*Visual Cognition,* 2014
http://dx.doi.org/10.1080/13506285.2013.879630

Routledge
Taylor & Francis Group

# Parafoveal preview benefits during silent and oral reading: Testing the parafoveal information extraction hypothesis

**Albrecht W. Inhoff[1] and Ralph Radach[2]**

[1]Department of Psychology, Binghamton University, Binghamton, NY, USA
[2]Department of General and Biological Psychology, University of Wuppertal, Wuppertal, Germany



The preview of a parafoveally visible word conveys benefits when it is subsequently fixated. The current study examined whether these benefits are determined by the effectiveness of parafoveal information extraction, as implied by current models of eye movement control during reading, or by the effectiveness with which extracted information is integrated when a previewed word is fixated. For this, the boundary technique was used to manipulate the extent to which parafoveal information could be extracted, and text was read silently or orally. Consistent with prior work, a parafoveal target word preview conveyed fewer benefits when less parafoveal information could be extracted, target viewing durations were longer during oral than during silent reading, and the two factors interacted in the target fixation data, with smaller preview benefits during oral than during silent reading. Survival analyses indicated that this occurred because parafoveal information use occurred at later point in time during oral reading. Diminished opportunity for parafoveal information extraction also diminished target skipping rate, and it resulted in smaller saccades to target words, but these effects were not influenced by reading mode. Parafoveally extracted information was thus used less effectively during oral reading only when it involved the integration of parafoveally extracted information during subsequent target viewing. The dissociation of extraction from integration challenges current models of eye movement control.

***Keywords:*** Oral reading; Silent reading; Parafoveal preview benefit; Visual attention.

Please address all correspondence to Albrecht Inhoff, Department of Psychology, Binghamton University, Binghamton, NY 13760, USA. E-mail: inhoff@binghamton.edu

We would like to thank Matthew Solomon for his help with the programming of the experiment, Julie Gregg and Christian Vorstius for their help with the manuscript, and Sarah Risse, Jane Ashby, and Heather Sheridan, for helpful comments on an earlier version of the manuscript.

Written and spoken language signals differ fundamentally. Spoken language is perceived sequentially over time, whereas visual symbols are visible in parallel at different spatial locations. Readers generally discern the identity and order of visual symbols through spatially selective allocation of attention and corresponding eye movements (saccades). Saccades are followed by short viewing pauses (fixations), and McConkie and Rayner (1975) and Rayner (1975) were the first to show conclusively that the recognition of individual words during fluent reading typically involves more than one fixation. Readers obtain linguistic information from the directly fixated (foveally visible) word and also from spatially adjacent (parafoveally visible) words. Information extracted from the parafoveally visible word preview is used when the word is subsequently fixated thereby facilitating its recognition. Effective use of parafoveally obtained information when a previewed word is subsequently fixated is generally referred to as parafoveal preview benefit.

A substantial body of research has examined parafoveal preview benefits as a function of a large number of task-related factors, including reading skill and task difficulty, and also of visuospatial and linguistic word properties. The results showed that parafoveal preview benefits increase with reading development, with reading skill, with the ease of visual word identification, and that parafoveal preview benefits can be derived from available visual, spatial, orthographic, phonological, and perhaps even semantic information (see Radach & Kennedy, 2013; Rayner, 1998, 2009; Schotter, Angele & Rayner, 2012, for reviews). The "sequential" processing of attended words during reading, in so far as recognition of a word typically involves extraction and integration of information during successive fixations, is well established in good readers; it occurs not only during silent reading but also during oral reading (Ashby, Yang, Evans, & Rayner, 2012) and even when visual text is typed (Inhoff & Wang, 1992).

Changes in the magnitude of parafoveal preview benefits are generally attributed to changes in the effectiveness of parafoveal information extraction. In their influential study, Henderson and Ferreira (1990) obtained smaller preview benefits when fixated words were difficult to parse or difficult to recognize than when their processing was relatively easy. They suggested that readers responded to a word's increased processing difficulty with a longer focusing of visual attention and that this delayed the shifting of attention from the attended (fixated) word to the next word in the text. Because the saccade from the fixated word to the next word in the text was already programmed,[1] the delay in the shifting of attention diminished the temporal window during which useful parafoveal information could be extracted from the parafoveal preview, and this diminished its benefit. A conceptually similar account was implemented in recent

[1] According to Henderson and Ferreira (1990), this occurs because readers establish saccade programming deadline.

computational simulations of reading (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2006) that successfully modelled parafoveal preview benefits during reading. Other computational accounts of parafoveal preview benefits (Engbert, Nuthman, Richter, & Kliegl, 2005; Reilly & Radach, 2006) assume that increases in the allocation of attention to words that are difficult to recognize result in a diminished uptake rather than a delay in parafoveal information extraction. Both theoretical accounts converge, however, in that they assume that the size of parafoveal preview benefits is determined by the effectiveness with which parafoveal information can be extracted. This view will be referred to as the *parafoveal information extraction hypothesis*.

