the identification of briefly presented nouns (Jacobs, Nuerk, Graf, Braun, & Nazir, 2008).

In conlcusion, these studies clearly demonstrate a beneficial effect of German noun capitalization on the recognition processes. Most likely, the use of German nouns as targets in Experiment 1 enhanced lexical processing of the parafoveal preview and therefore contributed to the semantic preview benefit. To date, there has been no study on the effect of capitalization for parafoveal processing. In the studies reviewed above, targets were always fixated directly. In Experiment 2, words were presented according to spelling rules of German; that is, nouns were capitalized or written completely in lowercase. If German noun capitalization was a major reason for the outcome in Experiment 1, we expect a reduced semantic preview benefit for noncapitalized sentences and previews.

METHOD

SUBJECTS

Thirty-two students (20 women, 12 men) participated in the experiment. They were between 16 and 39 years of age (*M* = 23, *SD* = 4.8).

MATERIAL

We used 100 of the 102 experimental sentences of Experiment 1, since four within-subject conditions were present (see below). In the capitalized condition, capitalization followed the spelling rules of German. In the noncapitalized condition, all characters were presented in lower case.

DESIGN

The experimental design implemented the two within-subject factors preview (related vs. unrelated) and capitalization (capitalized vs. noncapitalized). Capitalization was manipulated in a block design as a between-subject factor (capitalized first vs. noncapitalized first); it was applied not only to previews and targets, but to all nouns of the sentences in the block. Each experimental condition was presented the same number of times, rendering 25 experimental sentences per condition and subject. Since 32 subjects were tested, each sentence was read four times in each condition.

PROCEDURE

At the beginning of the experiment, subjects were told that the experiment consisted of two parts. One part of the sentences was presented following German rules of capitalization, and the other was presented completely in lowercase. Each part started with six training sentences, followed by 62 experimental and filler sentences. Subjects were informed when the second part started. Each person read 136 sentences, including 100 experimental ones. Accuracy of comprehension was 95%. Thirty-one out of 32 subjects completed the questionnaire concerning the detection of display changes.

Measures, selection criteria, and contrast specification

Data selection followed the procedure described for Experiment 1. After applying all filtering criteria for the target region, approximately 72% valid trials remained. For skipping probabilities for the target, 76% of all trials remained. The experimental factors preview and capitalization were specified as two sum contrasts and were of primary interest in almost all analyses.

Results

Target: Semantic preview benefit

Table 5 summarizes results for the target $n + 1$. The analyses are based on 2,296 gaze durations, 2,296 first-fixation durations, and 2,062 single-fixation durations. Again, fixation times on the target were significantly longer for unrelated than for semantically related previews ($b = 0.08$, $t = 5.4$, for gaze durations; $b = 0.07$, $t = 4.8$, for first-fixation durations; $b = 0.08$, $t = 5.3$, for single-fixation durations). When sentences were presented in lowercase, targets were fixated longer compared to sentences following the German rules of capitalization. This main effect of capitalization was reliable for gaze durations ($b = 0.06$, $t = 2.9$), first-fixation durations ($b = 0.07$, $t = 3.9$), and single-fixation durations ($b = 0.07$, $t = 3.9$). The interaction of preview and capitalization—a tendency of lesser preview benefit from noncapitalized previews—did not reach significance (all $|t|$s < 1.4).[3]

Furthermore, the relative landing position on the target was not significantly influenced by preview type ($t = -0.6$), capitalization ($t = -1.0$), or the interaction ($t = -1.4$). The probability of a target refixation also was not reliably modulated by preview type ($z = 1.05$), capitalization ($z = -0.66$), or the interaction ($z = 0.35$).

[3] Post hoc comparisons revealed reliable preview benefit for both capitalized ($t = 4.6$, for gaze durations; $t = 4.2$, for first-fixation durations; $t = 4.6$, for single-fixation durations) and noncapitalized presentation ($t = 2.9$, for gaze durations; $t = 2.4$, for first-fixation durations; $t = 2.7$, for single-fixation durations).

Table 5

Means and Standard Deviations of Target Reading (Experiment 2)

		Gaze duration [ms]		First fixation duration [ms]		Single fixation duration [ms]		Refixation probability		Skipping probability		Landing position	
Capitalization	Preview	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Regular	Related	258	130	241	112	243	112	.10	.30	.11	.31	.46	.25
	Unrelated	280	121	257	102	262	100	.11	.31	.06	.23	.47	.25
Lowercase	Related	279	118	263	108	267	109	.09	.29	.03	.16	.46	.24
	Unrelated	292	116	274	111	279	111	.11	.31	.03	.16	.45	.23

Note. Refixation probability, skipping probability, and landing position ranged from 0 to 1.

Target skipping rate was significantly reduced in the noncapitalized condition, compared to the capitalized condition (b = −1.32, z = −5.74). The type of parafoveal preview had no reliable influence (b = −0.36, z = −1.60) on skipping probability, but the interaction was marginally significant (b = −0.85, z = −1.90).

Pretarget

Table 6 summarizes results for the pretarget. Fixation durations were not influenced by the type of preview present for the succeeding word (all $|t|$s < 0.9); that is, there were no significant parafoveal-on-foveal effects. Surprisingly, pretargets were fixated for shorter durations when the sentence was presented completely in lowercase (b = −0.10, t = −5.6, for gaze durations; b = −0.06, t = −4.3, for first-fixation durations; b = −0.09, t = −5.4, for single-fixation durations). The interaction terms were not reliable (all $|t|$s < 1.4).

The analyses of the effect of capitalization on fixation durations measured on pretarget and targets revealed rather peculiar results: Violation of German rules of capitalization led to longer target fixations, but pretargets were fixated for shorter time spans in this condition. We analysed this trade-off for all data and found an interplay between capitalization and word class, indicating different reading strategies in capitalized and noncapitalized texts (Hohenstein & Kliegl, 2013).

Table 6

Means and Standard Deviations of Pretarget Reading (Experiment 2)

		Gaze duration [ms]		First fixation duration [ms]		Single fixation duration [ms]	
Contrast	Preview	*M*	*SD*	*M*	*SD*	*M*	*SD*
Regular	Related	260	101	238	90	244	92
	Unrelated	270	119	241	90	246	91
Lowercase	Related	241	114	223	90	223	84
	Unrelated	237	97	224	85	225	82

1.1.1.2 Modulation by pretarget fixation duration

Figure 3 displays target gaze duration as a function of preview type, pretarget gaze duration, and capitalization; the corresponding three-factor interaction was significant ($b = -0.2$, $t = -2.6$). The figure shows that the semantic preview benefit (i.e., the difference between unrelated and related previews) was observed in capitalized (left panel) and noncapitalized (right panel) conditions, but was stronger in the capitalized than in the noncapitalized condition. Moreover, the effect of pretarget gaze duration was different for the two conditions. A strong semantic preview benefit was observed in the capitalized condition for long pretarget gaze durations. Post hoc analyses yielded a significant interaction between preview type and pretarget gaze duration for the capitalized condition ($b = 0.14$, $t = 2.4$), but not for the noncapitalized condition ($t = -1.19$). The same significant pattern of results (i.e., a reliable three-factor interaction) was also obtained for the combinations including pretarget gaze or single-fixation duration as predictor. Finally, the numerical trends were similar for the three remaining combinations with pretarget first-fixation duration as predictor.

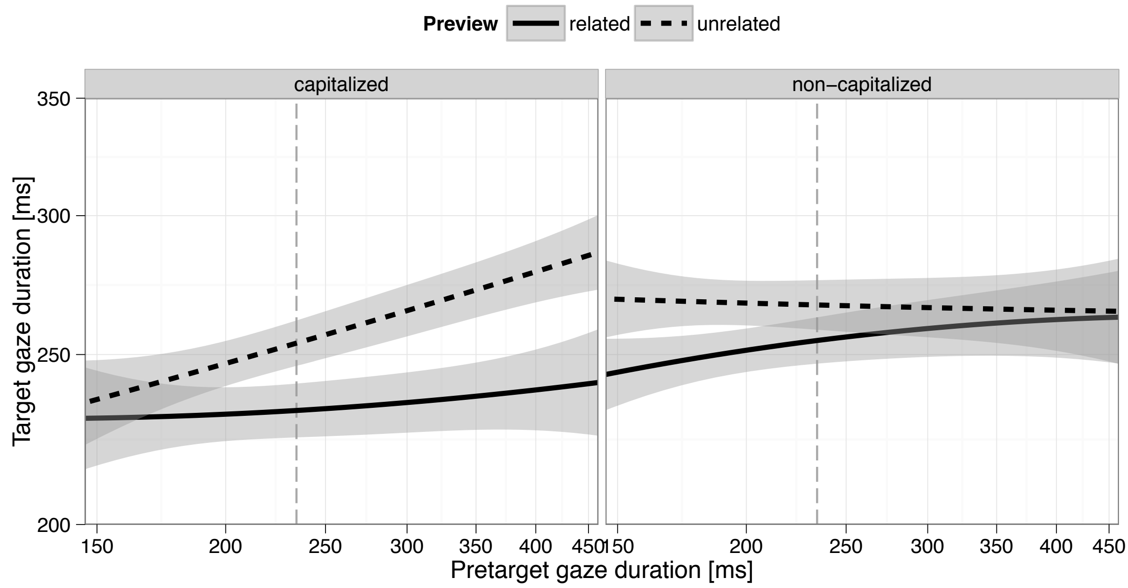

Figure 3. Second-order polynomial trend of the regression of target gaze duration (on a log scale) on pretarget gaze duration (on a log scale) for related and unrelated previews as a function of capitalization (Experiment 2). Between-subject and between-sentence variance have been removed from the dependent variable. Shaded error bands represent 95% confidence interval. The horizontal axis covers roughly 90% of the data; minor differences are due to choosing the same *x*-axis limits for both panels; the mean is denoted by the vertical line.

