This is a preprint of an article whose final and definitive form was published in

Journal of Experimental Psychology: Human Perception and Performance

Online First Publication, March 19, 2012. doi: 10.1037/a0027735

EVIDENCE FOR DELAYED PARAFOVEAL-ON-FOVEAL EFFECTS FROM WORD N+2 IN READING

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Running Head: Delayed parafoveal-on-foveal effects from word *n*+2

Keywords: perceptual span, *n*+2-boundary paradigm, preview benefit, parafoveal-on-foveal effect, mislocated fixations, eye movements

11,418 words

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Abstract

During reading information is acquired from word(s) beyond the word that is currently looked at. It is still an open question whether such parafoveal information can influence the current viewing of a word, and if so, whether such parafoveal-on-foveal effects are due to distributed processing or to mislocated fixations which occur when the eyes are directed at a parafoveal word but land on another word instead. In two display-change experiments, we orthogonally manipulated the preview and target difficulty of word *n*+2 in order to investigate the role of mislocated fixations on the previous word *n*+1. When the eyes left word *n*, an easy or difficult word *n*+2 preview was replaced by an easy or difficult *n*+2 target word. In Experiment 1, *n*+2 processing difficulty was manipulated by means of word frequency (i.e., easy high-frequency vs. difficult low-frequency word *n*+2). In Experiment 2, we varied the visual familiarity of word *n*+2 (i.e., easy lower-case vs. difficult alternating-case writing). Fixations on the short word *n*+1, which were likely to be mislocated, were nevertheless not influenced by the difficulty of the adjacent word *n*+2, the hypothesized target of the mislocated fixation. Instead word *n*+1 was influenced by the preview difficulty of word *n*+2, representing a delayed parafoveal-on-foveal effect. The results challenge the mislocated-fixation hypothesis as an explanation of parafoveal-on-foveal effects and provide new insight into the complex spatial and temporal effect structure of processing inside the perceptual span during reading.

EVIDENCE FOR DELAYED PARAFOVEAL-ON-FOVEAL EFFECTS FROM WORD N+2 IN READING

The time readers spend fixating individual words while reading has long been known to reflect the processing difficulty associated with the currently fixated word in *foveal* vision (Huey, 1908; see also Just & Carpenter, 1980; Rayner & Duffy, 1986). The perceptual span from which useful information is acquired during reading, however, covers also words that are not yet fixated and reside in *parafoveal* vision. During reading of English, information is effectively used from 3-4 letters to the left and up to 14-15 letters to the right of fixation (McConkie & Rayner, 1975; 1976). Given sufficiently short words, the perceptual span can thus comprise one word to the left but more than one word to the right of a fixated word.

Preview benefit, Crosstalk, and Mislocated Fixations

Parafoveal preview benefit

The impact of processing parafoveal words in the perceptual span has been extensively studied with the boundary paradigm (Rayner, 1975). During fixations on words prior to an invisible boundary located after word *n*, selective word properties of the neighboring word *n*+1 are masked. As soon as the eyes cross the boundary, the parafoveal preview is replaced with the correct target word. Research with the gaze-contingent display-change technique established substantial *preview benefit* on word *n*+1: Fixation times are typically 20-50 ms shorter if identical preview was available throughout sentence reading compared to when correct preview was denied (for a review see Rayner, White, Kambe, Miller, & Liversedge, 2003). This difference in fixation durations suggested that parafoveal information is not only successfully extracted during pretarget fixations but also integrated across saccades facilitating word recognition when the target word is eventually fixated (Inhoff, 1990; Inhoff & Tousman, 1990). Parafoveal preview starts the identification process of a word before fixation.

Parafoveal-on-foveal effects

A controversial issue of eye-movement control during reading is whether processing a preview in parafoveal vision affects identification processes at the currently fixated word in foveal vision (see Rayner & Juhasz, 2004; Rayner et al., 2003). Several studies suggested that parafoveal difficulties such as low-level orthographic irregularities of an *n*+1 preview (e.g., a random string of letters) prolong fixation durations on word *n* (Drieghe, Rayner, & Pollatsek, 2008; Inhoff, Radach, Starr, & Greenberg, 2000; Inhoff, Starr, & Shindler, 2000). In contrast, higher-level linguistic information such as the upcoming word's lexical frequency did not systematically affect pretarget fixation durations in the boundary paradigm (Hyönä & Bertram, 2004, Kennedy, 1998; Kennedy, Pynte, & Ducrot, 2002; Rayner, Warren, Juhasz, & Liversedge, 2004). However, the frequency of word *n*+1 showed effects in regression analyses of fixation durations reading large corpora of texts (Kennedy & Pynte, 2005; Kliegl, Nuthmann, & Engbert, 2006; Pynte & Kennedy, 2006, 2007; Schad, Nuthmann, & Engbert, 2010). The latter typically include more words with a wider range of lengths and frequencies than studies focusing on fixation durations on selected target words embedded into sentences. At present, evidence for so called *parafoveal-on-foveal effects* is often perceived as being ambiguous and may vary with parafoveal word properties and experimental paradigms.

Parafoveal-on-foveal effects as evidence for parallel word-processing. Aside from the debate concerning the reliability of parafoveal-on-foveal effects, there is additional debate concerning their nature when they are observed. The latter directly relates to one of the core issues in research on eye-movement control during reading that is whether lexical word-processing is parallel or serial (Reichle, Liversedge, Pollatsek, & Rayner, 2009). If attention is distributed across multiple words simultaneously and words are processed in parallel (Engbert, Nuthmann, Richter, & Kliegl, 2005; Inhoff, Radach, et al., 2000; McDonald, Carpenter, & Shillcock, 2005; Reilly & Radach, 2006; Vitu, Lancelin, Jean, & Farioli, 2006), lexical processing of consecutive words can overlap. Parafoveal-on-foveal effects may reflect crosstalk between the simultaneous extraction of foveal and parafoveal information and its impact on ongoing identification processes at the fixated word. From this perspective, parafoveal-on-foveal effects have been interpreted as evidence for parallel word-processing inside the perceptual span (Kennedy, 1998; Murray, 1998). Conversely, if word processing is restricted to one word at a time and attention is shifted sequentially from word to word across the sentence (see Morrison, 1989; Reichle, Rayner, Fisher, & Pollatsek, 1998), overlap in lexical processing of consecutive words is impeded and crosstalk impossible. It has been claimed, therefore, that parafoveal-on-foveal effects are incompatible with the notion of serial word-processing during reading. If processing of the next word starts only after the current word has been fully recognized, parafoveal word difficulties should not affect fixation durations on the foveal word. Motivated by empirical evidence, recent sequential attention-shift models provide for parallel processing of early orthographic information while lexical processing remains strictly serial (e.g., Pollatsek, Reichle, & Rayner, 2006a).

Parafoveal-on-foveal effects as a consequence of mislocated fixations. There is, however, an alternative explanation of parafoveal-on-foveal effects: Instead of reflecting crosstalk they could result from mislocated fixations while serial processing is maintained. Specifically, a saccade may undershoot an intended target word *n*+1 and instead land on word *n* simply due to oculomotor error (McConkie, Kerr, Reddix, & Zola, 1988). In this case, attention and processing may nevertheless focus on the originally intended word *n*+1 and processing difficulties of word *n*+1 would be reflected in the mislocated fixation on word *n*. If parafoveal-on-foveal effects are nothing but evidence for a dissociation of fixation position and attention location due to oculomotor error, there is no need to assume that processing is distributed across more than one word at a time. The fixation duration on word *n* simply reflects the “immediate processing difficulty” of word *n*+1 from a non-optimal fixation position. Drieghe, Rayner, and Pollatsek (2008) investigated parafoveal-on-foveal effects in the boundary paradigm and obtained effects only for fixation durations at the end of word *n* close to the boundary where oculomotor error should be most likely (Nuthmann, Engbert, & Kliegl, 2005). Drieghe et al. argued that serial word-by-word processing remains a viable explanation given that such near-boundary fixations were mislocated and the parafoveal word *n*+1 was attended and processed. Of course, this result does not rule out parallel processing-crosstalk, which may likewise explain effects preferably in fixations close to the boundary[1]. Indeed, another study obtained parafoveal-on-foveal effects up to seven characters prior to a target word at a distance at which oculomotor error is quite an unlikely explanation (Kennedy, 2008). Thus, a spatial-distance criterion does not allow us to unambiguously test the *mislocated-fixation hypothesis* about parafoveal-on-foveal effects.

Mislocated Fixations in the *n*+2-Boundary Paradigm

Rayner, Juhasz, and Brown (2007) first introduced a boundary experiment in which they varied preview not of the neighboring word *n*+1, but of the subsequent word *n*+2, that is of the second word to the right of the invisible boundary. While the readers fixated to the left of the boundary located at the end of word *n*, the parafoveal word *n*+2 was either presented as the identical target word, an alternative word, or a nonword preview. They obtained no evidence that readers were able to use informative preview of word *n*+2 but confirmed substantial preview benefit from word *n*+1. The lack of benefit from identical word *n*+2 preview was interpreted as evidence against parallel word-processing across the entire perceptual span. Instead, if attention is shifted serially from word to word, parafoveal processing should be limited mainly to the next word *n*+1 (see also Angele & Rayner, 2011; Angele, Slattery, Yang, Kliegl, & Rayner, 2008).

In contrast, we documented *n*+2 preview effects in two studies comprising three experiments with a very similar procedure (Kliegl, Risse, & Laubrock, 2007; Risse & Kliegl, 2011). For example, we found particularly robust effects from word *n*+2 in fixation durations on a short pretarget word *n*+1 after crossing the boundary (i.e., shorter fixations for identical than nonword preview of word *n*+2). This novel finding was discussed as either being a preview benefit of word *n*+2 mislocated in fixations on the earlier word *n*+1, or a parafoveal-on-foveal effect from word *n*+2 on word *n*, but delayed into fixations on word *n*+1. Analogous to the explanation of parafoveal-on-foveal effects by means of mislocated fixations, an *early preview-benefit effect* on the pretarget word *n*+1 would be compatible with serial word-processing. If attention was shifted rapidly enough up to word *n*+2, starting processing of this word while still fixating on the pre-boundary word *n*, the resulting preview benefit should be obtained even when the next saccade does not land on the intended target word *n*+2 but falls short on word *n*+1. Conversely, a *delayed parafoveal-on-foveal effect* would be new evidence for processing crosstalk. Our previous experiments did not permit to distinguish between these two alternative explanations.