Smaller preview benefits during oral than during silent reading (Ashby et al., 2012) are consistent with the information extraction hypothesis, as the overt articulation of identified words may increase task difficulty. This could delay the extraction of linguistic information from a parafoveal word preview or diminish the rate of parafoveal information extraction. Ashby et al. (2012) also outlined an intriguing alternative account, according to which smaller preview benefits during oral reading are not due to differences in the extraction of linguistic information from parafoveally visible words during oral and silent reading, but to differences in the use of parafoveally extracted information when a previewed word is subsequently fixated. According to Ashby et al., *use* of parafoveally extracted information could be “mitigated downstream”, meaning that it would affect processing at a later point in time. During oral reading, articulation of a recognized word occurs typically after one to three subsequent words in the text have been identified, and readers continuously adjust the order and the time spent viewing individual words to maintain a particular eye–voice distance (Inhoff, Solomon, Radach, & Seymour, 2011). This coordination of word viewing durations with the overt articulation of previously identified words may provide less opportunity for the immediate use of parafoveally extracted information. A conceptually related distinction between information extraction and information use was proposed by Blanchard, McConkie, Zola, and Wolverton (1984); see also McConkie & Zola, 1987). The view that parafoveal preview benefits are not only determined by parafoveal information extraction but also by the extent to which parafoveally extracted information can be used during the following fixation of the previewed word is referred to as the (*transsaccadic*) *information integration hypothesis*.

Similar to Ashby et al. (2012), the vast majority of studies that examined parafoveal preview benefits compared conditions in which the parafoveal preview of a target word was either available or denied throughout the viewing of the preceding word. With this approach, the extraction of information from a useful parafoveal preview during pretarget word viewing is up to the reader and not under experimental control. Parafoveal preview benefits are measured during the *subsequent* viewing of the target, and benefits that emerge at this point in time could either be due to the parafoveal extraction or the subsequent integration of parafoveally extracted information. That is, the parafoveal information extraction and parafoveal information integration hypothesis provide equally plausible accounts for parafoveal preview benefits.

In their study, Ashby et al. (2012) used a modification of McConkie and Rayner's (1975) moving window technique to determine preview benefits. Parafoveal preview of individual words was controlled through the use of a window of visible text that moved in synchrony with readers' eyes. All letters outside experimentally established windows were replaced with Xs. No parafoveal word previews were available in one condition (that revealed only the directly fixated word); preview of two parafoveal words was available in a three-word condition, where the window revealed the directly fixated word and the following two words. Since window size determined the visibility of text during each fixation, and since it was held constant throughout sentence reading, readers are likely to have noticed that parafoveal previews were either denied or available. Visual and graphemic properties of text outside the window were also quite distinct, and when previews were denied, readers could have responded with a more cautious progression through the sentence, especially when reading was relatively fluent, as occurred during silent reading. That is, larger preview benefits during silent than during oral reading could be due to a mask-induced response strategy that influenced silent reading more than oral reading.

To avoid these potential limitations, we used Rayner's (1975) boundary technique to determine parafoveal preview benefits during oral and silent reading. With this methodology, all words of a sentence, except for a specific target word, are fully visible throughout sentence reading until the pretarget word was fixated. In the present study the target word occupied various sentence locations, and care was taken to hide the usefulness of a parafoveal preview. Following Inhoff, Eiter, and Radach (2005), informative and uninformative previews of the target consisted of orthographically legal letter sequences rather than homogenous strings of Xs. As in our earlier study, all words of experimental sentences, including the informative and uninformative target preview, were shown in AlTeRnAtInG case. Target words and their visual masks had unfamiliar visuospatial configurations, further diminishing the distinction between visible and masked target previews.

The current study pursued two main goals. One was to distinguish between the parafoveal information extraction and the parafoveal information integration hypotheses, and the other was to determine whether effective parafoveal information extraction—or information integration—differed during oral and silent reading when readers could not anticipate the usefulness of a parafoveal target word preview. To distinguish between the parafoveal information extraction and the information integration hypotheses, we manipulated the temporal availability of a parafoveal target word preview. This manipulation was predicated on the assumption that a diminished temporal opportunity for the extraction of useful parafoveal target word information would directly affect the extraction of parafoveally available target word information. When, for instance, a pretarget word was fixated for 250 ms, readers should have more opportunity to extract parafoveal target information when the preview is available throughout pretarget word viewing than when it is available for a distinctly shorter duration, such as 50 ms or 100 ms. According to the information extraction hypothesis, any decrease in the opportunity of parafoveal information extraction should diminish parafoveal preview benefits when the previewed word is subsequently fixated. This should occur during oral and silent reading, although the rate of parafoveal information extraction might be smaller during oral reading.