Modulation by launch site distance

Figure 4 displays target gaze duration as a function of preview type, launch site distance, and capitalization; the corresponding three-factor interaction was significant ($b = 0.07$, $t = 3.2$). The figure shows that the effect of launch site distance on semantic preview benefit differed for the two capitalization conditions: The semantic preview benefit increased with decreasing launch site distance for capitalized nouns, but not when nouns were presented completely in lowercase. Post hoc analyses revealed a significant interaction between preview type and launch site distance for the capitalized condition ($b = −0.05$, $t = −3.5$), but not for the noncapitalized condition ($b = 0.007$, $t = 0.48$). The same significant pattern of results (a reliable three-factor interaction) was also obtained for single-fixation duration (b = 0.05, t = 2.2); the effect was similar for first-fixation duration (b = 0.03, t = 1.55).[4]

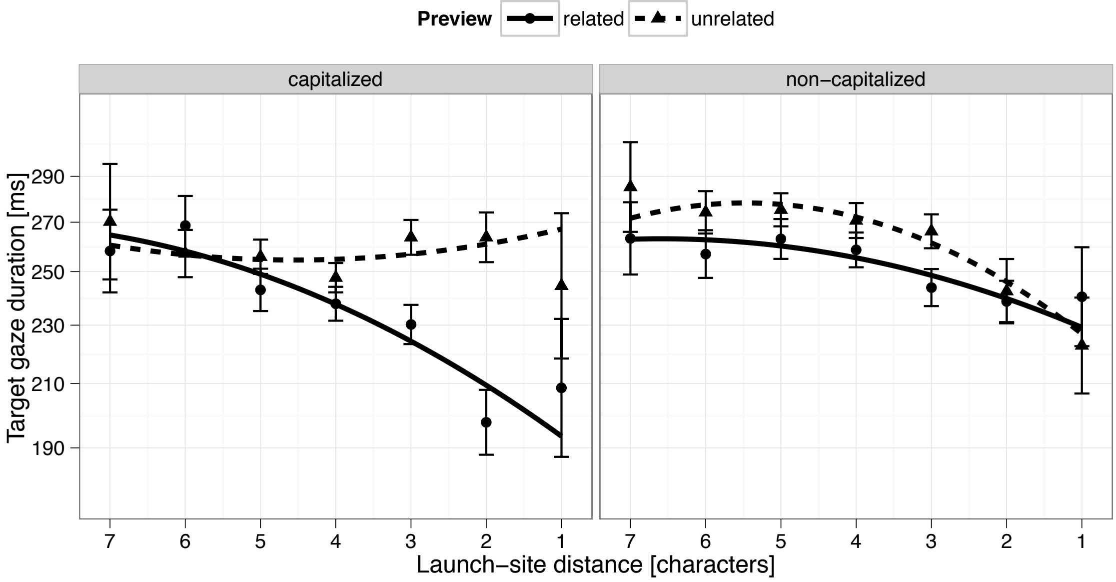

Figure 4. Second-order polynomial trend of the regression of target gaze duration (on a log scale) on launch site distance for related and unrelated previews as a function of capitalization (Experiment 2). Between-subject and between-sentence variance have been removed from the dependent variable. Error bars represent standard errors. The very infrequent trials with a launch site distance of eight or nine characters were omitted (0.7%).

Awareness of display change

Twenty-five out of 31 subjects (81%) noticed that display changes took place. The self-reported frequency of display changes ranged from 0% to 98%. Mean of the self-reported detection rate was 26% (SD = 31%); the median was 10%.

The main question is whether semantic preview benefits correlate with the perception of display changes. A model including preview type, capitalization, display-change recognition rate, and all interactions between these variables revealed a significant main effect of recognition rate (b = 0.002, t = 2.4, for gaze durations; b =

[4] Although the three-factor interaction was not reliable for first-fixation durations, the numerical pattern of effects in the post hoc analyses matches the results of gaze and single-fixation durations.

0.002, t = 2.7, for first-fixation durations; b = 0.002, t = 2.6, for single-fixation durations), but no reliable two- or three-factor interactions including display-change recognition rate (all $|t|$s < 1.63). Thus, as in Experiment 1, subjects with longer fixation durations on targets reported a higher percentage of display changes, but again there was no evidence of this measure relating differentially to related and unrelated previews.

Discussion

In Experiment 2, subjects read sentences in which a parafoveal preview for a critical target was either semantically related or unrelated to the target. In addition, sentences were presented as capitalized nouns, as required by spelling rules of German, or completely in lowercase. Manipulation of capitalization was used to test whether significant semantic preview benefits in Experiment 1 were exclusively due to the capitalization of all nouns in German.

The results were clear. Fixation durations were shorter for related than for unrelated previews, irrespective of capitalization. German subjects were able to process previews presented parafoveally, even when the whole sentence was presented in lowercase letters. Therefore, we conclude that semantic preview benefits did not depend exclusively on this German rule of capitalization.

Along with semantic preview benefit, we also replicated significant interactions between preview type and launch site distance, as well as preview type and pretarget fixation durations, but only if the presentation followed the German rules of capitalization. With increasing distance between the pretarget fixation position and the preview word, the preview benefit decreased. Furthermore, if the pretarget was fixated longer, the difference between related and unrelated previews for target fixation duration was more pronounced. The interaction between preview type and pretarget fixation duration was present only in a subset of combinations of the various durations, similar to results of Experiment 1 and to Kliegl et al. (2013).

Most subjects were aware of display changes; the average self-reported detection rate was 26%. As in Experiment 1, there was no evidence that semantic preview benefit was significantly influcenced by the subjects' awareness (or vice versa). Thus, again, we have no evidence that our finding of a benefit from semantically related previews in parafoveal vision was an artifact of the noticeable display changes. This finding contrasts with those of White et al. (2005) and Slattery et al. (2011), who reported a larger difference between nonword and identical previews for aware subjects, compared to unaware subjects.

Comparison between our first two experiments and earlier studies is limited because we used two nonidentical previews, whereas in earlier research one of the previews (namely the identical condition) was not accompanied by a detectable display change. Possibly, these methodological differences were responsible for some of the differences in the results. Therefore, we conducted a third experiment in which we used not only related and unrelated previews, but also identical and neutral nonword previews.

Experiment 3

The main goals of Experiment 3 were to evaluate benefits and, possibly, costs of related and unrelated parafoveal previews and compare them to conditions with identical (no display change) and neutral (nonword) previews.

Identical preview condition

In the identical preview condition, the target was constantly available for parafoveal processing without any detectable change in the display (the preview was replaced by itself). This condition allows us to assess the preview cost associated with the semantically related preview. It also reduces the probability of a trial containing a display change from 100% to 75% for experimental sentences (which we reduced further to 69% with additional fillers). Thus, display-change awareness was now evaluated under conditions that resembled earlier research more than our first two experiments (White et al., 2005).

This condition also allows us to follow up on several reports of modulation of identical preview benefit (relative to unrelated words) by pretarget fixation duration. The influence of pretarget fixation duration has also been examined in several boundary experiments with alphabetic scripts for *identical* preview benefit (i.e., identical vs. unrelated previews). Schroyens, Vitu, Brysbaert, and D'Ydewalle (1999) used a word triad task in which a sequence of three words, rather than a complete sentence, was presented. Results showed a (marginally significant) trend for smaller preview benefit if the single fixation on the pretarget was short. With the classical boundary paradigm and using identical vs. unrelated previews in natural reading, White et al. (2005) did not obtain a significant modulation of preview benefit by pretarget fixation duration. However, Kliegl et al. (2013; reanalysis of McDonald, 2006) reported evidence of a positive relationship between the preboundary fixation duration and preview benefit for English sentences. In other words, the difference between identical and unrelated previews increased with preview time.