The present experiments

In this article, we introduce a variant of the *n*+2 boundary paradigm in which effects of preview benefit, parafoveal-on-foveal crosstalk, and mislocated-fixation effects are mapped onto different sources of variance of fixation durations in linear mixed models (LMM). Thus, explanations of crosstalk and mislocated fixations are potentially complementary with each other. The novel change is that we orthogonally manipulated the processing difficulty of word *n*+2 before the boundary (i.e., the *n*+2 preview difficulty) and after crossing the boundary (i.e., the *n*+2 target difficulty). Preview and target difficulty of word *n*+2 was manipulated through lexical frequency in Experiment 1 (easy: high frequency; difficult: low frequency), and through visual familiarity in Experiment 2 (easy: familiar lower-case writing; difficult: unfamiliar alternating-case writing). As illustrated in Figure 1 this resulted in four preview conditions: (a) an easy preview of word *n*+2 during fixations before the boundary was replaced by a difficult target word *n*+2 when the boundary was crossed; (b) a difficult preview of word *n*+2 was replaced by an easy *n*+2 target word; (c) an easy and (d) a difficult identical-preview condition in which preview and target word *n*+2 remained the same.

- Figure 1 about here -

Parafoveal-on-foveal and preview benefit effects in the present experiments. With the present *n*+2 preview-difficulty (2) x *n*+2 target-difficulty (2) design we can test two main effects and one interaction. First, for fixations on word *n,* the main effect of *n*+2 preview difficulty tests the effect of parafoveal processing of word *n*+2 when the eyes are still before the boundary, irrespective of whether the subsequent target will be identical to or different from the preview word. Thus, for fixations on word *n*, we obtain a test of the parafoveal-on-foveal effect of word *n*+2. Such an effect would be strong evidence for an explanation in terms of crosstalk, rather than mislocation, given that the probability of missing a target by two words is very low.

Second, for fixations on word *n*+2, the main effect of the *n*+2 target difficulty reflects the processing difficulty associated with the currently fixated word *n*+2 after crossing the boundary (i.e., immediacy processing). More importantly, the interaction between preview and target difficulty tests the difference between the mean of the two different-preview conditions ("easy-difficult", "difficult-easy") and the mean of the two identical-preview conditions ("easy-easy", "difficult-difficult"). Shorter fixation durations in the identical-preview than different-preview conditions constitute evidence for *preview benefit* when finally fixating the target word *n*+2. Our manipulation, therefore, still embodies the core idea of the boundary paradigm that an identical preview should facilitate processing more than a different preview.

Distinguishing between delayed parafoveal-on-foveal and mislocated-fixation effects. With the present variant of the boundary paradigm, we can go beyond the two tests of parafoveal-on-foveal and preview-benefit effects from word *n*+2. As in our previous studies, we used three-letter words in position *n*+1 to increase the chances that word *n*+2 falls into the perceptual span. In addition, word *n*+1 was either a function word (e.g., a preposition) or a content word (e.g., a noun) expanding the present study to a 2 x 2 x 2 design. In our experiment, both word types are easy to process with function words having an even higher frequency than content words. This difference in difficulty of word *n*+1 could show an additional parafoveal-on-foveal effect in fixations on word *n*. At the same time, short and easy words tend to be skipped frequently (Brysbaert & Vitu, 1998; Drieghe, Brysbaert, Desmet, & DeBaecke, 2004; Gautier, O'Regan, & Le Gargasson, 2000). Indeed, there is good empirical reason for the assumption that a majority of fixations measured on word *n*+1 were intended for word *n*+2; Engbert and Krügel (2010) estimated that most fixations on three-letter German words are actually due to failed skipping. Consequently, the fixations we observe on word *n*+1 are a mixture of fixations intended for this word and fixations intended for word *n*+2 (i.e., mislocated fixations).

Given the present preview manipulation in which the *n*+2 preview difficulty is orthogonal to the processing demand of the later target word, we can now test what is processed during fixations on the critical word *n*+1. A significant effect of the *n*+2 target-difficulty on word *n*+1, ideally in combination with a significant interaction between preview and target difficulty, provides evidence for mislocated fixations on word *n*+1 while attention is on the intended target word *n*+2. In this case, a difficult target word *n*+2 should lead to longer fixations on word *n*+1. Moreover, as argued above for fixations on word *n*+2, the interaction between preview and target difficulty, is a test of preview benefit. In case of mislocated fixations, this effect should be measured on word *n*+1, not on word *n*+2.

A significant effect of *n*+2 preview-difficulty (i.e., the difficulty of word *n*+2 before the eyes crossed the boundary), however, represents a delayed parafoveal-on-foveal effect. If fixations on word *n*+1 were shorter after easy *n*+2 previews, this effect would be obtained despite the fact that, due to the display change when the eyes moved from word *n* to word *n*+1, the current difficulty of word *n*+2 was switched in 50% of the trials. In this case, it is reasonable to assume that the eyes moved too fast for the parafoveal-on-foveal effect to be visible on word *n*. Thus, with the new variant of the *n*+2 boundary paradigm, none, one or both explanations of the previously reported *n*+2 preview effect on word *n*+1 might receive statistical support in one single analysis. The results may provide crucial insight into the full dynamics of processing in the perceptual span during reading.

EXPERIMENT 1

In Experiment 1, the frequency of word *n*+2 was orthogonally manipulated contingent on the eye crossing the invisible boundary. Word *n*+2 was presented either as a high-frequent (easy) or low-frequent (difficult) preview before the boundary and as an easy or difficult target word after the boundary.

Method

Subjects

Sixty young adults (11 male, 49 female; either students of the University of Potsdam or high-school students of the Potsdam community) participated in a one-hour session. They were on average 24 years old (SD = 5) and had normal or corrected-to-normal vision. All participants signed informed consent prior to the experiment and received either course credit or 7 € for their attendance.

Sentence material

A three-word target region was embedded in simple-structured main clauses without intra-sentential punctuation. Word *n* of the critical word triplet occurred at positions three to seven (M = 5, SD = 1) in sentences with seven to eleven words (M = 9, SD = 1). Word *n*+2 was never the last or penultimate word in the sentence. Word length of the pre-boundary word *n* ranged from 4 to 13 letters (M = 7, SD = 2). The post-boundary word *n*+1 was always a three-letter word and the target word *n*+2 ranged from four to six letters (M = 5, SD = 1). In line with our previous studies, the word class of word *n*+1 was varied between sentences. In half of the sentences, word *n*+1 was a three-letter function word (a closed-class, grammatical word; i.e., prepositions or conjunctions) whereas in the other half it was a three-letter content word (an open-class, lexical word; i.e., nouns). Word-frequency norms were retrieved from the dlexDB-database based on the *Digitales Wörterbuch der Deutschen Sprache des 20. Jahrhunderts* corpus (Geyken, 2007; Heister et al., 2011; http://www.dlexDB.de). Average frequency was 306 per million (*SD* = 854) for word *n* and 2,822 per million (*SD* = 5,235) for the short post-boundary word *n*+1. Content words were of lower frequency (*M* = 33 per million, *SD* = 60) than function words (*M* = 5,611 per million, *SD* = 6,277). This between-sentence manipulation allowed us to test further effects relating to preview of word *n*+1 (e.g., higher skipping probability of word *n*+1 for function than content words).

The critical manipulation concerned the *n*+2 preview-word and target-word frequency. Each sentence frame enabled both a high-frequency (easy) and low-frequency (difficult) word at position *n*+2; they were matched in word length and fitted into the sentence context. Easy words *n*+2 had an average frequency of 312 per million (*SD* = 643) whereas difficult words averaged 3 per million (*SD* = 6). Word frequency is associated with the frequency of the word's initial bigram and trigram letters with correlations in the present Experiment amounting to *r* = 0.45 and *r* = 0.77, respectively. As the comparison in Table 1 illustrates, both measures were on average higher for the easy than for the more difficult word *n*+2 in each target-word pair. As we aimed at manipulating processing difficulty as a general concept, the present confound is not problematic to our question. However, caution is necessary when attributing frequency effects to processing up to a lexical level if it is assumed that bigram and trigram frequencies may exert rather sublexical influences. We will address this issue below with a supplementary analysis.

- Table 1 about here -

In addition, predictability of an upcoming word interacts with its parafoveal information extraction (e.g., Balota, Pollatsek, & Rayner, 1985). In the present context, this concerns the predictability of word *n*+2 given the sentence context up to the pre-boundary word *n* which, in fact, implies a conditional probability of guessing word *n*+2 given that word *n*+1 was also guessed correctly. Thus, the predictability of word *n*+2 will probably be much lower than for the neighboring word *n*+1, but it may still differ between easy and difficult target words in the present experiment. We used the conditional probability of occurrence of the critical word triplets (i.e, word *n*, *n*+1, and *n*+2) in the dlexDB database as an indicator for how predictable word *n*+2 was during pre-boundary fixations and compared this for cases with easy and difficult target word. Only 17 out of 160 test sentences (one with difficult target and 16 with easy targets) contained a critical word triplet with a frequency of occurrence greater than zero. However, even for these cases, predictabilities were still smaller than 0.06. The summary is provided in Table 1.

Apparatus and procedure

Participants were seated 60 cm in front of a 22-inch Iiyama Vision Master Pro 514 monitor with a screen resolution of 1024 x 768 pixels and a monitor refresh rate of 150 Hz. Their heads were positioned in a chin rest to minimize head movements. Reading was binocular and both eyes were monitored with an Eye-Link II system (SR Research, Osgoode, Ontario, Canada). Eye movements were recorded with a 500 Hz sampling rate and an instrument spatial resolution of 0.01°. Sentences were presented in black monospace letters on a white background using Courier bold with a 20 point font size resulting in 2.2 characters per degree of visual angle.

Each experiment started with familiarizing participants with apparatus and procedure, collecting their informed consent, and providing the written instruction. Both eyes were calibrated on a standard nine-point grid and re-calibrated every 15 trials. Each trial started with a fixation point on the left side of the horizontal midline that indicated the center of the upcoming sentence-initial word. If gaze detection on the fixation point failed for two seconds, a drift correction was applied in the center of the computer screen. After two successive failures a re-calibration was performed. If the initial fixation was successful the sentence was displayed on the horizontal midline of the monitor. Participants were instructed to read for comprehension and to fixate a dot in the lower right corner to signal the termination of the trial. Comprehension questions were asked after one third of the trials (three-alternative multiple-choice questions).