Extraction of useful information from a parafoveally visible target preview will also affect subsequent integration of information, as less extraction of useful parafoveal target word information implies that less useful information can be integrated during subsequent target viewing. However, not all extracted information may be integrated, and the extraction and integration of parafoveal information may be dissociated. Although readers' parafoveal information extraction should decrease when the temporal window of the preview is diminished, this may not influence the size of the parafoveal preview benefit, if very little or none of the extracted information was used when the previewed word was subsequently fixated. That is, the size of parafoveal preview benefits is not only determined by parafoveal information extraction but also by the success with which extracted information is integrated when the previewed word is subsequently fixated. According to the integration hypothesis, smaller parafoveal preview benefits during oral than during silent reading could thus be due the less effective integration of parafoveal information.

Four time-specific target preview conditions were used in the current study to control the temporal opportunity for parafoveal information extraction. In a 0 ms delay condition, preview of a target word was available at the onset of pretarget word viewing, and the parafoveal preview of the target was not impeded, as occurs during normal reading. In three preview delay conditions, presentation of the parafoveally visible target was delayed after the onset of pretarget viewing by 50 ms, 100 ms, or 150 ms. The target word's location was occupied by an uninformative pseudoword in these conditions until the preview of the target was presented in its place. The target then remained fully visible until it was fixated, and target viewing duration was examined as a function of the time course of the parafoveal target delay (0–150 ms) and, as the second factor in our experimental design, reading mode. Based on our prior work, use of alternating case text was assumed to obscure the change from the pseudoword preview to a target word preview during the pretarget word's fixation, as a preview's prominent visual configuration remained unchanged even when the previewed mask was replaced with the target (Inhoff et al., 2005, see also Inhoff, Radach, & Eiter, 2006).

Two sets of statistical analyses were used to discern effects of parafoveal target delay and of reading mode on target viewing. One set used linear mixed models to examine experimental effects. Another used survival analyses to determine when parafoveally extracted target information was used during the following target fixation. Similar to this, Reingold, Reichle, Glaholt, and Sheridan (2012) and Yang and McConkie (2004) used survival analyses to determine the time course of information use during target word viewing.

# METHOD

## Participants

Forty-two undergraduate students at the State University of New York participated for course credit in the experiment. All were fluent readers and native speakers of English with normal or corrected-to-normal vision. All were also naïve regarding the purpose of the experiment.

## Materials

To-be-read materials were taken from Inhoff et al. (2005). To familiarize participants with the reading of alternating text, the experiment started with the reading of a 1820 word story, presented on a single page of text, which described the symptoms of aphasia. All words were written in aLtErNaTiNg CaSe to familiarize readers with resulting configurational changes to words. Although case alterations generate unfamiliar word patterns, they were not expected to influence the integration of parafoveal information across fixations (McConkie & Zola, 1979; Slattery, Angele, & Rayner, 2011). Eye movements were not monitored during story reading in the current study, but they had been monitored during the reading of the same story in Inhoff et al. (2005, Exp. 1A). The results of that study showed that practice increased the reading rate for alternating case substantially so that it almost matched the reading rate for lower case text.

The sentence materials consisted of Inhoff et al.'s (2005) 66 normed experimental sentences, from which we removed two sentences with pretarget words that contained fewer than four characters. This yielded a total of 64 sentences with related pretarget–target word sequences, such as "MoRnInG cOfFeE" or "tRaFfiC lIgHt", with mean word lengths for pretarget and target words of 5.8 and 5.3 letter spaces, and CELEX (1995) mean frequencies of 43 and 66 per million, respectively. Sentences contained between nine and 16 words, each of which was written in alternating case to obscure target word changes. Readers were asked to paraphrase sentence content immediately after one of a randomly selected subset of (6–15) sentences was read. This showed that sentences were relatively easy to comprehend and that the content of virtually all probed sentences was correctly reported (accuracy for each reader >.9).