Evidence is also mixed in the case of Chinese script. Yan, Risse, et al. (2012) found a significant interaction between unrelated vs. identical preview and pretarget single-fixation duration for target gaze duration, but not for first- and single-fixation duration. In Yan, Zhou, et al.'s (2012) study, the interaction was only marginal significant for first-fixation duration. Tsai et al. (2012) used pretarget gaze duration as predictor and reported an increase in identity preview benefit measured in single-fixation duration. Thus, at this point, there are various reports according to which pretarget fixation duration contributes to (identity) preview benefit during reading of alphabetic and Chinese scripts, but the conditions required for these effects to occur are not clear.

NEUTRAL PREVIEW CONDITION

A neutral condition was included to test interference triggered by semantically unrelated previews. A difference between unrelated and related preview may materialize due to lexical difficulties induced by unrelated previews, rather than semantic facilitation by related previews. In this scenario, fixation durations should not be shorter after a related preview than after a neutral preview, but unrelated previews should lead to longer target fixations than neutral previews. In short, in this hypothetical case, results are more compatible with a notion of preview cost than preview benefit.

Which condition qualifies as a *neutral preview*? In their classic review of the implications of cost-benefit analyses in the field of reaction time studies, Jonides and Mack (1984) demonstrated that, in general, a neutral condition is not neutral with respect to performance. Furthermore, changes in reaction times induced by experimental covariates are not limited to valid and invalid items, but also occur for neutral ones. Jonides and Mack recommended foregoing usage of a neutral condition and focusing on examining performance under valid and invalid cues relative to other variables. Our approach of analysing preview benefit modulation by covariates such as preview time and preview space implements this perspective (Kliegl et al., 2013; Yan, Risse, et al., 2012). If neutral conditions are necessary when it comes to addressing theoretical questions, Jonides and Mack suggested that constructing neutral stimuli required great effort and that neutral and nonyneutral items needed to match as closely as possible.

McNamara (2005) reviewed the question as to what to choose as a neutral condition in the context of semantic priming, an issue closely related to semantic preview benefit. He concluded that "orthographically regular, pronounceable nonwords may be the best choice for neutral primes" (p. 52). Furthermore, nonword primes should not be repeated to avoid repetition priming. Also, from the perspective of eye-movement control during reading, first letters should be a primary concern when generating nonwords. Saccade amplitudes to a parafoveal word or nonword appear to increase with the frequency of first letters and thereby influence landing positions in the targets (Hyönä, 1995; Plummer & Rayner, 2012; Radach, Inhoff, & Heller, 2004; Vonk, Radach, & van Rijn, 2000; White & Liversedge, 2004, 2006a, 2006b). Furthermore, even the duration of the pretarget fixation seems to be affected by a familiar beginning-letter sequence of the parafoveal stimulus (Inhoff, Starr, & Shindler, 2000; Plummer & Rayner, 2012; Pynte, Kennedy, & Ducrot, 2004; Rayner, 1975; Starr & Inhoff, 2004; Underwood, Binns, & Walker, 2000; White, 2008). To avoid preview-related differences in these early measures, beginnings of neutral nonwords should match real words as closely as possible.

Text contrast

Furthermore, we manipulated text contrast in this experiment to evaluate the influence of low-level visual properties on preview benefit and display-change recognition. Contrast has an impact on a subject's ability to recognize characters and other patterns in peripheral vision (see Strasburger, Rentschler, & Jüttner, 2011, for a review). The levels of contrast in experimental reading studies conducted in different laboratories may differ slightly, and there is not much research to date on whether such differences matter for preview benefits. Our subjects' self-reported display-change awareness was comparable to the hit rates in the no-delay condition reported by Slattery et al. (2011). On the other hand, the majority of White et al.'s (2005) subjects were unaware of words being exchanged. We suspect that the main reason for the difference in display-change awareness is the difference in the overall probability of display changes, but a difference in display contrast may be another source.

We used the *Michelson contrast* definition (Michelson, 1927), $C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$, where I_{max} and I_{min} denote the maximum and minimum luminance, respectively, yielding a contrast value between 0 and 1. For text, I_{min} refers to the dark letters and I_{max} to the background. The minimum text contrast for reading at maximum speed is about 10% (Legge, Parish, Luebker, & Wurm, 1990; Legge, Rubin, & Luebker, 1987). Reading rate suffers from reductions of contrast below this value. Legge, Ahn, Klitz, and Luebker (1997) demonstrated that when reading speed slows down due to low contrast, this is linked to a reduced visual span, that is, the number of letters that may be recognized reliably without moving the eyes. Under these conditions, text is read with more and longer fixations (see also White and Staub, 2012). Note that text contrast seems to have a major influence on reading, but visual quality does not generally have strong effects on fixation durations (Jordan, McGowan, & Paterson, 2013).

Several recent eye-movement studies used contrast manipulation for a single target. Reingold and Rayner (2006) presented sentences with a contrast of 85% with the critical target presented at the same or reduced contrast (10%). Fixation durations on the target were increased in the low-contrast condition. This finding was replicated in similar studies with different text contrast levels (99% vs. 6%, Drieghe, 2008; 95% vs. 21%, Wang & Inhoff, 2010; 84% vs. 10%, White & Staub, 2012). Wang and Inhoff (2010) also manipulated parafoveal preview of the posttarget word (identical vs. nonword). Although they found a reliable preview benefit, its magnitude was not influenced by stimulus quality.

In the present experiment, in addition to the four preview types, we manipulated the contrast of the whole sentences, following the work of Legge et al. (1997, 1990, 1987), and White and Staub (2012). We did not want to disrupt normal reading by setting contrast below the critical level and, therefore, chose levels of 93% and 21%, closely matching those used by Wang and Inhoff (2010). We specified text contrast as a between-subject factor because we also wanted to evaluate its effect on display-change awareness with a questionnaire following the experiment.

Method

Subjects

Forty-eight students (38 women, 10 men) participated in the experiment. They were between 19 and 34 years of age (*M* = 22, *SD* = 3.9).

Apparatus

Sentences in the high-contrast condition were presented in black on a white background (just as in Experiments 1 and 2). Luminance of the background was 92.3 cd/m^2; luminance of the text was below 3.4 cd/m^2. In the low-contrast condition, sentences were presented in dark gray (14.5 cd/m^2) on a light gray background (22.2 cd/m^2). Michelson contrast for the low-contrast conditions was .21. In the high-contrast condition, the Michelson contrast was higher than .93.

Material

We used the material of Experiment 2, including 100 experimental sentences. In addition to the semantically related and unrelated previews, we introduced two further conditions: identical preview and neutral preview. In the identical condition, the target was present as a parafoveal preview and replaced by itself. The neutral previews were pronounceable nonwords constructed by changing one to five letters in existing German nouns, which were not used as preview or target. All neutral previews were unique. All previews—this includes the pronounceable nonword as well—were matched on a number of relevant lexical variables (see Table 7). We took great care to insure that the information provided by the initial letters and their frequency did not differ between the parafoveal previews. Furthermore, we controlled orthographic overlap between previews and target.

Table 7

Means and Standard Deviations of Lexical Properties for the Four Preview Conditions in Experiment 3

	Identical preview		Related preview		Unrelated preview		Nonword preview	
Stimulus characteristic	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Length [characters]	5.3	1.0	5.3	1.0	5.3	1.0	5.3	1.0
Initial unigram frequency[a]	4.1	0.2	4.1	0.3	4.1	0.2	4.1	0.3
Initial bigram frequency[a]	3.1	0.4	3.2	0.5	3.2	0.5	3.2	0.5
Initial trigram frequency[a]	2.2	0.6	2.2	0.7	2.2	0.6	2.2	0.8
Regularity[b]	1.0	0.5	1.0	0.5	1.0	0.6	1.0	0.5
Relative character overlap with target[c]	1	0	.10	.13	.10	.13	.10	.11

Note. Frequency values are case-sensitive and scaled to $\log_{10}$ counts per million. Relative character overlap with target ranged from 0 to 1.

[a] The cumulated frequency of all words (types) sharing the same initial *n*-gram. [b] Regularity is defined as the number of different words (types) of the same length sharing the same initial trigram. [c] The number of characters the preview shares with the target (at the same position), relative to word length.

For the training and filler sentences, we also had an identical condition, but not a neutral one. Instead, in 50% of the nonexperimental trials, we presented an identical preview. The idea behind this approach was to lower the overall rate of display changes. Throughout the whole experiment words were exchanged in 69% of all trials.

1.1.1.3 Design

The experimental design implemented the within-subject factor preview (identical vs. related vs. unrelated vs. neutral) and the between-subject factor contrast (high vs. low). Each experimental condition was presented equally often, rendering 25 experimental sentences per preview condition and subject and 24 subjects per contrast condition and experimental sentence. As 48 subjects were tested, each sentence was read 6 times in each condition.