The experiment started with six practice sentences without manipulation. In the remaining 160 test sentences, an invisible boundary was located after word *n* followed by a three-letter content or function word *n*+1. The subsequent word *n*+2 was manipulated contingent on whether the gaze was detected online to be before or after the boundary. Word *n*+2 was either an easy high-frequency (e.g., "young") or a difficult low-frequency (e.g., "tamed") preview during pre-boundary fixations that was then replaced either by an easy ("young") or a difficult ("tamed") target word *n*+2 as soon as one of the eyes crossed the boundary (see Figure 1 for an illustration of the conditions). Each test sentence was presented in one of four conditions: (1) easy - difficult, (2) difficult - easy, (3) easy - easy, or (4) difficult - difficult. In conditions 3 and 4, in which *n*+2 preview and target word difficulty was identical, word *n*+2 was replaced by itself and participants gained correct preview of word *n*+2 during pre-boundary fixations. In conditions 1 and 2, preview of word *n*+2 was different from the subsequent target word, but the preview was not "incorrect" because the preview likewise fit into the sentence context. Experimental conditions were counterbalanced across participants. After the experiment, participants were asked whether they noticed any display changes.

Data selection and analysis

None of the participants reported noticing a display change. This indicates that replacements of words at *n*+2 locations in parafoveal vision are less likely detected than, for example, changes of the direct fixation neighbor word *n*+1. Therefore, data of all 60 subjects were analyzed after removing 6% of a total of 9,600 experimental sentences due to blinks and signal losses. Sentences were also excluded if the fixation onset after crossing the boundary preceded the termination of the display change. Due to system delays within the eye tracker (SR Research Ltd., 2006) and the refresh rate of the monitor, display changes were not always completed before the eyes landed on a word after the boundary. To exclude invalid display-change trials, we determined the time of each trial's visual display change on the monitor in a post-hoc manner by adding the time left of each monitor's refresh cycle at the moment of the first eye crossing the boundary to the time when crossing the boundary was detected online. The total delay of the display changes relative to their online detection averaged to 8.3 ms, ranging from 5 to 11.7 ms. The display-change criterion amounted to an additional 14% of data loss. Fixations with durations shorter than 50 ms and longer than 750 ms, being the first or last fixation within the sentence, or when both eyes did not fixate the same word were also removed. All fixations on a word were deleted if one of its constituent fixations was declared as invalid. In total, 30% of the recorded word-based fixations in the target region were excluded (21% for word *n*, 42% for word *n*+1, 29% for word *n*+2). This left 6,827 valid word-based fixations on word *n*, 3,512 on word *n*+1, and 6,977 on word *n*+2 for descriptive and inferential statistics.

We used linear mixed models (LMMs) for statistical inference because they cope with the situation of unbalanced designs with smaller loss in statistical power compared to repeated-measures ANOVAs (e.g., Baayen, 2008). In boundary experiments, aside from data loss due to technical recording failures of the eye tracker, all trials are excluded in which the display change did not occur during a saccade and, therefore, unbalanced designs are often the case. We used the *lmer* program (*lme4* package; Bates & Meachler, 2010) in the R system for statistical computing (version 2.11.1, The R Foundation of Statistical Computing, 2010) to fit separate LMMs for each of the three words in the target region.

Main effects and interactions were effect coded with contrast coefficients of -0.5 and 0.5. This resulted in the LMM estimates of the fixed effects to represent (a) the grand mean of the dependent variable as intercept and (b) the main effects and interactions as differences from the grand mean. In particular, we estimated fixed effects of *n*+2 preview difficulty (easy vs. difficult), *n*+2 target difficulty (easy vs. difficult), and word class of word *n*+1 (function vs. content word). Target difficulty of word *n*+2 cannot affect pre-boundary fixation durations on word *n* and, therefore, was not included as a factor in the respective LMMs; including the factor and its interactions did not significantly increase the goodness of fit.

As the short word *n*+1 was skipped very frequently, we were further interested in how skipping affect preview uptake of word *n*+2. For example, McDonald (2006) argued that effective preview is only obtained from the saccade goal suggesting that we may find the critical preview-benefit interaction particularly in cases in which word *n*+1 was successfully skipped. Therefore, we included skipping of word *n*+1 (fixated vs. skipped) as an additional factor into the LMMs for fixation durations on the target word *n*+2 but also for fixation durations on the pre-boundary word *n*. Obviously, skipping word *n*+1 cannot be included as a factor for analysis of fixations on word *n*+1.

Subjects, words, and sentences were included as crossed random effects. For each analysis we report the regression coefficients (*b*) and standard errors (*SE*s). Effects larger than twice their standard errors are interpreted as significant at the 5% level (i.e., given the large number of subjects and the large number of observations for each subject, the t-statistic [i.e., *b/SE*] effectively corresponds to the *z*-statistic).

Results

Statistical analyses focused on first-pass fixation-duration measures, that is the time spent on fixating a word when it is first encountered during reading. Specifically, we computed gaze durations (GDs) as the sum of all fixation durations on a word before leaving to another word, first-fixation durations (FFDs) containing only the word's initial fixation irrespective of whether the word was refixated or not, and single fixation durations (SFDs) consisting of all instances in which a word was fixated only once. Analysis of the residuals after model fitting strongly suggested that log-transformed fixation durations comply best with the normal-distribution assumption of the LMM. Therefore, inferential statistics are based on log-transformed fixation durations.

Results on the pre-boundary word n

Fixation durations on word *n* were analyzed with an LMM containing preview difficulty of word *n*+2 (easy vs. difficult), word class of word *n*+1 (function word vs. content word), skipping of word *n*+1 (fixated vs. skipped), and all their interactions as fixed effects. Summary statistics are provided in Table 2. The main effect of *n*+2 preview difficulty was marginally significant and positive indicating that GDs on word *n* were slightly longer if the parafoveal word *n*+2 was difficult to process (b = .01, SE = .01, t = 1.98). However, this effect was only 3 ms, and there was no evidence for a similar effect of word *n*+2 in FFDs (b = .01, SE = .01, t = 1.00) or SFDs (b = .01, SE = .01, t = 1.52).

- Table 2 about here -

Fixation durations on word *n* showed a substantial parafoveal-on-foveal effect of the neighboring word *n*+1 (i.e., main effect of *n*+1 word class). GDs were 35 ms longer if the upcoming word *n*+1 was a more difficult content word than an easy function word (b = .14, SE = .02, t = 5.69; FFD: 9 ms, b = .03, SE = .02, t = 2.00; SFD: 13 ms, b = .05, SE = .02, t = 2.93). Thus, there is strong support for an immediate parafoveal-on-foveal effect from word *n*+1.

There was an additional main effect of *n*+1 skipping. For FFDs and SFDs, the estimated slopes were negative indicating shorter fixations before skipping of the upcoming word *n*+1 (b = -.05, SE = .01, t = -6.10 and b = -.03, SE = .01, t = -4.03, respectively). GDs however, were longer before skipping (b = .02, SE = .01, t = 2.34). Word class of word *n*+1 modulated the skipping cost in GDs suggesting that the cost was reduced for upcoming function words (b = .05, SE = .02, t = 3.03). No other effects were significant on the pre-boundary word *n* (all absolute t values < 1.77).

Results on the post-boundary word n+1

Results on word *n*+1 are summarized in Table 3. As fixating the post-boundary word *n*+1 triggered the replacement of the *n*+2 preview with the target word, we included the *n*+2 target difficulty as a factor into the LMM for fixation durations on word *n*+1. There was only one significant effect on word *n*+1, and this was the *n*+2 preview difficulty as perceived prior to crossing the boundary (GD: $b = .02$, $SE = .01$, $t = 2.15$; FFD: $b = .02$, $SE = .01$, $t = 2.18$; SFD: $b = .02$, $SE = .01$, $t = 2.25$). Fixation durations on word *n*+1 were 4 ms longer if word *n*+2 had been a difficult preview during pre-boundary fixations and shorter if word *n*+2 was easy. No other effects were significant with absolute *t* values < 1.63. This result provides support for a delayed parafoveal-on-foveal effect.

- Table 3 about here -

There was no evidence for an effect of the *n*+2 target difficulty (all absolute *t* values < .73) and no evidence for an interaction of *n*+2 preview and target difficulty (all *t* values < .96). Thus, there was no evidence that during fixations on word *n*+1 the neighboring target word *n*+2 was processed or that previewing word *n*+2 entailed a processing advantage during a mislocated fixation on word *n*+1. Thus, there was no statistical support for the alternative explanation of an early *n*+2 preview benefit in mislocated fixations on word *n*+1.

Finally, fixation durations on word *n*+1 showed no effect of word class of the currently fixated word *n*+1 (all absolute *t* values < .37). This could be evidence that processing a short word *n*+1 often terminated in parafoveal vision during previous fixations (see results from fixations on word *n*). Only in a remaining portion of cases the fixation on word *n*+1 may have been intended to continue word *n*+1 processing in foveal vision. As these two types of fixations (i.e., intended and mislocated) mix on word *n*+1, the immediate word-class effect might have been too weak to manifest significantly.

Results on the target word n+2

For fixation durations on target word *n*+2, we fitted an LMM including word class and skipping of word *n*+1 as well as preview and target difficulty of word *n*+2 as factors. The results showed a strong effect of *n*+2 target difficulty (GD: $b = .07$, SE = .01, $t = 6.29$; FFD: $b = .05$, $SE = .01$, $t = 4.78$; SFD: $b = .06$, $SE = .01$, $t = 5.00$). As can be seen in Table 4, GDs were 20 ms longer (FFD: 13 ms, SFD: 16 ms) on a difficult *n*+2 target (i.e., low-frequency word *n*+2) than on an easy *n*+2 target (i.e., high-frequency word *n*+2). Neither the main effect of preview difficulty nor the interaction between preview and target difficulty was significant (all absolute *t*-values for GD, FFD, and SFD < .63).

- Table 4 about here -

Skipping of word *n*+1 led to significantly longer fixations on word *n*+2 (GD: $b = .27$, $SE = .01$, $t = 26.3$; SFD: $b = .10$, $SE = .01$, $t = 8.63$), however, not significant in FFD ($b = .01$, $SE = .01$, $t = .93$). This post-skipping cost was somewhat larger for easy *n*+2 targets than for difficult *n*+2 targets with an easy word *n*+2 showing a more pronounced reduction in *n*+2 reading times when additional preview was available during fixating word *n*+1 (interaction of *n*+2 target difficulty and *n*+1 skipping; GD: $b = -.06$, $SE = .02$, $t = -3.26$; FFD: $b = -.07$, $SE = .02$, $t = -4.62$; SFD: $b = -.07$, $SE = .02$, $t = -4.11$; see Table 4).