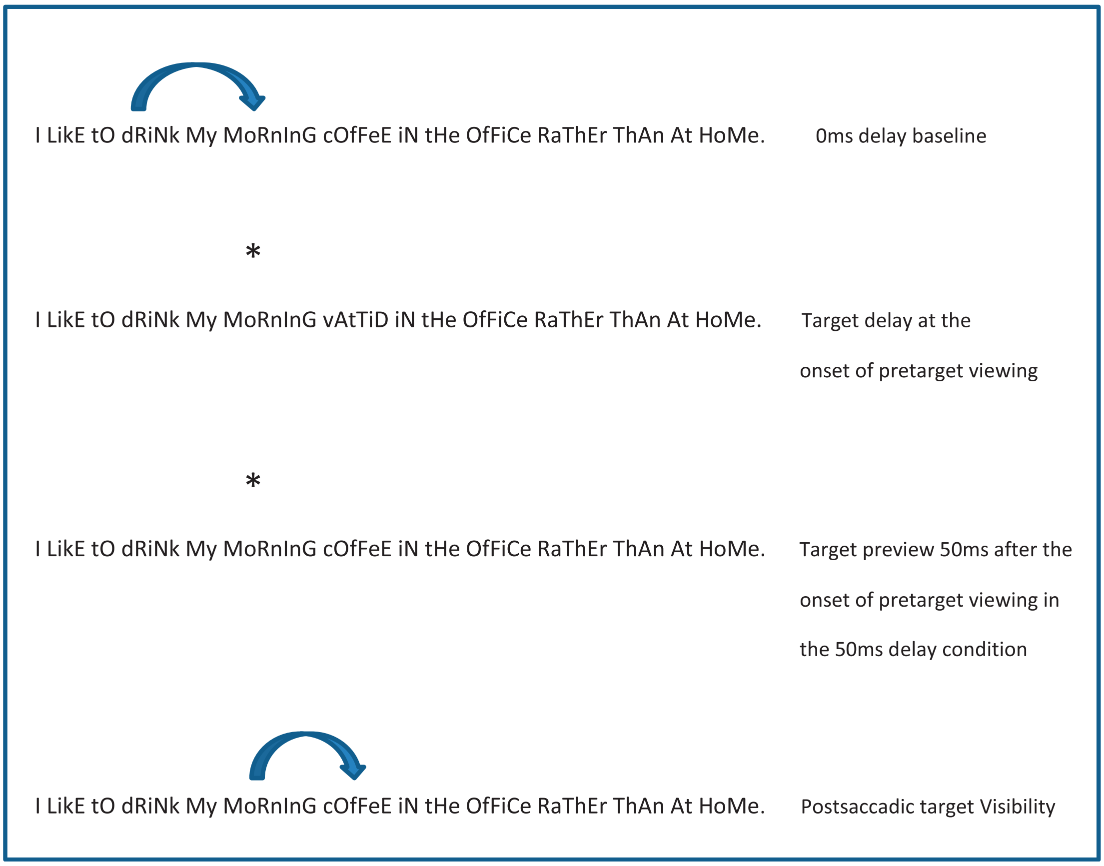


**Figure 1.** Target visibility in the 0 ms and the 50 ms delay conditions. Potential saccades are shown as arrows and potential fixations are shown as asterisks. To view this figure in colour, please see the online issue of the Journal.

Each sentence contained an invisible display change boundary (Rayner, 1975), located at the blank space preceding the pretarget word, e.g., the space preceding the first and second word in the word sequence “tHeIr MoRnInG cOfFeE”. This boundary was used to manipulate the target’s (“cOfFeE”, in the example) parafoveal preview while the pretarget word (MoRnInG) was fixated. The target was masked with a visually dissimilar length-matched pseudoword (“vAtTiD”) at the onset of sentence reading, and the mask was visible for 0 ms (no delay baseline), 50 ms, 100 ms, or 150 ms after the onset of pretarget viewing. After this, it was replaced with a target word preview. Extraction of useful target information was thus delayed to various degrees in three experimental delay conditions. Figure 1 illustrates the 50 ms delay condition. The delay intervals were smaller than in Inhoff et al.’s (2005) study, as the time course of parafoveal information extraction after onset of pretarget viewing was of particular interest for the discrimination of the parafoveal information extraction and parafoveal information integration hypotheses. All readers noticed instances of parafoveal flicker in the three target delay conditions. However, none associated them with changes in the informative value of a target preview.

## Apparatus

The same setup was used as in Inhoff et al. (2005). More specifically, all sentences were presented on a 22-inch Iiyama CRT monitor at 1024 × 768 resolution in black text on a light grey background with a refresh rate of 150 Hz, and they were displayed on a single line on the horizontal midline of the monitor. A head-mounted SR Research Eyelink II eye tracker was used so that the eye tracking apparatus would not hamper oral reading. The sampling rate was set to 500 Hz and relative tracking accuracy was approximately 0.25 degrees of visual angle. The experiment was programmed using Eyelink Experiment Builder software, and Eyelink software was used to parse the continuously sampled eye positions into fixations, i.e., periods during which the eyes were relatively stationary, and saccades, i.e., movements in between successive fixations (Inhoff & Radach, 1998).