1.1.1.4 Procedure

Subjects read eight training sentences, followed by the experimental and filler sentences. The contrast of the sentences was constant throughout the experiment. The background of the sentences was also used for instruction screens and calibrations. In the identical preview condition, the target was present as parafoveal preview and replaced itself as soon as the subjects' gaze crossed the invisible boundary.

In total, each person read 132 sentences including 100 experimental ones. Accuracy of comprehension was 97%. Forty-seven out of 48 subjects completed the questionnaire concerning the detection of display changes.

1.1.1.5 Measures and selection criteria

Data selection followed the procedure described for Experiment 1. After applying all filtering criteria for the target region, approximately 75% of all trials remained valid. For skipping probabilities for the target, 80% of all trials remained.

1.1.1.6 Statistical analysis

We manipulated two experimental factors: text contrast and preview. In the analyses, the binary predictor text contrast was coded with the (statistical) sum contrast. As to the effects of the different types of parafoveal preview, we specified three planned nonorthogonal contrasts: (a) unrelated vs. related preview, (b) related vs. identical preview, and (c) nonword vs. unrelated preview. The first contrast replicates the semantic preview benefits of Experiments 1 and 2. The second contrast represents the benefit related to the availability of the target for parafoveal preprocessing as opposed to a semantically related preview. This contrast is of major interest because it also represents the effects of display change vs. constant display. The third contrast was specified to evaluate potential preview cost associated with unrelated words relative to a nonword baseline (McNamara, 2005), with control for relevant properties of initial letters.

1.1.2 RESULTS

Table 8 summarizes results for the target *n* + 1. The analyses are based on 3,600 observations for gaze and first-fixation duration and 3,250 for single-fixation duration, respectively.

Table 8

Means and Standard Deviations of Target Reading (Experiment 3)

		Gaze duration [ms]		First fixation duration [ms]		Single fixation duration [ms]		Refixation probability		Skipping probability		Landing position	
Contrast	Preview	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
High	Identical	235	84	221	70	222	71	.08	.27	.06	.23	.47	.24
	Related	255	110	239	100	242	102	.09	.29	.06	.23	.48	.24
	Unrelated	281	104	260	99	268	100	.12	.32	.05	.21	.48	.25
	Nonword	292	103	271	99	278	99	.13	.34	.03	.17	.47	.24
Low	Identical	237	93	221	73	224	73	.07	.26	.10	.30	.51	.27
	Related	246	88	235	82	238	83	.06	.24	.09	.29	.51	.27
	Unrelated	273	107	251	94	256	93	.12	.32	.05	.23	.49	.27
	Nonword	284	94	263	89	272	87	.10	.30	.05	.21	.50	.26

Note. Refixation probability, skipping probability, and landing position ranged from 0 to 1.

In the following, we report results sorted according to the three planned comparisons, (a) semantic preview benefit, (b) display-change effect, and (c) differences between neutral and unrelated previews, and their associated interactions for fixation durations, refixations, and skippings—we obtained no significant effects on the relative target landing position (all $|t|$s < 1.4). The sections about (a) main effects of text contrast and covariates, (b) the pretarget, and (c) the influence of display-change awareness will follow. Omission of dependent variables or effects within one of the sections implies that there was no significant result.

CONTRAST 1: SEMANTIC PREVIEW BENEFIT (UNRELATED VS. RELATED PREVIEW)

Fixation durations

The semantic preview benefit of the first two experiments was replicated for all types of fixation durations and at both levels of contrast. Fixation times on the target again were significantly longer for unrelated than for semantically related previews (b = 0.11, t = 6.0, for gaze durations; b = 0.10, t = 5.4, for first-fixation durations; b = 0.08, t = 4.3, for single-fixation durations). The new text contrast did not interact with related vs. unrelated preview (all $|t|$s < 1.66).

Figure 5 shows target gaze duration as a function of preview type and launch site distance. The difference between unrelated and related previews significantly decreased with launch site distance (b = −0.03, t = −3.3, for gaze durations; b = −0.03, t = −3.0, for first-fixation durations; b = −0.03, t = −2.8, for single-fixation durations). These results replicate Experiments 1 and 2, but we failed to replicate the influence of pretarget fixation durations on preview benefit reported for the first two experiments (all $|t|$s < 1.08); the trend was in the expected direction for six out of nine combinations.

Refixation probability

The probability of a target refixation was reliably higher for unrelated than related previews (b = 0.56, z = 3.2), indicating more efficient processing of targets for which a semantically related preview was presented.

Skipping probability

The probability of target skipping was lower in the unrelated preview, when compared to the related preview condition (5% vs. 7%; b = −0.54, z = −2.4). There was no evidence indicating that preview condition influences skipping in Experiments 1 and 2, but this result is in agreement with findings from the first study on semantic preview benefit: Rayner et al. (1986) reported a significantly higher probability of target skipping if the preview was identical, or a semantically related word (7%), compared to an unrelated word (1%).

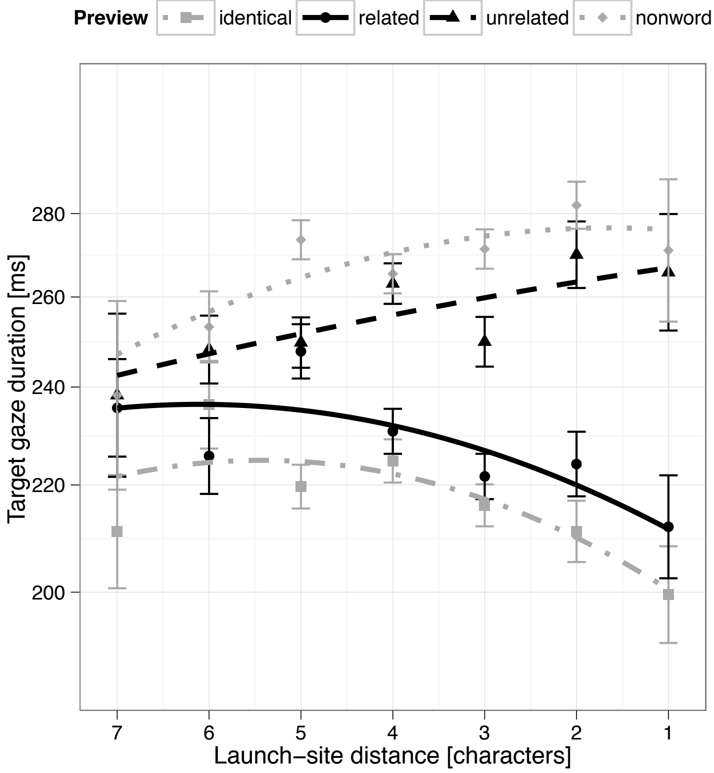

Figure 5. Second-order polynomial trend of the regression of target gaze duration (on a log scale) on launch site distance for identical, related, unrelated, and nonword previews (Experiment 3). Data from both contrast conditions were combined. Between-subject and between-sentence variance and fixed effects associated with text contrast have been removed from the dependent variable. Error bars represent standard errors. The very infrequent trials with a launch site distance of eight characters were omitted (0.8%).

1.1.2.1 Contrast 2: Display-change effect (related vs. identical preview)

We may interpret the second contrast as the influence associated with the display change. In the identical condition, the target was constantly visible during the reading process.

Fixation durations

First-fixation durations (b = 0.05, t = 2.2) and single-fixation durations (b = 0.05, t = 2.3) were significantly shorter for identical rather than related previews; the contrast is marginally significant for gaze durations (t = 1.89). This difference between preview conditions was not significantly modulated by text contrast (all $|t|$s < 0.65), launch site distance (all $|t|$s < 0.6; see Figure 5), or pretarget fixation duration (all $|t|$s < 1.66).

1.1.2.2 Contrast 3: Preview cost due to unrelated word (nonword vs. unrelated preview)

Fixation durations

Furthermore, compared to neutral nonword previews, target fixations were shorter for unrelated ones (b = 0.05, t = 3.6, for gaze durations; b = 0.06, t = 4.2, for first-fixation durations; b = 0.05, t = 3.8, for single-fixation durations). Thus, we have no evidence in fixation durations of preview cost from “wrong” words interfering. Rather, the parafoveal presence of an unrelated word resulted in shorter target fixations, if compared to a pronounceable nonword preview. This difference between preview conditions was not significantly modulated by text contrast (all $|t|$s < 1.24) or launch site distance (all $|t|$s < 1.07; see Figure 5).

This contrast depends on pretarget fixation duration: The interaction between neutral vs. unrelated preview and pretarget first-fixation duration was reliable for target first-fixation duration (b = 0.09, t = 2.1) and single-fixation duration (b = 0.11, t = 2.4); for target gaze duration the effect was marginally significant (t = 1.80). Longer pretarget fixations were connected to larger differences of target fixation durations between neutral and unrelated previews.