Finally, we obtained a spillover effect of the difficulty of word class of word *n*+1 in fixation durations on word *n*+2, which were longer if the preceding word *n*+1 was a content word rather than a function word (GD: $b = .13$, $SE = .02$, $t = 6.86$; FFD: $b = .09$, $SE = .01$, $t = 6.36$; SFD: $b = .10$, $SE = .02$, $t = 5.66$). The longer *n*+2 fixations after a content word *n*+1 additionally revealed a preview-benefit effect; the three-factor interaction of *n*+1 word class and *n*+2 preview and target difficulty was marginally significant for FFD ($b = -.06$, $SE = .03$, $t = -1.97$) but not for GD or SFD (both absolute *t* values < .84). No other interactions were significant.

Sublexical contributions to lexical n+2 preview effects

Processing difficulty of word *n*+2 was operationalized based on its lexical word-frequency that correlates strongly with sublexical properties such as the frequency of the word's initial letters. However, our theoretical argument for word *n*+1 fixations does not rest on whether *n*+2 difficulty effects are due to lexical or sublexical processing. Any effect of the preview difficulty indicates a delayed parafoveal-on-foveal effect because it suggests that processing the preview can still have an impact on eye-movement control although it is physically not available in the environment anymore. In contrast, an early preview benefit would emphasize a direct impact of target-word processing on pretarget viewing which is only modulated by previous preview. Which levels of processing may be involved and responsible for such finding is a related but additional issue.

Two supplementary analyses were to shed some light on the question whether we have evidence for independent sublexical or lexical effects. First, when we used initial bigram or trigram frequency instead of word frequency as a predictor for fixation durations on word *n*+1, the critical effect of the *n*+2 preview difficulty was not significant anymore (GD: both absolute t values < .61; FFD: both absolute t values < .44; SFD: both absolute t values < .46). This lends some credibility to the lexical nature of our difficulty categorization of *n*+2 words based on word frequency. However, second, when we tested the word frequency effect for *n*+2 preview and target for the residuals of the first analysis, the categorical preview-frequency effect was no longer significant either (GD: both absolute t values < 1.28; FFD: both absolute t values < 1.29; SFD: both absolute t values < 1.33). Taken together, there was little evidence for exclusively lexical preview effects in the data. Thus, the present experiment does not allow us to resolve the question of whether the obtained preview-difficulty effect is due to lexical or sublexical processes.

Discussion

The new variant of the *n*+2-boundary paradigm provides new evidence on issues of parafoveal preprocessing during reading. There were two significant parafoveal-on-foveal effects. First, low-frequency content words in position *n*+1 led to longer fixations on word *n* than high-frequency functions words. Second, a difficult preview word in position *n*+2 led to marginally longer GDs on word *n* than an easy preview.

Most importantly, the orthogonal manipulation of preview and target difficulty allowed simultaneous tests of delayed parafoveal-on-foveal and early preview-benefit explanations for fixation durations on word *n*+1. The effect of *n*+2 preview difficulty on word *n*+1 is compatible with a delayed parafoveal-on-foveal effect from previewing word *n*+2 during pre-boundary fixations, which is lagging behind into fixating the post-boundary word *n*+1. Although a large portion of fixations on word *n*+1 were likely to be unintended, there was no evidence for processing the target word *n*+2 in mislocated fixations on the pretarget word *n*+1. Neither the main effect of target difficulty, nor the interaction between preview and target difficulty postulated by the mislocated-fixation hypothesis were significant.

In general, however, the *n*+2 effects were small, even smaller than in previous experiments using the *n*+2-boundary paradigm (e.g., Kliegl et al., 2007; Risse & Kliegl, 2011). This could be due to the fact that also higher-level linguistic properties of word *n*+2 (i.e., lexical frequency) may have contributed to the different *n*+2 processing demands before and after crossing the boundary. In previous experiments, preview effects were mainly based on contrasts of random-letter strings and words. The test of delayed parafoveal-on-foveal effects and early preview benefit, however, does not depend on the assumption that word *n*+2 is processed in parafoveal vision up to its lexical level. Therefore, we replicated Experiment 1 using a low-level orthographic difficulty-manipulation to increase the size of the preview effects of word *n*+2.

EXPERIMENT 2

With Experiment 2 we asked the same theoretical questions as in Experiment 1, but we manipulated the preview and target difficulty of word *n*+2 by varying its visual familiarity rather than its lexical frequency. Specifically, word *n*+2 was previewed either in familiar lower-case notation (easy: e.g., "before") or in unfamiliar alternating-case letters (difficult: e.g., "bEfOrE"). Therefore, on a semantic level, preview of word *n*+2 was always identical irrespective of whether there was a change in the processing difficulty between preview and target word or not.

From prior research it is known that case alternation does not eliminate preview benefit, suggesting that abstract letter-code rather than visual letter-information is integrated across saccades (McConkie & Zola, 1979; Rayner & Pollatsek, 1983). However, this research also reported longer reading times for case alternation suggesting that reading a word in alternate case increases the difficulty of its processing. Therefore, the orthogonal manipulation of processing difficulty by means of case-alternation affords another test of delayed parafoveal-on-foveal and mislocated preview-benefit effects during reading.

Method

Subjects

Data were collected from 32 students of a Potsdam high-school (14 male, 18 female) who were on average 19 years old (*SD* = 2). They received 10 € for their one-hour attendance and had normal or corrected-to-normal vision. Ten participants noticed some display changes and were excluded from the analyses.

Sentence material

The same sentence material was used as in Kliegl et al. (2007; see also Risse & Kliegl, 2011). More importantly, the structure of sentences was similar to the material used in Experiment 1 with each sentence containing a three-word target region of word *n*, word *n*+1, and word *n*+2. The overlap of words with the material from Experiment 1 amounted to 87 % for word *n*, 98 % for word *n*+1. Given the previous manipulation of frequency of word *n*+2, the overlap for word n+2 in the present Experiment 2 was only 5 %. Length of word *n* ranged from 4 to 13 letters (*M* = 7, *SD* = 2) and averaged in word frequency to 295 per million (*SD* = 847). Word *n*+1 was either a three-letter function word (i.e., preposition or conjunction) with a mean frequency of 5,141 per million (*SD* = 5,966), or a three-letter content word (i.e., noun) with a much lower frequency of 32 per million (*SD* = 59). Length of the target word *n*+2 ranged from four to seven letters (*M* = 5, *SD* = 1). Target words were adverbs, adjectives, or verbs with an average frequency of 769 per million (*SD* = 1,370). Due to having only one target word instead of a target-word pair as in Experiment 1, there were no differences in the predictability of an easy or difficult word *n*+2, and no differences in their initial bigram and trigram frequencies. The first word *n* of the target-word triplet occurred on position three to nine in sentences containing 8 to 11 words ($M = 10$, $SD = 1$).

Apparatus and procedure

Technical equipment was identical to Experiment 1. The present experiment differed in that there was only one word *n*+2 for each sentence frame and the visual familiarity of the preview and target word *n*+2 was varied across conditions. Word *n*+2 was presented either in lower case (e.g., "before") or in alternating case (e.g., "bEfOrE") prior to and after crossing the boundary. In German, the case of a word's initial letter is an important marker for its word class. For example, upper-case word beginnings indicate a German noun. In the present experiment, the sequence of case alternations was chosen such that word *n*+2 always started with a lower-case letter. Thus, there were no differences in word-class information between preview and target word *n*+2 in the change conditions that could be derived from processing the initial letter.

Results

Blinks and measurement problems caused a loss of 6% of 3,520 possible sentences. An additional 4% of sentences were excluded because the display change was not completed prior to fixation onset after crossing the boundary. Individual fixations were removed if they were (a) shorter than 50 ms or longer than 750 ms, (b) if they were the first or last fixation within the sentence, or (c) when the eyes fixated different words. In total, about 9% of the recorded word-based fixations in the target region were excluded leaving 3,221 valid GD on word *n*, 1,470 on word *n*+1, and 2,796 on word *n*+2 for analysis. Analogous to Experiment 1, LMMs contained the experimental variables word preview and target difficulty of word *n*+2 as well as class of word *n*+1 as factors. Skipping of word *n*+1 was included as post-hoc factor for the analysis of fixation durations on word *n* and word *n*+1. For analyses of word *n* fixations, *n*+2 target difficulty was removed from the LMM (without significant loss in the goodness of fit of the statistical model). All LMMs were based on log-transformed fixation durations.

Results on the pre-boundary word n

The results of word *n* are summarized in Table 5. The *n*+2 preview-difficulty effect was not significant for fixation durations on the pre-boundary word *n* (GD: b = -.02, SE = .01, t = -1.67; FFD: b = -.01, SE = .01, t = -1.09; SFD: b = -.02, SE = .01, t = -1.58). The effect even went in the opposite direction as in Experiment 1 where it was marginally significant. The direction of the nonsignificant parafoveal-on-foveal effect of word *n*+2 in Experiment 2 was rather similar to a magnetic effect of attraction (e.g., Hyönä & Bertram, 2004).

- Table 5 about here -

There was again a substantial effect of the word class of the neighboring word *n*+1 (GD: b = .12, SE = .02, t = 5.30; FFD: b = .04, SE = .02, t = 2.48; SFD: b = .06, SE = .02, t = 3.10). GDs were 28 ms longer if the upcoming word *n*+1 was a content word rather than a function word (FFD: 10 ms; SFD: 13 ms). Thus, as in Experiment 1, there is strong support for a parafoveal-on-foveal effect from word *n*+1.

The effects relating to skipping of the upcoming word *n*+1 were similar to those in Experiment 1. FFD were significantly shorter prior to skipping than fixating word *n*+1 (b = -.03, SE = .01, t = -2.16) and nonsignificantly so for SFDs (b = -.02, SE = .01, t = -1.37). GDs, however, were longer prior to skipping word *n*+1 (b = .04, SE = .01, t = 2.72). None of the interactions were significant (all absolute t-values < 1.14).

Results on the post-boundary word n+1

Table 6 shows the summary statistics for fixations on word *n*+1. As in Experiment 1, fixation durations on word *n*+1 showed a significant effect of the *n*+2 preview difficulty (GD: b = .10, SE = .02, t = 5.52; FFD: b = .10, SE = .02, t = 5.32; SFD: b = .10, SE = .02, t =

5.37). GDs were 20 ms longer if word *n*+2 had been a difficult preview rather than an easy preview prior to the current fixation (21 ms both for FFD and SFD, respectively). Thus, we replicated the delayed parafoveal-on-foveal effect.