## Procedure

The same procedure was used as in Inhoff et al. (2005), except that participants read sentences either orally or silently. Sentences were displayed after a successful horizontal three-point calibration, and the onset and offset of to-be-read sentences was controlled by the reader though button pressing. Participants were told that sentence reading could be followed by a test for knowledge of sentence content. There was no formal assessment and evaluation of oral reading errors, but sentences were relatively easy to read, and articulation errors occurred on a relatively small proportion of sentences (less than 15%), and these sentences were removed from analyses.

## Experimental design and data analysis

Reading mode (oral vs. silent reading) and target delay during pretarget viewing (0–150 ms) were manipulated within subjects. Half of the experimental sentences were read orally and the remaining sentences were read silently, and there were an equal number of sentences in each delay condition. Eight identical lists of alternating case sentences were generated to implement different target preview delays and different reading mode assignments, so that a different parafoveal delay and a different reading mode was applied to each sentence across lists. Prior to the presentation of each sentence, participants were asked to read it either orally or silently, and target delay and reading mode were randomly ordered within list.

Three standard viewing duration measures of visual word processing, first fixation duration, gaze duration, and total viewing duration, were computed to determine the influence of a target delay on the size of the preview benefit in the two reading modes. First fixation duration comprised the duration of the first fixation on a selected word; gaze duration comprised its cumulated viewing time, including the time spent refixating the word until another word was fixated; total viewing duration consisted of a word's gaze duration plus the time spent rereading it. Gaze durations were of primary interest, as this measure is typically used to index the success of a word's lexical processing (see also Inhoff & Weger, 2003; Radach & Kennedy, 2004; Rayner, 1998). We also examined the size of saccades that moved the eyes from pretarget to target words to determine whether preview delay and reading mode influenced the programming of saccade size. Since not all target words were fixated, we also examined instances in which a saccade leaving the pretarget word moved over (skipped) the target word.

No data were available for approximately 15% of the trials due to track losses or due to premature termination of the experiment when repeated recalibration during the experiment failed to establish sufficient tracking accuracy. We also excluded sentences with oral reading errors. Fixated pretarget words were excluded from analyses when the outgoing saccade did not land at the subsequent target word, when the first fixation duration was smaller than 70 ms, and when gaze duration exceeded 900 ms. This yielded 1644 eligible pretarget words, 860 in the silent and 784 in the oral reading condition. Target words were excluded from analyses when the pretarget word was skipped, when the preceding fixation was on a word other than the pretarget word, and when pretarget viewing duration was 100 ms or less (so that each of the four different target delays could be implemented during pretarget viewing). This left 1641 eligible targets (776 in the oral and 865 in the silent condition) with a first fixation duration of 70 ms or more and a gaze duration of 900 ms or less.

Pretarget and target words were analysed using (generalized) linear mixed models (GLMM), as implemented in the lme4 library (Bates, Maechler, & Bolker, 2013) of the R system for statistical computing (R Development Core Team, 2013). Target delay and reading mode and the interaction between the two factors were entered as fixed factors. Delay values were centred. Visual inspection of the data indicated that the delay effect was often not linear. Statistical models thus included linear and quadratic delay components. Subjects and items were entered simultaneously as crossed random factors in models with random intercepts and also in models with random intercepts and random slopes (Baayen, 2008; Baayen, Davidson, & Bates, 2008). Maximum likelihood tests were used to select the most parsimonious model. Statistical analyses were applied to raw and log transformed viewing duration data. We report effect sizes for nontransformed data since the significance of experimental effects was rarely affected by the transformation. Since sample sizes were relatively large, significance levels were estimated using a normal distribution, and all absolute $t$-values > 1.96 were considered significant. Binomial skipping and incoming regression rate data were analysed using generalized linear mixed models. For these two measures, we report intercepts (in logits), effect sizes, standard errors, $z$-values, and significance levels.

To determine the time course of the preview delay effect during silent and oral reading, survival probabilities were computed for target gaze durations.

A continuous time vector was generated that extended from the shortest gaze duration (70 ms) to a very long gaze duration (600 ms) in increments of 5 ms[2] and each target gaze duration was then mapped onto the time vector so that bins with values smaller than the gaze duration received a survival probability of 1 (i.e., the gaze duration survived the bin value), and bin values larger than a particular gaze duration received a value of 0 (i.e., the gaze duration had been terminated). For instance, with a gaze duration of 307 ms, bin values 70 to 310 received a value of 1, and all larger bin values received a value of 0. All bins received a value of 1 when a target's gaze duration exceeded 600 ms (thus, target viewing probabilities did not always reach a probability value of 0).