Finally, analyses revealed a three-factor interaction between neutral vs. unrelated preview, pretarget fixation duration, and text contrast, indicating that the influence of preview time on the processing of neutral and unrelated previews depended on contrast. This effect was only significant with single-fixation duration as predictor and gaze duration as dependent variable (b = 0.21, t = 2.1). Post hoc analyses of gaze durations revealed that also a reliable interaction between nonword vs. unrelated preview and pretarget single-fixation duration was present for the low-contrast condition (b = 0.17, t = 2.3), this interaction was not significant for the high-contrast condition (b = −0.04, t = −0.60).

1.1.2.3 Main effects of text contrast, pretarget fixation duration, and launch site distance

The design includes main effects of text contrast, pretarget fixation duration, and launch site. As main effects, by implication, they are of potential interest if they are accentuated in interactions with preview contrasts.

Text contrast

The main effect of text contrast was not significant for fixation durations (all $|t|$s < 0.7). However, target skipping rate was significantly reduced in the high-contrast condition, compared to the low-contrast condition (5% vs. 7%; b = 1.01, z = 2.0). At first glance, this result appears counterintuitive, but most likely it is due to the pretarget fixation duration being significantly longer at low text contrast (see below), entailing a longer availability of the parafoveal preview.

Pretarget fixation duration

The combination of gaze duration, first-fixation duration, and single-fixation duration as pretarget (predictor) and target (dependent variable) resulted in nine analyses. First-fixation and single-fixation durations on targets increased significantly with increasing pretarget gaze (both ts > 2.3) and single-fixation (both ts > 2.1) durations; the effect was not significant in the remaining analyses (all $|t|$s < 1.5).

Launch site distance

The main effect of launch site distance was significant for gaze duration (b = 0.01, t = 3.5), but not for first- and single-fixation duration (both $|t|$s < 1.43).

1.1.2.4 Pretarget

Table 9 summarizes results for effects on pretarget fixation durations. They were significantly shorter when the text was presented with high rather than low contrast (b = 0.08, t = 1.97, for gaze durations; b = 0.08, t = 1.96, for first-fixation durations; b = 0.08, t = 2.0, for single-fixation durations). We obtained no reliable effects of preview and therefore no parafoveal-on-foveal effects.

Table 9

Means and Standard Deviations of Pretarget Reading (Experiment 3)

		Gaze duration [ms]		First fixation duration [ms]		Single fixation duration [ms]	
Contrast	Preview	*M*	*SD*	*M*	*SD*	*M*	*SD*
High	Identical	242	86	225	72	228	71
	Related	236	88	217	68	219	69
	Unrelated	240	91	223	83	228	84
	Nonword	247	103	221	77	224	79
Low	Identical	270	115	239	75	244	73
	Related	263	95	239	82	246	83
	Unrelated	260	93	241	82	245	81
	Nonword	256	88	235	75	241	74

1.1.2.5 Awareness of display change

Display changes occurred on 69% of the trials in this experiment; in the first two experiments, they occurred on every trial. Thirty-four out of 47 subjects (72%) noticed that display changes took place. The self-reported frequency of display change ranged from 0% to 80%; two answers indicated estimates (70% and 80%) higher than the actual frequency. Mean was 17% (*SD* = 21%); median was 10%. Relative to the actual number of display changes, mean detection rate was 25% (in accord with the hit rate reported by Slattery et al., 2011). The values reported by subjects did not reliably differ between the text contrast conditions, when using a Wilcoxon rank sum test to correct for skewness ($W = 299$, $p = .62$); numerically, however, the mean in the low-contrast condition was lower than in the high-contrast condition (15% vs. 19%). Figure 6 displays target gaze duration as a function of preview type and the proportion of trials in which a display change was detected (self-report). One main question is whether the semantic preview benefit correlates with the perception of display changes. In an LMM for gaze durations with effects of preview types, text contrast, display-change recognition rate, and all interactions only recognition rate was significant ($b = 0.002$, $t = 2.1$); this effect was marginally significant for single-fixation durations (t = 1.75), but not for first-fixation durations (t = 1.56). Text contrast was never significant (all $|t|$s < 0.86).

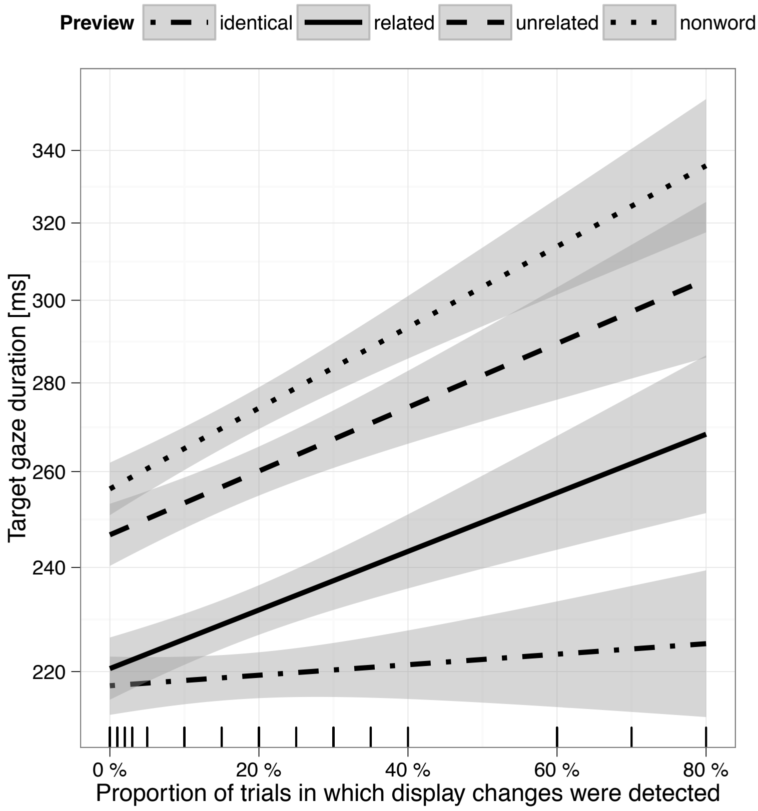

Figure 0.6. Linear trend of the regression of target gaze duration (on a log scale) on the proportion of trials in which display changes were detected (self-report) for identical, related, unrelated, and nonword previews (Experiment 3). Data from both contrast conditions were combined. Between-subject and between-item variance and fixed effects associated with text contrast have been removed from the dependent variable. Tick marks on the horizontal axis indicate observed values. Shaded error bands represent 95% confidence interval.

Interestingly, we obtained a reliable interaction between the self-reported display-change awareness and the display-change contrast (b = 0.002, t = 2.6, for gaze durations; b = 0.002, t = 2.2, for first-fixation durations; b = 0.002, t = 2.3, for single-fixation durations). The difference between related and identical previews increased with increasing display-change awareness. Just as in Experiments 1 and 2, there was no reliable interaction between display-change awareness and the semantic preview benefit (all $|t|$s < 0.62). Hence, there is no evidence that a subject's ability to detect display changes affects the magnitude of the semantic preview benefit. Similarly, display-change awareness does not relate differentially to neutral and unrelated previews (all $|t|$s < 1.53). In Figure 3.6, the slope of the regression line for identical previews is not significantly different from zero (b = 0.0004, t = 0.39, for gaze durations; b = 0.00004, t = 0.04, for first-fixation durations; b = −0.00001, t = −0.01, for single-fixation durations).

Discussion

Subjects read sentences in which a critical target was initially occupied by an identical, a semantically related, an unrelated, or a neutral pronounceable nonword preview, which subsequently was replaced by the target. Sentences were presented with a high or a low contrast. As opposed to unrelated previews, target fixations were shorter if a semantically related preview was presented parafoveally, replicating the critical results of Experiments 1 and 2.

As expected, fixation times were further reduced when the preview was identical to the target and therefore allowed for parafoveal processing of the target. When compared to nonidentical previews, the major advantage of identical previews has been demonstrated in many studies (see Schotter et al., 2012, for a review). Importantly, although we took great care in constructing neutral nonwords, target fixation times were shorter in the unrelated, compared to the nonword preview condition. All nonword stimuli were unique and pronounceable. In addition, identical, related, unrelated, and nonword previews were matched on several orthographic and lexical variables. We agree with other researchers who state that a "neutral" preview is difficult to define for reading, but the use of nonwords as reference condition for the computation of preview benefit leaves open an interpretation of preview benefit in terms of preview cost if nonwords induce inhibitory processes during lexical access. Nonwords may take longer to encode than real words. As a consequence, the processing of a parafoveal nonword may spill over into processing of the target (see McNamara, 2005, for a discussion). Since unrelated previews did not result in longer fixations than nonwords, we have no evidence that the semantic preview benefit obtained was due to inhibition from unrelated previews. However, it is also possible that all types of nonidentical preview cause interference, but related words do so less than unrelated ones. In White et al.'s (2008) study on semantic preview benefit within Finnish compounds, the order of gaze durations across preview types was identical < semantically related < unrelated < pronounceable nonword. Most importantly, gaze duration on the compound (measured from when the target constituent was fixated first) was significantly longer for nonword than unrelated previews.