- Table 6 about here -

As in Experiment 1, there was no significant evidence for processing the neighboring target word *n*+2 during mislocated fixations on word *n*+1. Neither the main effect of target difficulty (GD: b = -.03, SE = .02, t = -1.83; FFD: b = -.03, SE = .02, t = -1.82; SFD: b = -.03, SE = .02, t = -1.80), nor the interaction between preview and target difficulty (all absolute t values < .50; three-factor interaction with *n*+1 word class: all absolute t values < .38) were significant. Different from Experiment 1, *n*+1 fixation durations revealed a tendency towards shorter *n*+1 fixations if the neighboring word was a difficult *n*+2 target; as reported for fixation durations on word *n* this resembles an attraction effect of parafoveal processing difficulties. This effect, however, was not what we had expected.

As in Experiment 1, the word class of the currently fixated word *n*+1 had no immediate effect on GDs (b = .02, SE = .03, t = .63), FFDs (b = .01, SE = .03, t = .46), or SFDs (b = .01, SE = .03, t = .50), presumably due to preprocessing during fixation on word *n.* Also this factor did not interact with preview or target difficulty (all absolute t-values < 0.38).

Results on the target word n+2

Summary statistics of the results on word *n*+2 are presented in Table 7. Fixation durations on word *n*+2 revealed the expected effect of the *n*+2 target difficulty: GDs on word *n*+2 were 40 ms longer if word *n*+2 was presented in alternate than in lower case (b = .17, SE = .02, t = 11.3; FFD: 24 ms, b = .10, SE = .01, t = 7.12; SFD: 29 ms, b = .12, SE = .02, t = 8.40). As in Experiment 1, neither the main effect of preview difficulty (all absolute t-values for GD, FFD, and SFD < 1.2) nor the interaction between preview and target difficulty was significant (GD: b = -.05, SE = .03, t = -1.79; absolute t-values for FFD and SFD < .95).

- Table 7 about here -

Considering skipping of word *n*+1 as a further factor modified these conclusions. First, fixation durations were longer after skipping word *n*+1 (GD: *b* = .23, *SE* = .02, *t* = 12.9; SFD: *b* = .08, *SE* = .02, *t* = 4.41; but, as in Experiment 1, not FFD: *b* = .02, *SE* = .02, *t* = 1.15) and skipping cost was larger for easy targets (interaction of *n*+2 target difficulty and *n*+1 skipping; SFD: *b* = -.07, *SE* = .03, *t* = -2.50; FFD: *b* = -.10, *SE* = .03 *t* = -3.45; but, different from Experiment 1, not for GD: *b* = -.02, *SE* = .03, *t* = -.64). This was mainly due to short viewing times on an easy word *n*+2 when word *n*+1 was previously fixated.

Second, different from Experiment 1, there was a significant preview benefit on word *n*+2 after skipping word *n*+1 (3-factor interaction in GD: *b* = -.15, *SE* = .06, *t* = -2.60). As depicted in the right panel of Figure 2, GDs revealed the critical interaction between the *n*+2 preview and target difficulty suggestive of an *n*+2 preview-benefit effect when word *n*+1 was skipped. There was a trend in the same direction for SFDs (*b* = -.11, *SE* = .06, *t* = -1.77), but not for FFDs (*b* = -.05, *SE* = .06, *t* = -.82). Thus, there is evidence for a preview benefit effect for word *n*+2.

- Figure 2 about here -

Third, also different from Experiment 1, there was an effect of the *n*+2 preview difficulty in target word FFDs after skipping word *n*+1. FFDs after skipping were 9 ms longer if word *n*+2 had been presented as a difficult preview rather than an easy preview (i.e., interaction of *n*+2 preview difficulty and *n*+1 skipping in FFD: *b* = .06, *SE* = .03, *t* = 2.24). The SFD pattern was numerically of a similar magnitude but not significant (*b* = .04, *SE* = .03, *t* = 1.45) and it was far from significance for GDs (*b* = .02, *SE* = .03, *t* = .78). This effect is testimony to the strength of the delayed parafoveal-on-foveal effect reported for fixations on word *n*+1. Obviously, in this experiment there was some evidence for this effect in all fixation durations after the boundary, irrespective of whether this fixation occurred on word *n*+1 or on word *n*+2.

Finally, as in Experiment 1, the difficulty of word *n*+1 spilled over into target-word fixation durations; there were longer fixation durations after content than function words (GD: $b = .06$, $SE = .03$, $t = 3.00$; FFD: $b = .04$, $SE = .02$, $t = 2.23$; SFD: $b = .04$, $SE = .02$, $t = 2.16$). Moreover, the *n*+1 spillover depended on the presence of a fixation on word *n*+1 (interaction of *n*+1 skipping and *n*+1 word class, GD: $b = -.11$, $SE = .03$, $t = -3.70$; FFD: $b = -.15$, $SE = .03$, $t = -5.50$; SFD: $b = -.14$, $SE = .03$, $t = -4.61$). No other effects were significant (all absolute t values < 1.67).

Discussion

Experiment 2 replicated the main findings of Experiment 1. There was a significant parafoveal-on-foveal effect of word *n*+1, but not of word *n*+2. Preview difficulty of word *n*+2 resulted in a delayed effect on word *n*+1, while the *n*+2 target difficulty showed an effect when word *n*+2 was fixated. Preview benefit from word *n*+2 was obtained only after word *n*+1 was skipped. First and foremost, the results of Experiment 2 further reinforce the notion that words are preprocessed even at the spatial limits of the perceptual span. Second, the results on word *n*+1 argue against the assumption that during mislocated fixations only the intended saccade target is attended and processed. We will detail the theoretical implications in the General Discussion.

Interestingly and in agreement with Experiment 1, there was again no effect of the immediate processing difficulty of word *n*+1 when it was fixated. This could be indicative for mislocated fixations while word *n*+1 was recognized already in parafoveal vision on the earlier fixation on word *n*. However, there was also a spillover effect of word *n*+1 in fixation durations on word *n*+2, which seems at odds if word *n*+1 was fully recognized prior to its fixation. As saccade targeting is prone to error, some fixations on word *n*+2 may also be mislocated and intended for word *n*+1. Presumably, these fixations represent cases in which word *n*+1 processing was not completed during pre-boundary fixations and has now to continue from an overshoot location on word *n*+2.

General Discussion

In the present study, we implemented a variant of the n+2-boundary paradigm to obtain a better understanding of how preview effects are distributed across fixations on successive words during reading. Preview and target difficulty of word *n*+2 was orthogonally manipulated before and after the eyes crossed an invisible boundary located after word *n*. Display change of word *n*+2 was triggered when the eyes moved from word *n* into the direction of word *n*+1 which was always a three-letter function or content word. The experimental design afforded tests of classical and new versions of parafoveal-on-foveal effects and preview benefit.

Parafoveal-on-foveal effects and mislocated fixations

The key result of the present study was that fixation durations on the short post-boundary word *n*+1 reflected the difficulty of the preview of word *n*+2 (i.e., the status of the sentence when the eyes were still on word *n*), not the difficulty of the target word *n*+2 (i.e., the status of the sentence during the current fixation when the eyes were on word *n*+1). This result was obtained in two experiments with different manipulations of *n*+2 preview/target difficulty (i.e., frequency of word *n*+2 in Exp. 1; visual familiarity of word *n*+2 in Exp. 2). In Experiment 1, the size of the effect was very small and less than 5 ms. The difficulty manipulation in Experiment 2 showed substantial *n*+2 effects up to 20 ms and thus replicated the results from the first experiment.

A straight-forward interpretation of the *n*+2 preview-difficulty effect on word *n*+1 is that the processing difficulty of word *n*+2 during fixations on the previous word *n* appeared with some delay on word *n*+1. As the preview difficulty can only be obtained on fixations prior to crossing the boundary, this result strongly suggests a parafoveal-on-foveal effect which was delayed or spilled over into the post-boundary fixation. The same interpretation holds for an additional effect of preview difficulty in FFDs on word *n*+2 in Experiment 2. This effect was observed only when word *n*+1 was skipped, that is when the fixation on word *n*+2 immediately followed the pre-boundary fixation on word *n*. We refer to these effects as *delayed parafoveal-on-foveal effects*.

Delayed parafoveal-on-foveal effects replicate earlier findings in a very similar *n*+2-boundary paradigm contrasting random-letter and identical-preview conditions (see Kliegl et al., 2007; Risse & Kliegl, 2011). Specifically, we observed an *n*+2 preview effect on the short post-boundary word *n*+1. However, in those studies we were not able to say whether this effect was due to delayed parafoveal-on-foveal effects or due to a preview benefit of word *n*+2 measured in mislocated fixations on word *n*+1. As described in the Introduction, the orthogonal manipulation of preview and target difficulty in the present experiments afforded separate tests of these two explanations. As short words tend to be skipped very frequently, a large proportion of fixations observed on word *n*+1 might represent failed skipping of this word and are thus mislocated fixations. In addition, saccades to word *n*+1 triggered the display change of word *n*+2 and target-word processing had to restart in 50 % of the cases. Given that a high proportion of *n*+1 fixations are mislocated but directly associated with processing the intended saccade target, the current *n*+2 processing demand after crossing the boundary should reflect in such fixations on the unintended word *n*+1. However, neither the effect of *n*+2 target difficulty nor the interaction between preview and target difficulty were significant, with the latter reflecting the preview benefit of word *n*+2 in the two identical-preview conditions in which target-word processing did not have to restart. It has to be noted that probably not all fixations on word *n*+1 were mislocated and that *n*+1 fixations may rather be a mixture of intended and mislocated ones. As we do not know the actual portion of failed skipping, the null effect of target-word processing must not be interpreted as evidence *against* an early preview benefit. Yet, the significant evidence for a delayed parafoveal-on-foveal effect argues against attention and processing being focused only on the intended saccade-target during mislocated fixations.

There were also examples of immediate parafoveal-on-foveal effects. In both experiments the difficulty of the closer word *n*+1 (i.e., function/high-frequency vs. content/low-frequency word) was measured directly in fixation durations on word *n.* Such parafoveal-on-foveal effects have been attributed to oculomotor error resulting in unintended refixations on word *n* while attention and processing had already moved ahead to the neighboring word *n*+1 (Drieghe et al., 2008; Rayner et al., 2004). The processing situation, however, should not differ significantly from the above logic of mislocated fixations on word *n*+1: In both cases, attention should be on the intended saccade target while the pretarget word is fixated. The present study calls the mislocated-fixation interpretation into question.