Survival probabilities for each fixated target word were then analysed with a generalized additive model (R library mgcv, version 1.7–26; Wood, 2006) as a function of the smoothed gaze time vector (0–600) and target preview delay, with participants and words as random factors. This approach is conceptually equivalent to the survival analyses used by Yang and McConkie (2004) and Reingold et al. (2012; see also Sheridan et al., 2013; Sheridan & Reingold, 2012),[3] except that smoothing functions were used to estimate survival probabilities and that readers' model-based survival probabilities were used to compute standard errors over participants. The silent and oral reading data were analysed separately, and divergence points, i.e., the points in time at which survival probabilities differed between two contrasted delay conditions, were defined as the smallest time value for which the standard errors of the two conditions did not overlap.

## RESULTS

### Pretarget word

Mean first fixation duration, gaze duration, and total viewing duration for the pretarget word are presented as a function of reading mode and target delay in Table 1. Figure 2 shows actual and model-based (fitted) pretarget gaze durations.

As can be seen in Table 1 and Figure 2, pretarget fixation durations were longer during oral than during silent reading, and the corresponding reading mode effect was highly significant across all three fixation time

[2] Reingold et al. (2012; Sheridan, Rayner, & Reingold, 2013; Sheridan & Reingold, 2012) used smaller 1 ms bins. A somewhat larger bin size was used in the current study for computational convenience, as the computation of statistical models was relatively time consuming.

[3] Generalized additive models rather than Reingold et al.'s (2012; Sheridan et al., 2013; Sheridan & Reingold, 2012) survival analyses were used to estimate divergence points, as these models provided more stable estimates of error variance. Reingold et al. used bootstrapping to estimate error. However, with our data, their approach resulted in substantial changes in the divergence point, which shifted towards shorter values when the number of bootstrappings was increased. Yang and McConkie (2004) did not determine error variance for survival probabilities.

TABLE 1
Pretarget viewing durations (in ms) as a function of parafoveal target delay and reading mode (standard errors of the mean are shown in parentheses)

| *Target delay* | *First fixation duration* | *Gaze duration* | *Total viewing duration* |
|---|---|---|---|
| Silent reading | | | |
| 0 ms | 250 (7.7) | 277 (9.6) | 304 (14.5) |
| 50 ms | 280 (12.6) | 305 (11.7) | 328 (17.9) |
| 100 ms | 269 (11.5) | 306 (11.1) | 345 (16.4) |
| 150 ms | 268 (8.8) | 297 (9.0) | 350 (13.7) |
| Oral reading | | | |
| 0 ms | 273 (8.5) | 328 (10.5) | 365 (15.9) |
| 50 ms | 289 (10.1) | 364 (11.6) | 390 (14.6) |
| 100 ms | 277 (11.0) | 346 (13.9) | 379 (16.1) |
| 150 ms | 283 (8.7) | 337 (12.0) | 363 (14.2) |