Experiments 1 and 2 produced reliable evidence indicating that launch site distance has an impact on semantic preview benefit. Experiment 3 produced this evidence as well. The interaction was statistically the same for both levels of contrast. Interestingly, neither related vs. identical nor nonword vs. unrelated preview benefits were significantly influenced by the distance between pretarget fixation location and the preview word. As is shown in Figure 5, the regression lines of nonword and unrelated previews are quite similar. Also, the regression lines of related and identical previews are almost parallel.

As opposed to the robust effect of an impact of launch site distance on preview benefit, the evidence of an influence of pretarget fixation duration is very elusive. The difference between unrelated and related previews was never significantly modulated by pretarget fixation duration or the interplay between pretarget fixation duration and text contrast. In Experiments 1 and 2, this effect was tenuous at best and present only in a few analyses. However, there was some evidence indicating a modulation of the difference between nonword and unrelated previews by pretarget fixation duration and contrast. Surprisingly, this preview benefit modulation by pretarget fixation time was limited to the low-contrast condition. Possibly, inhibition processes arising from prolonged presence of the parafoveal nonword were responsible for this outcome. Reduced contrast may delay parafoveal information extraction and therefore inhibition. In general, modulation of preview benefit effects by pretarget viewing time was weak, but follow-ups on these results may greatly contribute to an understanding of parafoveal information extraction during reading.

The impact of the text contrast manipulation on reading was—aside from main effects on target skipping and pretarget fixation duration—negligible. Increased fixation durations at low contrast were in accord with previous studies in which contrast was reduced for the whole sentence (Legge et al., 1987; 1990; 1997; White & Staub, 2012) and for critical targets (Drieghe, 2008; Reingold & Rayner, 2006; Wang & Inhoff, 2010; White & Staub, 2012). In our data, the effect was reliable for the pretarget, but not for the target. Possibly, the contrast reduction we implemented was not strong enough to dramatically change reading performance. We had deliberately chosen the lowest level of contrast that still allowed for normal reading speed (cf. Legge et al., 1987); we did not want to induce a qualitatively different reading behavior. Manipulating contrast did not significantly affect semantic preview benefit or display-change awareness. Of course, our results may not hold for more severe reductions of visual contrast, but they establish the reliability of the semantic preview benefit for a considerable range of text contrast.

Finally, we found no evidence of a relation between a subject's self-reported display-change awareness and the magnitude of the semantic preview benefit in any of the experiments. Similarly, there was also no evidence of a relation with the benefit arising from unrelated previews (compared to nonword previews). At first glance, these results look different from those of White et al. (2005) and Slattery et al. (2011), who reported a larger difference between nonword and identical previews for aware, as opposed to unaware subjects. However, as shown in Figure 6, the difference between related and identical previews also increased with increasing display-change awareness in our experiment. Regression lines of the three nonidentical conditions were close to parallel, whereas the regression line of identical previews was stastistically unaffected by display-change awareness.

Meta-analysis of semantic preview benefit in Experiments 1−3

We conducted three experiments in which related and unrelated previews were used. An analysis integrating all the data affords a test of whether interactions involving semantic preview benefit, launch site, and display-change awareness were missed due to limited statistical power of individual experiments. Interactions involving continuous covariates are known for their poor reliability (McClelland & Judd, 1993). In addition, we used the aggregated data to test whether mislocated fixations could be the main source of the semantic preview benefit. This argument has served as an alternative explanation for parafoveal-on-foveal effects (Drieghe, Rayner, & Pollatsek, 2008; Rayner, Pollatsek, Drieghe, Slattery, & Reichle, 2007) and might also apply to semantic preview benefits.

Semantic preview benefit and display-change awareness

Figure 7 displays the distribution of the proportion of reported display changes, along with the mean target gaze duration of all subjects, separately for related and unrelated previews. Even for most of the subjects who were aware of display changes, the probability of detecting a display change was lower than the opposite outcome; that is, most of the points in Figure 7 are below 50% on the horizontal axis (see also shape of density curve). In none of the three experiments did we obtain a reliable interaction between unrelated and related preview. These results are reflected in the virtually parallel lines in Figure 3.7.

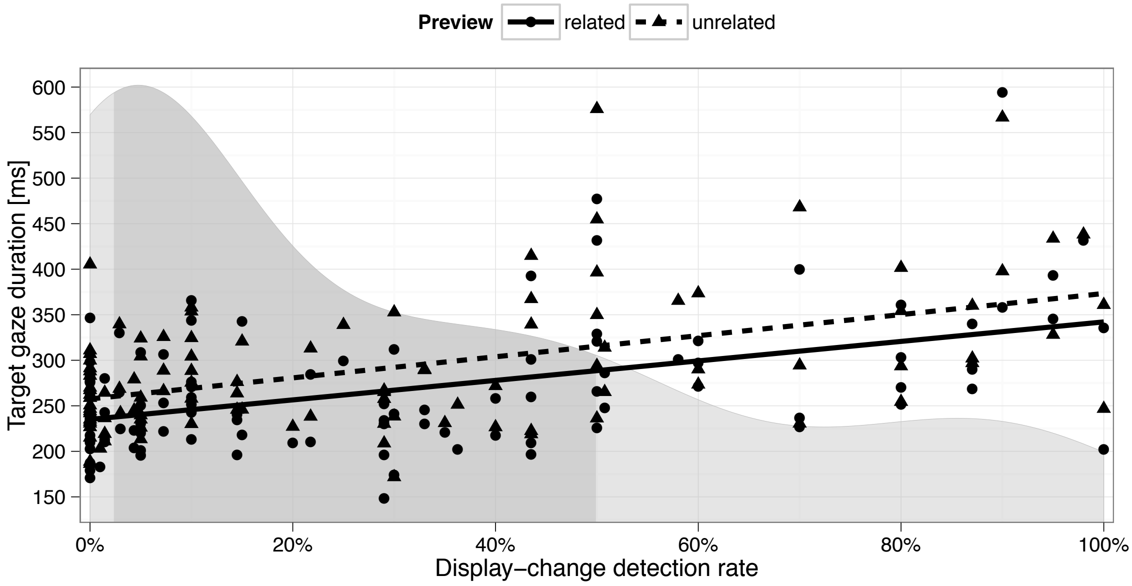

Figure 7. Linear trend of the regression of average target gaze duration on display-change detection rate (self-report; relative to the actual proportion of display changes) for related and unrelated previews (Experiments 1–3). Data from both capitalization and both contrast conditions were combined. Black symbols indicate subjects' average gaze durations for related (circles) and unrelated previews (triangles), respectively. The shaded area in the background represents the density of the detection rate (without relationship to the vertical scale; zero density is represented by the position of the horizontal axis); the darker area indicates the interquartile range of the distribution.

To evaluate this issue with better statistical power, we analysed data of related and unrelated trials of all three experiments.[5] This analysis encompasses observations from 107 subjects. There still was no significant modulation of semantic preview benefit by self-reported display-change detection rate (b = −0.000008, t = −0.03, for gaze durations; b = −0.0001, t = −0.36, for first-fixation durations; b = 0.00006, t = 0.21, for single-fixation durations). To assess the reliability of these null results, we generated 95% confidence intervals for the regression coefficients of the interaction effect, based on 10,000 posterior simulations (Gelman et al., 2012). Intervals for gaze durations ([−0.0007; 0.0005]), first-fixation durations ([−0.0007; 0.0005]), and single-fixation durations ([−0.0006; 0.0006]) roughly correspond to fixation duration changes ([−0.17 ms; 0.13 ms], [−0.17 ms; 0.11 ms], and [−0.15 ms; 0.16 ms], respectively), associated with a 1% increase in detection rate. Effects outside these ranges could reliably be rejected, given the data and analyses. Even if we compared detection rates of 0% and 100%—the latter not representative of the distribution of reported values—the interaction effects were considerably below the main preview effects.

Traditionally, subjects who reported display-change awareness in boundary experiments were excluded from the analyses; usually this number was very small. In contrast, in each of our three experiments, there were only a few participants who reported no detection of display changes. Therefore, we did not limit our analyses to unaware subjects. When aggregated across the three experiments, the number of subjects unaware of display change adds up to 22 (21%), warranting a separate analysis. These subjects showed longer fixation duration when the preview was unrelated, compared to semantically related previews (b = 0.09, t = 4.9, for gaze durations; b = 0.09, t = 5.2, for first-fixation durations; b = 0.10, t = 5.4, for single-fixation durations). Thus, the extraction of semantic code from the parafovea remained significant even for subjects meeting the traditional criterion of being unaware of display changes.