As German nouns are always capitalized, it could be argued that the nature of this parafoveal-on-foveal effect is orthographic and that recent serial models considering parallel processing of early visual information prior to lexical processing (e.g., Pollatsek et al., 2006a) may account for such findings. While this remains speculative and needs to be addressed empirically and with simulations, the present results suggest that mislocated fixations do not play a significant role in explaining parafoveal-on-foveal effects in serial models.

If the parafoveal-on-foveal effect of word *n*+1 indicates parallel processing, one might wonder why there was no reliable evidence for parafoveal-on-foveal effects of word *n*+2. We obtained a marginal effect of the *n*+2 preview difficulty in GDs on word *n* for Experiment 1 but nothing alike for Experiment 2, although manipulating a very distinct aspect of the preview’s orthography. A parsimonious explanation is that processing word *n*+2 in parafoveal vision is delayed relative to processing word *n*+1. Temporal delays in processing information at the spatial limits of the perceptual span agree with findings from Lee, Legge, and Ortiz (2003) who showed that word-frequency effects occurred later in time with increasing eccentricity of a target word from the current fixation position (see also Schiepers, 1980). Delayed parafoveal-on-foveal effects are also in agreement with evidence of decreasing visual acuity in parafoveal vision reducing the processing efficiency of parafoveal relative to foveal words (Bouma, 1973; O'Regan, 1990; Rayner & Morrison, 1981). Given a reduction in processing efficiency at increased parafoveal eccentricities, word *n*+2 processing difficulties should need more time to accumulate than those of the closer word *n*+1 and, therefore, have a later impact on eye-movement control. Thus, it seems plausible that parafoveal-on-foveal effects from word *n*+2 do not always occur directly in pre-boundary fixations. The additional finding of an *n*+2 preview effect in FFDs on the target word *n*+2 if word *n*+1 was skipped supports this interpretation. If parafoveal-on-foveal influences are simply delayed, they should be observed on the first fixation after crossing the boundary, which can be either on the post-boundary word *n*+1 or on word *n*+2 if word *n*+1 was skipped.

However, some of the results are also difficult to reconcile with a strict eccentricity-delay assumption. If delay in parafoveal-on-foveal effects was associated only with the parafoveal word's distance, then effects of close words should be even stronger. Fixating word *n*, we found strong evidence for a parafoveal-on-foveal effect of the neighboring word *n*+1. Fixating word *n*+1, however, the target word *n*+2 becomes a direct fixation neighbor and one would expect an additional parafoveal-on-foveal effect of the adjacent word *n*+2. In the present paradigm, this translates into a main effect of the *n*+2 target difficulty—an effect for which we obtained no strong evidence. There was a marginal effect in Experiment 2 with a tendency towards shorter fixation durations on word *n*+1 with difficult *n*+2 targets. In this case, the near parafoveal processing difficulty even seemed to have attracted an earlier saccade off word *n*+1 (Hyönä & Bertram, 2004) instead of a prolongation of the fixation on word *n*+1 as it was observed, for example, in the parafoveal-on-foveal effect on word *n*. Although both results reflect an influence of parafoveal word properties on foveal viewing times, it is unclear why the effect of parafoveal difficulties should reduce and reverse when moving from word *n* to word *n*+1.

Parafoveal-on-foveal effects from word *n*+1 are reliably observed in corpus analyses showing that variables such as the frequency of an upcoming word affected current fixations

(Kliegl et al., 2006; Pynte & Kennedy, 2006, 2007; Schad et al., 2010). The novel finding of temporal delays of parafoveal-on-foveal effects may further explain some of the inconsistencies in findings from gaze-contingent boundary experiments relative to corpus analyses. If parafoveal-on-foveal effects are sometimes delayed into fixations on the neighboring word(s), chances of detecting them immediately on the word where preview was acquired decreases with decreasing number of trials, and this is more likely in boundary experiments than in corpus analyses. In fact, a corpus analysis even documented significant influences of the frequency of a short word *n*+2 in single fixation durations on a currently fixated word *n* (see Risse, Engbert, & Kliegl, 2008). Although more research is necessary to support this hypothesis, the present results may allay some of the scepticism against corpus analyses.

Previewing word n+2 in the boundary paradigm

Parafoveal preview-benefit in the classical *n*+1-boundary paradigm belongs to the most robust effects associated with processing of not-yet-fixated words in the perceptual span. They have only rarely been reported for the boundary paradigm investigating preview of word *n*+2 (Kliegl et al., 2007; Radach, Glover, Vorstius, & Inhoff, in press; Risse & Kliegl, 2011). In the present study, we introduced a novel manipulation in which preview benefit translates into an interaction between the preview and target-word difficulty. Given that preview and target word were identical, previewing word *n*+2 should facilitate processing when it is eventually fixated and the mean of the two different-preview conditions (i.e., different target replaces preview) should be larger than the mean of the two identical-preview conditions. The present manipulation thus retains the main idea of the boundary paradigm in that identical preview of word *n*+2 should result in processing benefit when the word is later fixated.

In line with this prediction, we obtained preview benefit on word *n*+2: In Experiment 1 when the previous word *n*+1 was a more difficult content word and in Experiment 2 when word *n*+1 had been skipped, that is when the fixation on word *n*+2 followed immediately after the pre-boundary fixation on word *n*. These results represent a further challenge for studies reporting null effects of previewing word *n*+2 (e.g., Angele et al., 2008; Angele & Rayner, 2011; Rayner et al., 2007). There are several differences between these studies. For example, Angele and Rayner masked not only word *n*+2, but also word *n*+1. There may also be language differences between German and English reading studies (e.g., the capitalization of German nouns). The evidence for effects of previewing word *n*+2 in the present two experiments allows us to maintain the notion of parallel word-processing in the perceptual span as a viable alternative.

Indeed, evidence is accumulating that parafoveal processing inside the perceptual span is distributed beyond single target words. For example, Wang, Inhoff, and Radach (2009) tested whether cost due to parafoveal masking must be resolved locally as predicted from models postulating serial attention-shifts. Consistent with the present results, they obtained non-local effects that suggested distributed attention across a broader region than the single word unit. Although Wang et al. did not investigate preview effects of word *n*+2 and, therefore, used a paradigm that differed substantially from the experiments reported here their results also suggest a complex pattern of preview effects from the word's first encounter in parafoveal vision until it is finally fixated.

The present results also rule out an alternative explanation for effects in the *n*+2-boundary paradigm that would make the assumption of preprocessing word *n*+2 in parafoveal vision unnecessary. It has been argued that preview-benefit effects may be simply due to perceptual disruption when the preview is changed after crossing the boundary (for a discussion see Inhoff, Starr, Liu, & Wang, 1998; O'Regan, 1990), and such disruption should be more severe if the time of display change is delayed into the fixation onset on a post-boundary word (Slattery, Angele, & Rayner, 2011). For technical reasons, display changes can be occasionally delayed relative to their trigger, but cases in which they occurred within a post-boundary fixation were carefully excluded from all analyses (see the present sections describing data selection). Moreover, post-hoc comparisons showed a significant difference in fixation durations between the two conditions in which the display of word *n*+2 was changed, a difference that cannot be attributed to the display change itself (see Figure 3).

- Figure 3 about here -

Implications for the debate on serial and parallel word-processing during reading

The goal of this research was not to determine the issue of lexical word-processing during reading, but the question remains how our results relate to assumptions of serial and parallel processing and, moreover, to the implementation of such notions in computational models of eye-movement control. Indeed, the development of the *n*+2-boundary paradigm was initially motivated as a test of parallel processing and null results were interpreted as evidence against it (e.g., Angele & Rayner, 2011; Rayner et al., 2007). Finding preview effects relating to word *n*+2 is, however, not necessarily evidence against serial processing. For example, in a serial model such as E-Z Reader in which completion of lexical processing initiates a covert attention-shift towards the next word in sequence (Reichle, Pollatsek, Fisher, & Rayner, 1998; for the latest version see Reichle, Warren, & McConnell, 2009), a short and easy word *n*+1 may allow attention to shift rapidly even to word *n*+2 and generate a preview benefit when it is later fixated (Pollatsek, Reichle, & Rayner, 2006b). A two-word attention-shift implies an update of the next saccade target in that saccades to word *n*+1 will often be cancelled causing increased fixation durations on the pre-boundary word *n* (skipping cost). In Experiment 2, a significant preview benefit was obtained for GDs after skipping word *n*+1, and GDs were significantly longer on word *n* when word *n*+1 was skipped. However, it remains to be seen whether the significantly shorter FFDs before a skipped word *n*+1 can be reconciled with the model as well (see Kliegl & Engbert, 2005, for a discussion of this issue).

In Experiment 1, the *n*+2 preview benefit was larger after more difficult content words *n*+1. In other words, more difficult content words in close parafoveal vision seemed to have facilitated preview of the adjacent word *n*+2, contrary to the parafoveal-load hypothesis, as for example reported for Chinese (Yan, Kliegl, Shu, Pan, & Zhou, 2010), and the idea of rapid serial attention-shifts up to word *n*+2 (Pollatsek et al., 2006b). This counterintuitive finding could indicate the following: As the word class of word *n*+1 elicits a parafoveal-on-foveal effect, participants spend considerably more time on the pre-boundary word *n* prior to content words. If attention is distributed in parallel, additional processing time on word *n* leads also to additional processing time of word *n*+2 in parafoveal vision, which may compensate for potential disadvantages imposed by the higher parafoveal load and may even reverse it into larger preview benefit.

Parafoveal-on-foveal effects are an even bigger problem for serial models, because (lexical) difficulties of the upcoming word must not modulate the processing time of the currently fixated word or spill over into the next fixation. Proponents of serial models emphasized that these effects (if they are observed at all) tend to be weak. Moreover, even if these weak effects were statistically reliable, they may result from mislocated fixations. Our results present a serious challenge for this position. Mislocated fixations do not seem to play the expected role in parafoveal-on-foveal effects. Therefore, the present results have implications for computational models implementing sequential attention-shifts and serial word-processing such as the E-Z Reader model. If mislocated fixations cannot account for the delayed parafoveal-on-foveal effect on the post-boundary word *n*+1 (and most likely also not for immediate parafoveal-on-foveal effects), additional mechanisms have to be explored within such models to evaluate whether they may generate such complex and non-locally distributed preview effects as observed in the present study.