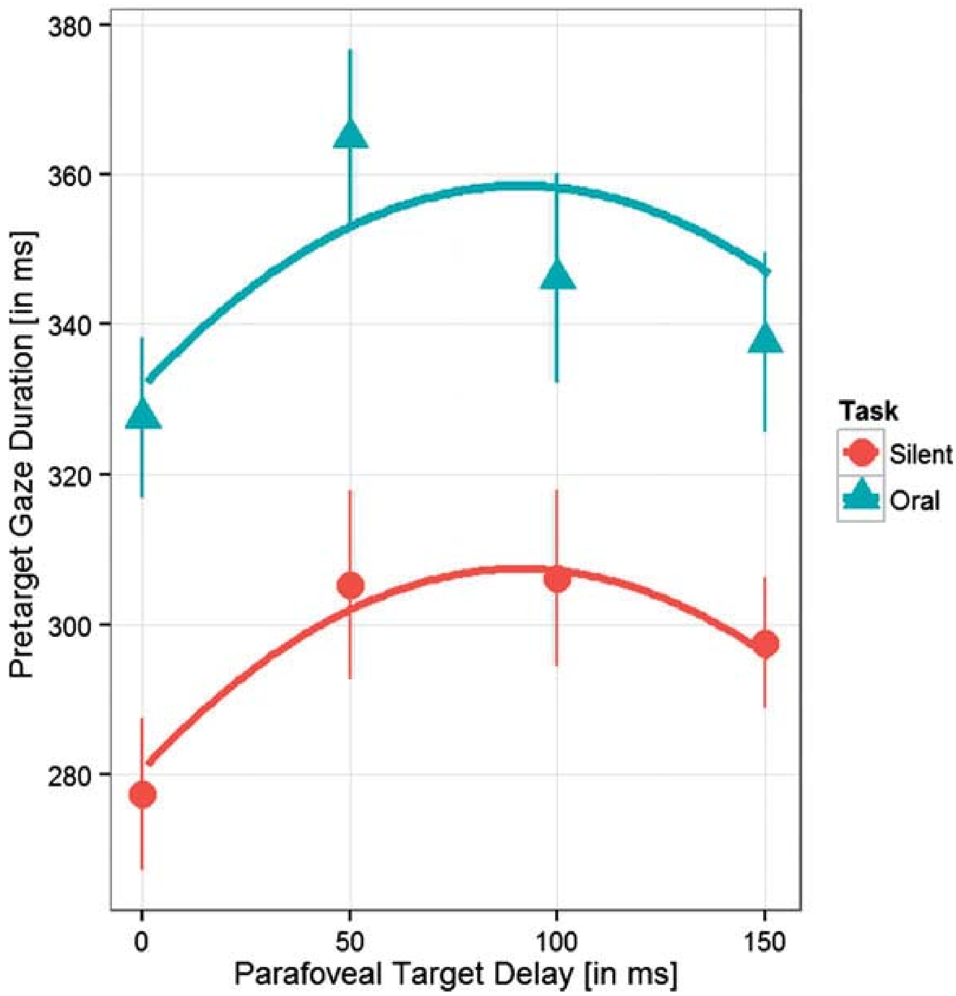


**Figure 2.** Pretarget gaze duration as a function of parafoveal target delay and reading mode. Condition means (in ms), computed over subjects, are shown with associated standard errors (also computed over subjects). The figure also shows model-estimated values. To view this figure in colour, please see the online issue of the Journal.

measures, $b = 15.5$ ms, $SE = 4.9$, $t = 3.14$, for first fixation duration; $b = 51.5$ ms, $SE = 9.9$, $t = 5.18$, for gaze duration; $b = 50$ ms, $SE = 7.6$, $t = 6.0$, for total viewing duration; all $ps < .001$. Pretarget first fixation duration, gaze duration, and total viewing duration increased with target delay, and the corresponding the linear components were marginally or fully reliable, $b = 0.06$ ms (for each 1 ms increase in target delay), $SE = 0.04$, $t = 1.52$, $p = .12$, for first fixation duration; $b = 0.09$, $SE = 0.055$, $t = 1.67$, $p < .1$, for gaze duration; $b = 0.14$, $SE = 0.07$, $t = 2.17$, $p < .05$, for total viewing duration. Inclusion of the quadratic delay components did not improve the statistical models for first fixation duration and total viewing duration, but gaze durations revealed a reliable quadratic delay effect, $b = -0.003$, $SE = 0.0012$, $t = -2.61$, $p < .01$, respectively.

As can be seen in Figure 2, reading mode and parafoveal preview delay did not interact during first pass pretarget viewing, $t$-values $< 0.8$, $p > .4$, for first fixation duration and gaze duration. The interaction approached significance when total viewing durations were analysed, $b = 0.22$, $SE = 0.13$, $t = 1.63$, $p = .11$, indicating that the viewing of subsequent words in the sentence may shift the effect pattern when the pretarget word is refixated. The viewing of the next word, the target, was examined to determine how parafoveally extracted target information influenced oculomotor responding to this word.

## Target word

The size of saccades from pretarget to target words, the rate of target skipping, and the three viewing duration measures for fixated targets, are shown in Table 2 as a function of reading mode and parafoveal target delay.

TABLE 2
Target viewing durations (in ms) and skipping rates (in %) and saccades to the target as a function of parafoveal target delay and reading mode (standard errors of the mean are shown in parentheses)

| *Target delay* | *First fixation duration* | *Gaze duration* | *Total viewing duration* | *Target skipping* | *Incoming saccade* |
|---|---|---|---|---|---|
| Silent reading | | | | | |
| 0 ms | 227 (6.6) | 250 (7.9) | 268 (10.2) | 13.7 (2.9) | 6.4 (0.15) |
| 50 ms | 245 (13.4) | 268 (11.6) | 288 (14.9) | 10.9 (2.6) | 6.1 (0.15) |
| 100 ms | 246 (8.7) | 273 (11.6) | 306 (14.7) | 10.7 (2.2) | 6.0 (0.13) |
| 150 ms | 276 (7.8) | 300 (9.4) | 334 (13.5) | 10.2 (2.2) | 6.0 (0.15) |
| Oral reading | | | | | |
| 0 ms | 261 (8.2) | 296 (9.9) | 318 (12.2) | 16.2 (2.7) | 6.2 (0.18) |
| 50 ms | 245 (7.1) | 292 (10.6) | 322 (13.9) | 11.0 (3.0) | 5.9 (0.15) |
| 100 ms | 264 (7.2) | 301 (7.3) | 340 (13.7) | 7.6 (1.9) | 5.7 (0.19) |
| 150 ms | 272 (9.7) | 325 (14.6) | 352 (15.) | 5.7 (1.6) | 5.8 (0.14) |