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[5] For this analysis, the proportion of detected display changes reported by subjects of Experiment 3 was linearly scaled to the actual proportion of display changes; according to this transformation, two subjects reported a relative detection rate of more than 100%. Since it logically is not possible to detect more display changes than trials, these two values were set to 100%.

SEMANTIC PREVIEW BENEFIT AND MISLOCATED FIXATIONS

We interpret our finding of a semantic preview benefit on the target as evidence of parafoveal processing of semantic information, but targeting of saccades is not perfect. Therefore, due to oculomotor error, saccades sometimes are too short and hence undershoot their goal (McConkie, Kerr, Reddix, & Zola, 1988). As a result, the fixation can be on the pretarget, but attention may still be on the intended preview word. If, despite the oculomotor error, attention were in fact on the intended saccade target, the semantic preview benefit would be a parafoveal effect with respect to the location of the eye, but not with the respect to the location of attention. We will refer to such fixations as “mislocated” fixations. Mislocated fixations are more likely to be on the edges of words (Nuthmann, Engbert, & Kliegl, 2005). Therefore, the closer a fixation is to the boundary preceding the target location, the higher the probability of it being a mislocated fixation.

Using the aggregated data, we can check the significance of the semantic preview benefit as a function of launch site. Since pretargets had a length of four to eight characters, launch site distance could range from one to nine characters. A fixation on the last character of the pretarget has a launch site distance of 1; a fixation on the space preceding an eight-character pretarget is indicated by a launch site of 9. Fixations on the space between pretarget and target are considered as target fixations.

Results from these analyses are listed in Table 10 Semantic preview benefit was significant for gaze durations, first-fixation durations, and single-fixation duration in a subset of data with pretarget fixations located five to nine characters before the target. In this region, there is a very low probability that the intended fixation location was on the target. Nevertheless, the negative relationship between launch site distance and the regression coefficient associated with the semantic preview effect could hint at an additional influence from mislocated fixations for fixations close to the boundary. We conclude that our finding of semantic processing of parafoveal words cannot be explained by mislocated fixations alone.

(Drieghe et al., 2008) found effects from properties of a critical target on the fixation of the preceding word (parafoveal-on-foveal effects) to be limited to near-target fixations and argued that mislocated fixations, rather than parallel processing, can explain this phenomenon. In contrast, Kennedy (2008) obtained parafoveal-on-foveal effects up to seven characters before the parafoveal target. In the present study, we did not find parafoveal-on-foveal effects but semantic preview benefit was greater for short rather than long launch site distances, but this effect was still significant for launch sites that are unlikely to be classified as mislocated fixations by any algorithm we are aware of.

Table 10

Linear Mixed-Model Analyses of Semantic Preview Benefit on the Target with the Dependent Variables Gaze Duration, First-Fixation Duration, and Single-Fixation Duration Subsets of Data Defined by Different Ranges of Launch Sites

	Gaze duration				First-fixation duration				Single-fixation duration			
Launch site distances	Obs (%)	*b*	*SE*	*t*	Obs (%)	*b*	*SE*	*t*	Obs (%)	*b*	*SE*	*t*
1–9	100.0	0.10	0.01	9.04	100.0	0.08	0.01	6.45	88.9	0.10	0.01	8.32
2–9	96.1	0.10	0.01	9.08	96.1	0.08	0.01	6.38	85.2	0.10	0.01	8.42
3–9	81.2	0.08	0.01	7.48	81.2	0.07	0.01	5.32	71.3	0.09	0.01	7.24
4–9	56.2	0.06	0.01	5.01	56.2	0.05	0.01	3.10	48.4	0.07	0.01	4.84
5–9	29.4	0.06	0.02	3.58	29.4	0.06	0.02	3.03	24.6	0.08	0.02	4.30
6–9	11.3	0.06	0.02	2.57	11.3	0.05	0.03	1.70	9.5	0.07	0.03	2.33
7–9	3.4	0.07	0.05	1.41	3.4	0.05	0.05	0.98	2.9	0.08	0.06	1.37

Note. Analyses are based on log data from 110 subjects of Experiments 1-3 and were performed on subsets of observations (obs). Launch site distances are given in characters. A launch site distance of 1 indicates a fixation on the pretarget's last letter. The proportion of observations is relative to all observations including related or unrelated preview (N = 6,251). Analyses based on the very infrequent trials with a launch site distance of eight or nine characters were omitted (0.6%).

1.2 General Discussion

We report a semantic preview benefit from the upcoming word next to the currently fixated one during reading of an alphabetic script, using the boundary paradigm as the experimental venue. So far, reports of semantically related parafoveal previews facilitating the reading process were limited to within-word processing (White et al., 2008), reading of character-based Chinese script (Cui et al., 2013; Yan et al., 2009; Yan, Zhou et al., 2012; Yang, Wang, et al., 2012), and Korean script (Kim et al., 2012), and delimitating the duration of preview presentation (parafoveal fast priming; Hohenstein et al., 2010). In the present study, we used the German language and highly frequent foveal pretargets and demonstrated a semantic preview benefit for fixation times on the target. We also showed that parafoveal semantic facilitation is potentially moderated by pretarget gaze duration and moderated by launch site distance; we did not find a significant relation between semantic preview benefit and subjects' self-reported ability to detect display changes. Furthermore, we found no evidence that the effect depended on capitalization of targets or contrast of text against background. The effect is also not an artifact of mislocated fixations. We conclude that extraction of semantic codes during reading can be demonstrated for the (right-directed) parafoveal region and does not depend on whether the parafoveal region is made up of a part of the fixated word or another word. Given this positive evidence, we can move on to determine the conditions required for its occurrence.

1.2.1 What abets parafoveal semantic preview benefit?

How does the present study differ from previous ones in which no semantic preview benefit has been reported? As described in the Introduction, with the exception of Rayner et al. (1986), earlier studies did not use the standard boundary paradigm. The positive findings for a semantic preview benefit in the present study could be due to the use of high-frequency pretargets. High-frequency words are easier to process and hence allow for more extensive preprocessing of parafoveal words, yielding a greater (identity) preview benefit than low-frequency words (Henderson & Ferreira, 1990; Kennison & Clifton, 1995; White et al. 2005). Such a dynamic modulation of the perceptual span, reflected in parafoveal-on-foveal effects of the frequency of word *n* + 1 on fixations on word *n*, has also been reported in analyses of large corpora of eye movements (Kennedy, Pynte, Murray, & Paul, 2013; Kennedy & Pynte, 2005; Kliegl, Nuthmann, & Engbert, 2006). For the present study, we explicitly selected pretargets to this end. The semantic facilitation effect obtained from parafoveal preview may, to some extent, be due to this characteristic of the foveal word.

Although there are invariant aspects of reading, across orthographies (see Frost, 2012, for a discussion), differences between languages are highly important. The orthographic consistency in German script is relatively high. As a consequence, immediate on-line assembly of syllables is much more likely in German than in English (Frith, Wimmer, & Landerl, 1998). Resulting differences in phonological encoding probably are relevant when it comes to extracting lexical information during reading (see Laubrock & Hohenstein, 2012).

PREVIEW SPACE AND PREVIEW TIME

The impact of both preview space and preview time on parafoveal preprocessing fits predictions of different computational models of eye-movement control during reading (see below). If the distance between pretarget fixation location and preview location is small, more information from the parafoveal preview falls into the perceptual span. This has implications for the parafoveal preprocessing of the upcoming word. In all three experiments, semantic preview benefit was reliably modulated by launch site distance. The difference in target fixation durations for semantically related and unrelated previews increased with decreasing space between pretarget fixation and preview word. We interpret this interaction as evidence of more efficient lexical processing of proximal previews. Since visual acuity is highest for the fovea and quickly drops in the parafoveal region, the low-level visual representation of the preview does benefit from a short launch site distance. This advance in the visual representation most likely abets processing speed of orthographic and lexical information.

Consistent with Kliegl et al. (2013), benefit associated with identical previews is higher, compared to nonword previews, if the distance between pretarget and target fixation location is short. Furthermore, the distance to a parafoveal preview influences the performance of subjects who are asked to detect display changes while reading sentences for comprehension (Slattery et al., 2011). Accuracy is higher if the eyes land closer to the target region. This more efficient detection of stimuli changes for closer launch sites, which we might explain with limitations of visual acuity. The influence of spatial distance also for semantic preview processing is evidence indicating that a low-level visual advantage of the preview location is not limited to parafoveal preprocessing of basic features, but applies also to the encoding of word meaning. The larger effect for small, rather than larger, distances may in part be due to mislocated fixations undershooting the intended target, but the effect was still significant for distances at which explanations exclusively in terms of mislocated fixations are highly unlikely.