One such option in E-Z Reader may be its pre-attentive visual stage (Reichle, Rayner, & Pollatsek, 2003) during which visual word features inside the perceptual span are scanned in parallel. Such parallel scanning is claimed to account for orthographic parafoveal-on-foveal effects, and may even include effects from word *n*+2. However, we did not obtain convincing evidence for parafoveal-on-foveal effects of word *n*+2 in fixations on word *n*. Whether a first parallel stage in an else strictly serial processing model can explain the delay in the parafoveal-on-foveal effect into fixations on word *n*+1 remains an open question and may be an interesting target for future simulations with the E-Z Reader model.

Finding distributed effects is strongly associated with the idea of parallel distributed processing within the perceptual span (e.g., Kliegl et al., 2006). In fact, delayed parafoveal-on-foveal effects are compatible with parallel processing and the notion of crosstalk that lags behind and/or spills over into post-boundary fixations. However, the present results do not allow us to conclude that direct interference had taken place between processing the parafoveal word *n*+2 and the foveal word *n*. In fact, it is equally plausible that parallel processing occurred without crosstalk, but was feeding into a common process-monitoring system, which then indirectly modulated oculomotor control and fixation durations (Kennedy, 1998; Kennedy et al., 2002). How computational models implementing a distributed-processing assumption with some sort of process-monitoring such as SWIFT (Engbert et al., 2005; Richter, Engbert, & Kliegl, 2006) or Glenmore (Reilly & Radach, 2006) accommodate to the temporal and spatial extent of *n*+1 and *n*+2 preview effects in the boundary paradigm is an interesting question for future research and can only be answered with extensive computer simulations.

In summary, the present experiments support the notion that processing in the perceptual span is highly non-local and broadly distributed across subsequent fixations. Our results suggest that previewing word *n*+2 can result in delayed parafoveal-on-foveal effects, which are lagging behind or spilling over into post-boundary fixations on word *n*+1. The present findings do not disconfirm the general hypothesis of serial word-processing during reading but they strongly suggest that mislocated fixations are not sufficient to account for the complex dynamics of processing in the perceptual span during reading.

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Acknowledgments

This research was supported by Grants KL 955/6-1 from the Deutsche Forschungsgemeinschaft as part of the Research Group 868 “Computational Modeling of Behavioral, Cognitive, and Neural Dynamics” and is part of the first author’s dissertation. We thank Albrecht Inhoff, Barabara Juhasz, and Simon Liversedge for helpful comments and constructive critique. Data and R scripts are available at the Potsdam Mind Research Repository (http://read.psych.uni-potsdam.de/pmr2/). Correspondence should be addressed to Sarah Risse, sarah.risse@uni-potsdam.de.

Footnote

1. Moreover, mislocated fixations are also occurring under the assumption of distributed processing. However, if they are not immediately corrected processing proceeds quite unaffected, although from a not intended viewing location.

Table 1.

N+2 difficulty characteristics in Experiment 1. Summarized are four different measures of processing difficulty of target words *n*+2 for comparison with mean (*M*), standard deviation (*SD*), minimum (min.) and maximum (max.) value for easy and difficult words *n*+2.

	Word frequency		**Initial bigram frequency**		**Initial trigram frequency**		**Word trigram predictability**	
Word *n*+2	easy	difficult	easy	difficult	easy	difficult	easy	difficult
M	312	3	7,351	2,954	3,142	422	0.0008	0.0004
SD	643	6	7,803	5,668	5,371	2,236	0.004	0.005
min.	3	< 1	304	6	40	< 1	0	0
max.	6,718	68	53,801	53,801	27,238	27,238	0.03	0.06

Note. Frequency measures are normalized per million. Word trigram predictability is given as the conditional probability of each word trigram given the occurrence of its first two components.

Table 2

<u>Experiment 1: Results on word *n*.</u> Summarized are the means (*M*) and standard deviations (*SD*). For fixation durations, the random-effect variance is removed.

Measures	Preview difficulty of word *n*+2	Fixating word *n*+1		Skipping word *n*+1	
		Word class of word *n*+1		Word class of word *n*+1	
		FW	CW	FW	CW
		M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
GD	easy (HF)	222 (65)	251 (83)	218 (61)	260 (91)
	diff. (LF)	221 (64)	253 (88)	223 (61)	267 (87)
FFD	easy (HF)	208 (53)	216 (62)	195 (51)	207 (66)
	diff. (LF)	208 (55)	214 (61)	200 (52)	208 (60)
SFD	easy (HF)	210 (50)	222 (59)	200 (48)	216 (65)
	diff. (LF)	212 (53)	220 (58)	204 (49)	218 (60)
SP	easy (HF)	.06 (.24)	.05 (.21)	.02 (.14)	.01 (.08)
	diff. (LF)	.06 (.24)	.04 (.19)	.03 (.16)	.02 (.14)

Note. GD: gaze duration; FFD: first fixation duration; SFD: single fixation duration; SP: skipping probability; HF: high frequency; LF: low frequency; FW: function word; CW: content word.

Table 3

Experiment 1: Results on word *n*+1. Summarized are the means (*M*) and standard deviations (*SD*). For fixation durations, the random-effect variance is removed.

Measures	Preview difficulty of word *n*+2	Target difficulty of word *n*+2	Word class of word *n*+1	
			FW	CW
			M (SD)	*M (SD)*
GD	easy (HF)	easy (HF)	208 (60)	200 (61)
	easy (HF)	diff. (LF)	203 (59)	206 (65)
	diff. (LF)	easy (HF)	208 (56)	210 (58)
	diff. (LF)	diff. (LF)	207 (60)	205 (56)
FFD	easy (HF)	easy (HF)	206 (58)	200 (61)
	easy (HF)	diff. (LF)	203 (60)	204 (62)
	diff. (LF)	easy (HF)	208 (56)	208 (57)
	diff. (LF)	diff. (LF)	206 (58)	204 (55)
SFD	easy (HF)	easy (HF)	206 (57)	200 (61)
	easy (HF)	diff. (LF)	203 (59)	204 (62)
	diff. (LF)	easy (HF)	208 (56)	209 (57)
	diff. (LF)	diff. (LF)	206 (58)	204 (55)
SP	easy (HF)	easy (HF)	.50 (.50)	.44 (.50)
	easy (HF)	diff. (LF)	.50 (.50)	.38 (.49)
	diff. (LF)	easy (HF)	.51 (.50)	.40 (.49)
	diff. (LF)	diff. (LF)	.49 (.50)	.43 (.50)

Note. GD: gaze duration; FFD: first fixation duration; SFD: single fixation duration; SP: skipping probability; HF: high frequency; LF: low frequency; FW: function word; CW: content word.

Table 4

Experiment 1: Results on word *n*+2. Summarized are the means (*M*) and standard deviations (*SD*). For fixation durations, the random-effect variance is removed.

Measures	Preview difficulty of word *n*+2	Target difficulty of word *n*+2	Fixating word *n*+1		Skipping word *n*+1	
			Word class of word *n*+1		Word class of word *n*+1	
			FW	CW	FW	CW
			M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
GD	easy (HF)	easy (HF)	201 (70)	241 (85)	276 (74)	310 (109)
	easy (HF)	diff. (LF)	220 (70)	270 (88)	294 (84)	318 (118)
	diff. (LF)	easy (HF)	197 (62)	241 (78)	276 (68)	312 (102)
	diff. (LF)	diff. (LF)	220 (76)	264 (87)	300 (82)	326 (117)
FFD	easy (HF)	easy (HF)	198 (60)	241 (94)	226 (55)	222 (69)
	easy (HF)	diff. (LF)	212 (65)	267 (93)	225 (63)	229 (71)
	diff. (LF)	easy (HF)	195 (59)	240 (78)	225 (52)	227 (65)
	diff. (LF)	diff. (LF)	215 (73)	257 (85)	229 (59)	228 (68)
SFD	easy (HF)	easy (HF)	195 (58)	242 (88)	241 (52)	241 (69)
	easy (HF)	diff. (LF)	212 (62)	267 (86)	249 (66)	249 (75)
	diff. (LF)	easy (HF)	194 (57)	238 (73)	243 (51)	248 (69)
	diff. (LF)	diff. (LF)	215 (70)	258 (79)	251 (58)	250 (72)
SP	easy (HF)	easy (HF)	.14 (.35)	.12 (.32)	.01 (.11)	.02 (.15)
	easy (HF)	diff. (LF)	.11 (.31)	.07 (.25)	.02 (.13)	.03 (.17)
	diff. (LF)	easy (HF)	.12 (.33)	.09 (.28)	.01 (.09)	.02 (.14)
	diff. (LF)	diff. (LF)	.09 (.29)	.05 (.22)	.03 (.17)	.02 (.15)

Note. GD: gaze duration; FFD: first fixation duration; SFD: single fixation duration; SP: skipping probability; HF: high frequency; LF: low frequency; FW: function word; CW: content word.

Table 5

Experiment 2: Results on word *n*. Summarized are the means (*M*) and standard deviations (*SD*). For fixation durations, the random-effect variance is removed.

Measures	Preview difficulty of word *n*+2	Fixating word *n*+1		Skipping word *n*+1	
		Word class of word *n*+1		Word class of word *n*+1	
		FW	CW	FW	CW
		M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
GD	easy (LC)	216 (66)	248 (80)	223 (64)	252 (78)
	diff. (AC)	210 (60)	238 (71)	220 (67)	248 (65)
FFD	easy (LC)	207 (60)	215 (66)	198 (60)	208 (61)
	diff. (AC)	200 (52)	212 (55)	197 (48)	202 (44)
SFD	easy (LC)	209 (57)	222 (64)	205 (57)	214 (49)
	diff. (AC)	203 (51)	218 (53)	201 (47)	209 (42)
SP	easy (LC)	.11 (.31)	.10 (.30)	.08 (.28)	.06 (.23)
	diff. (AC)	.12 (.33)	.08 (.27)	.07 (.25)	.05 (.21)

Note. GD: gaze duration; FFD: first fixation duration; SFD: single fixation duration; SP: skipping probability; LC: lower case; AC: alternating case; FW: function word; CW: content word.

Table 6

<u>Experiment 2: Results on word *n*+1.</u> Summarized are the means (*M*) and standard deviations (*SD*). For fixation durations, the random-effect variance is removed.