The effects of pretarget fixation duration on semantic preview benefit are less clear. The fixation duration on the pretarget limits parafoveal preview time. We obtained a reliable positive relationship between preview time and semantic preview benefit, but this effect was present only in a subset of analyses of Experiments 1 and 2. In Experiment 3, we found no reliable evidence of this interaction. In previous studies with alphabetic script, the impact of pretarget fixation duration on identity preview benefit was in the focus of attention. Schroyens et al. (1999) found an only marginally significant positive relationship; the effect was not reliable in White et al.'s (2005) data. As in the present study, Kliegl et al. (2013) found reliable positive effects in a subset of their analyses. In Chinese, the effect appears to be quite labile as well (Yan, Risse, et al., 2012; Yan, Zhou, et al., 2012). Thus, concerning the influence of preview time on preview benefit, our results are mixed and reflect the overall picture arising from findings in previous studies.

Preview time influencing parafoveal processing is also consistent with other recent findings showing that the perceptual span dynamically changes during a fixation (Ghahghaei, Linnell, Fischer, Davis, & Dubey, 2013). During the first half of a fixation, the perceptual span expands, entailing more processing of parafoveal stimuli. Such an influence of preview time on parafoveal processing during reading delivers important constraints for computational models of eye-movement control during reading. More research is necessary to determine the timelines of preview on semantic and other types of preview benefit (Dambacher et al., 2012).

1.2.2 Display-change awareness

The study of parafoveal preview benefit requires an exchange of words during reading. White et al. (2005) and Slattery et al. (2011) reported greater identity preview benefit (nonword vs. identical preview) when display changes were detected and therefore argued that subjects' awareness of these changes is critical to the results. Although we found a positive relationship between subjects' fixation durations and their ability to detect display changes, there was no evidence of a subject's self-reported display-change awareness having an impact on the magnitude of the semantic preview benefit. The result was very different when we compared nonidentical and identical previews: Increasing awareness of display changes increased the difference between related and identical previews. Comparing nonidentical and identical previews has one drawback. It confounds a comparison of relatedness and a physical change on the display; nonidentical previews require a display change, whereas identical previews do not. Our finding of an awareness-determined increase in preview benefit when including an identical condition is consistent with that of White et al. (2005) and Slattery et al. (2011), but for comparisons between nonidentical preview conditions, there was no evidence indicating that the magnitude of the preview benefit is affected by the detection of display changes.

Independence of semantic facilitation and degree of awareness is an important result concerning boundary studies in general and also concerning the reliability of the outcome of experiments using the parafoveal fast-priming technique (Hohenstein et al., 2010). The finding is reminiscent of research on the relation between action priming by metacontrast-masked primes and awareness of the prime (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). They showed that the time course of priming was identical for reportable and invisible prime stimuli and concluded that "experimental variations that modify the subjective visual experience of masked stimuli have no effect on motor effects of those stimuli in early processing" (p. 6275).

Implications for computational models of eye-movement control in reading

Our results are relevant to a controversial issue in computational modeling of eye-movement control in reading, namely, whether processing of consecutive words is serial, with one word being processed at a time, or spatially distributed with multiple words at a time (Starr & Rayner, 2001). Cognitive models of eye-movement control during reading (see Radach, Reilly, & Inhoff, 2007, for an overview) can analogously be divided into *sequential attention shift* (SAS) models (see Reichle, 2011, for an overview) and *processing gradient* (PG) models (see Engbert & Kliegl, 2011, for an overview).

The best known SAS model is E-Z Reader (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003; Reichle, Warren, & McConnell, 2009), which postulates consecutive stages of processing. In the early visual stage, low-level word shape information (e.g., length) is processed preattentively before the first stage of lexical processing (L_1) starts. This stage is influenced by word frequency and word predictability. Completing this stage triggers a saccade program from word *n* to word *n* + 1 and simultaneously the second stage of lexical processing (L_2), lexical access. When L_2 is completed, attention shifts to word *n* + 1 within 50 ms. If L_1 of word *n* + 1 is completed while the saccade program to the target *n* + 1 is still in the labile phase M_1, this old saccade program is cancelled and a new one starts toward word *n + 2*. If the saccade program is already in the nonlabile phase M_2, the saccade will arrive at the target and start the critical fixation duration.

How can an SAS model like E-Z Reader explain the present results? In general, preview benefit is greater with highly frequent pretargets, such as those used in the present experiments, since stages of lexical processing in E-Z Reader are shorter as frequency increases and attention shifts earlier from pretarget to target. Several findings coincide very well with these basic model assumptions. L_1 is longer if the word is farther removed from the center of vision. Thus, our result of a negative relationship between launch site distance and preview benefit can be explained by the slower lexical processing of a distant parafoveal preview word. In the E-Z Reader framework, greater preview benefit for long pretarget fixation durations is a consequence of the increased timespan during which the parafoveal preview could be processed. There are two potential sources of variation in the pretarget gaze duration: First, the M_1 and M_2 stages of saccade programming are random deviates from gamma distributions; second, if a word is refixated, the amount of lexical processing from the preceding fixations on the same word will reduce the time needed to finish lexical processing. Thus, attention will shift to the next word earlier, generating a longer period for parafoveal processing before the saccade to the next word is executed.

There are two conditions under which the model can account for semantic preview benefit, but the constraints for this to happen are quite formidable. First, the pretarget fixation could be a mislocated fixation resulting from an erroneous undershoot of the target. Our analyses suggest that this explanation is unlikely to account for all of the semantic preview benefit we observed. Second, the first stage of lexical processing of the parafoveal preview L_1 of word n + 1 must be completed during the remainder of the non-labile phase M_2 of the saccade program from word n to word n + 1; otherwise, the reader will skip the target, which will then not contribute to analyses of preview benefit. Thus, the time the preview is in stage L_2 must be shorter than the duration of M_2.

PG models provide an alternative perspective. According to these models, attention is distributed continuously as a gradient in the visual field. In the PG model SWIFT (Engbert, Longtin, & Kliegl, 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005; Schad & Engbert, 2012), the gradient is determined by word position and foveal processing. A dynamic field of lexical activations evolves as a function of the lexical processing difficulty of the words, as several words are processed in parallel. Hence, attention is not limited to a single word. Like E-Z Reader, word processing comprises two phases. The first phase represents low-level preprocessing. Activation of a word increases until it reaches a difficulty-determined maximum. In the second phase, lexical access takes place and activation decreases until the word is completely processed. In the most recent version of the model (Schad & Engbert, 2012), the processing span is also influenced by foveal word processing. During the increasing phase, the processing span is at a fixed minimum. After preprocessing is completed, the processing span dynamically increases with decreasing activation of the foveal word. This zoom lens behavior allows for more parafoveal processing if the fixated word is easier to process. The assumption of parallel lexical processing of words enables PG models to explain the present results.

Applying the theoretical framework of SWIFT to the current experiment includes the following: Lexical processing of the preview in parafoveal position occurs during fixation of the pretarget n. When processing of target n + 1 is in the decreasing (lexical) phase, semantic information is extracted. An increased preview benefit with short launch site distances is due to a higher processing gradient near the fixation location.

There are two sources for a positive relationship between preview benefit and pretarget fixation duration in the SWIFT framework: The longer the preview duration, the longer lexical processing of the preview will be, and the larger the processing span, with an increase of processing rate for the preview word.

Saccade target selection is not a deterministic process, but a stochastic process, assuming a word's target selection probability is proportional to its relative activation. The start of saccade programs is a stochastic process modulated by foveal activity. Therefore, although the amount of semantic parafoveal processing is positively correlated conceptually with the probability of skipping the next word, skipping probability depends on temporal, spatial, and lexical properties. Fixating a word implies lexical preprocessing, and thereby preview benefit is expected in SWIFT. The results of the present study are clearly in the theoretical spirit of PG models. Nevertheless, we must recognize that it is unlikely that any of the implemented model variants correctly reproduce the pattern of results.

1.2.3 Conclusion

The results of three experiments are in support of semantic parafoveal preprocessing for readers of an alphabetic script: Targets are read faster with a related-word preview than with an unrelated-word preview. The semantic preview benefit was greater when fixation position was close to the upcoming word. We also observed several positive effects of pretarget fixation durations (preview time) on semantic preview benefit. The degree of awareness of display change was positively related to average mean fixation duration and the magnitude of identity preview benefit, but subjects' degree of awareness of display changes was not significantly related to semantic preview benefit. The results are in support of theoretical and computational proposals allowing for complete parafoveal processing of words during reading.

AUTHOR NOTE

Sven Hohenstein and Reinhold Kliegl, Department of Psychology, University of Potsdam, Potsdam, Germany. We thank Jochen Laubrock for discussion, Raymond Bertram, Albrecht Inhoff, Wayne Murray, Keith Rayner, and Sarah White for their helpful comments on earlier versions of this manuscript and Petra Schienmann for testing the subjects. Data and R scripts are available at the Potsdam Mind Research Repository (PMR2; http://read.psych.uni-potsdam.de/pmr2/).

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