Measures	Preview difficulty of word *n*+2	Target difficulty of word *n*+2	Word class of word *n*+1	
			FW	CW
			M (SD)	*M (SD)*
GD	easy (LC)	easy (LC)	201 (66)	194 (52)
	easy (LC)	diff. (AC)	188 (45)	197 (58)
	diff. (AC)	easy (LC)	215 (48)	222 (63)
	diff. (AC)	diff. (AC)	205 (59)	216 (60)
FFD	easy (LC)	easy (LC)	201 (66)	194 (52)
	easy (LC)	diff. (AC)	188 (45)	197 (58)
	diff. (AC)	easy (LC)	215 (48)	219 (60)
	diff. (AC)	diff. (AC)	205 (59)	215 (60)
SFD	easy (LC)	easy (LC)	201 (66)	194 (52)
	easy (LC)	diff. (AC)	188 (45)	197 (58)
	diff. (AC)	easy (LC)	215 (48)	220 (60)
	diff. (AC)	diff. (AC)	205 (59)	216 (60)
SP	easy (LC)	easy (LC)	.59 (.49)	.50 (.50)
	easy (LC)	diff. (AC)	.63 (.48)	.51 (.50)
	diff. (AC)	easy (LC)	.64 (.48)	.48 (.50)
	diff. (AC)	diff. (AC)	.63 (.48)	.47 (.50)

Note. GD: gaze duration; FFD: first fixation duration; SFD: single fixation duration; SP: skipping probability; LC: lower case; AC: alternating case; FW: function word; CW: content word.

Table 7

<u>Experiment 2: Results on word *n*+2.</u> Summarized are the means (*M*) and standard deviations (*SD*). For fixation durations, the random-effect variance is removed.

Measures	Preview difficulty of word *n*+2	Target difficulty of word *n*+2	Fixating word *n*+1		Skipping word *n*+1	
			Word class of word *n*+1		Word class of word *n*+1	
			FW	CW	FW	CW
			M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
GD	easy (LC)	easy (LC)	187 (64)	216 (84)	232 (59)	244 (73)
	easy (LC)	diff. (AC)	217 (69)	254 (94)	298 (86)	300 (95)
	diff. (AC)	easy (LC)	182 (64)	203 (76)	245 (70)	264 (84)
	diff. (AC)	diff. (AC)	221 (74)	247 (99)	288 (84)	276 (102)
FFD	easy (LC)	easy (LC)	190 (62)	218 (83)	206 (50)	203 (51)
	easy (LC)	diff. (AC)	218 (73)	247 (92)	223 (68)	215 (77)
	diff. (AC)	easy (LC)	182 (44)	210 (82)	214 (51)	218 (70)
	diff. (AC)	diff. (AC)	221 (78)	248 (97)	237 (67)	218 (71)
SFD	easy (LC)	easy (LC)	189 (61)	214 (79)	210 (39)	210 (50)
	easy (LC)	diff. (AC)	217 (67)	248 (87)	244 (65)	240 (78)
	diff. (AC)	easy (LC)	177 (43)	207 (77)	219 (43)	228 (68)
	diff. (AC)	diff. (AC)	220 (73)	240 (87)	248 (67)	226 (72)
SP	easy (LC)	easy (LC)	.23 (.42)	.24 (.43)	.14 (.35)	.13 (.34)
	easy (LC)	diff. (AC)	.16 (.37)	.12 (.32)	.10 (.30)	.18 (.39)
	diff. (AC)	easy (LC)	.23 (.42)	.16 (.37)	.06 (.24)	.05 (.23)
	diff. (AC)	diff. (AC)	.12 (.33)	.05 (.22)	.05 (.22)	.08 (.27)

Note. GD: gaze duration; FFD: first fixation duration; SFD: single fixation duration; SP: skipping probability; LC: lower case; AC: alternating case; FW: function word; CW: content word.

Figure 1

<u>Experimental conditions of Experiment 1 and 2</u>. Subjects read 160 German test sentences similar to the English example sentences. Orthogonally manipulating the *n*+2 preview and target difficulty, the four preview conditions are depicted containing a function word or a content word *n*+1. High-frequency (easy) and low-frequency (difficult) words *n*+2 (Experiment 1) are underlined; in brackets is an example for visual familiarity (Experiment 2). The invisible boundary is represented as a dotted line; the asterisks illustrate the gaze position. Further details are provided in the text.

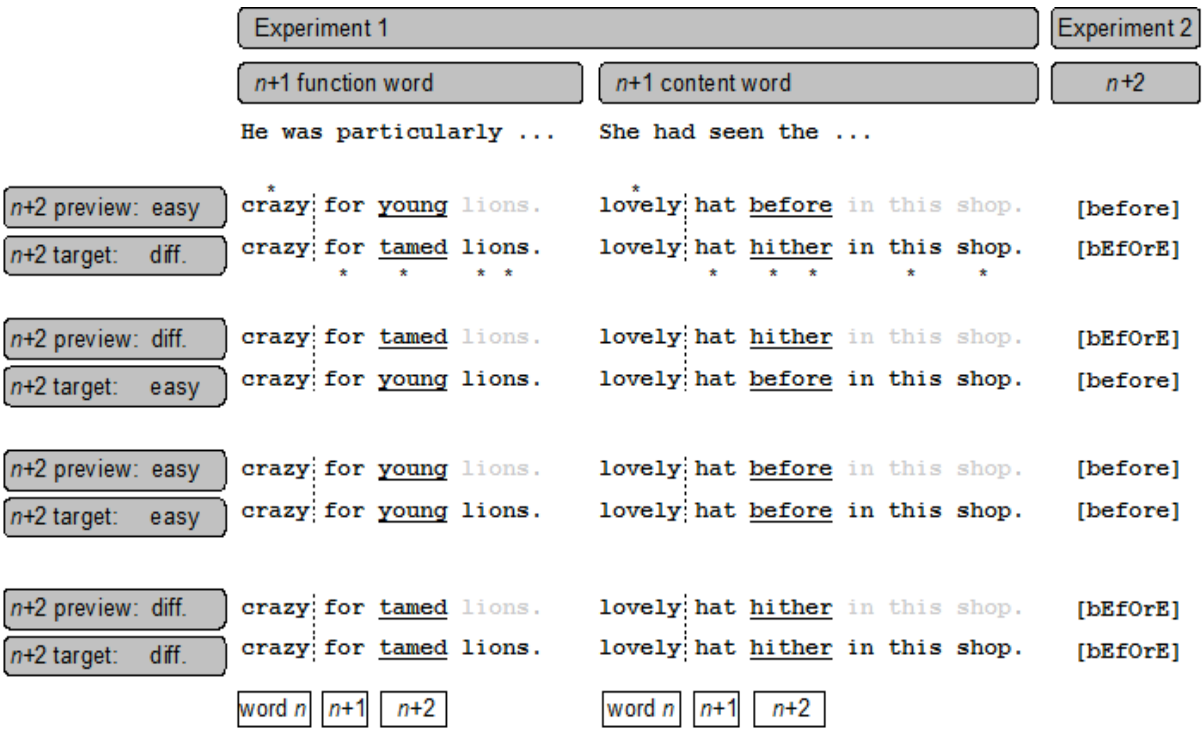

Figure 2

Preview benefit effect on word *n*+2 in Experiment 2. Plotted are the residualized mean gaze-durations after skipping word *n*+1 conditional on the preview and target difficulty of word *n*+2. Random-effect variance is removed; error bars reflect the 95 % confidence interval.

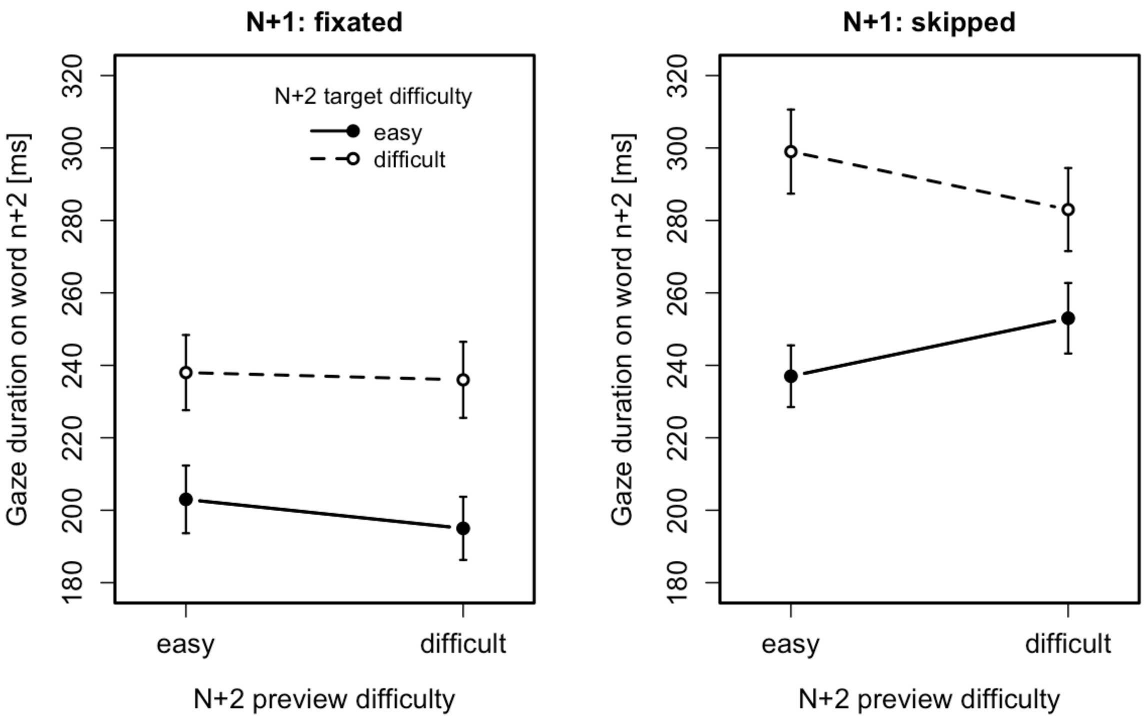

Figure 3

Comparison of change and no-change conditions. Plotted are the residualized means for gaze durations on word *n*+1 for the four possible combinations of *n*+2 preview and target difficulty, two conditions with visual change of the *n*+2 display (grey bars) and two without change (white bars), in Experiment 1 (left panel) and Experiment 2 (right panel). HF: high frequency/easy; LF: low frequency/difficult; LC: lower case/easy; AC: alternating case/difficult.