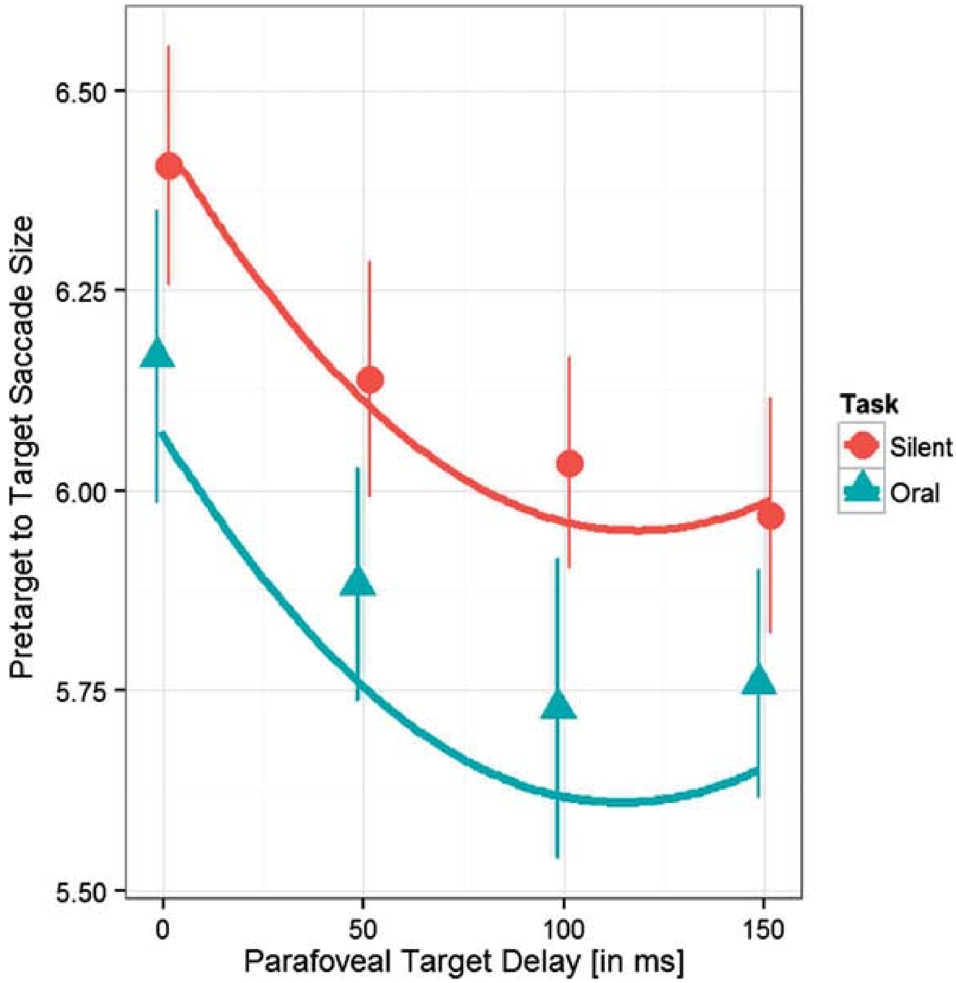


**Figure 3.** The size of saccades from pretarget to target words (in letter spaces) as a function of parafoveal target delay and reading mode. Condition means (in ms) are shown with associated standard errors (computed over subjects). The figure also shows model-estimated values. To view this figure in colour, please see the online issue of the Journal.



Saccades from pretarget to target words, shown in Figure 3, were larger in the silent than the oral reading condition, $b$ = 0.29 (letter space units), $SE$ = 0.12, $t$ = 2.38, $p$ < .05. Saccade size decreased with increased target delay, and the linear and quadratic delay component were significant, $b$ = 0.0027 (for each 1 ms increase in target delay), $SE$ = 0.00068, $t$ = –4.02, $p$ < .001; $b$ = 0.000035, $SE$ = 0.000015, $t$ = 2.32, $p$ < .01, respectively. The interaction of reading mode with target delay was negligible for the linear component, $t$ = 0.24, $p$ > .6, and it did not approach significance for the quadratic component, $b$ = 0.000036, $SE$ = 0.00003, $t$ = 1.22, $p$ > .22.

Instances in which the outgoing saccade skipped over the target were slightly less common during oral than silent reading (9.3% vs. 10.8%, respectively), but the difference was not reliable: intercept = –2.70, $b$ = –0.26, $SE$ = 0.17, $z$ = 1.50,

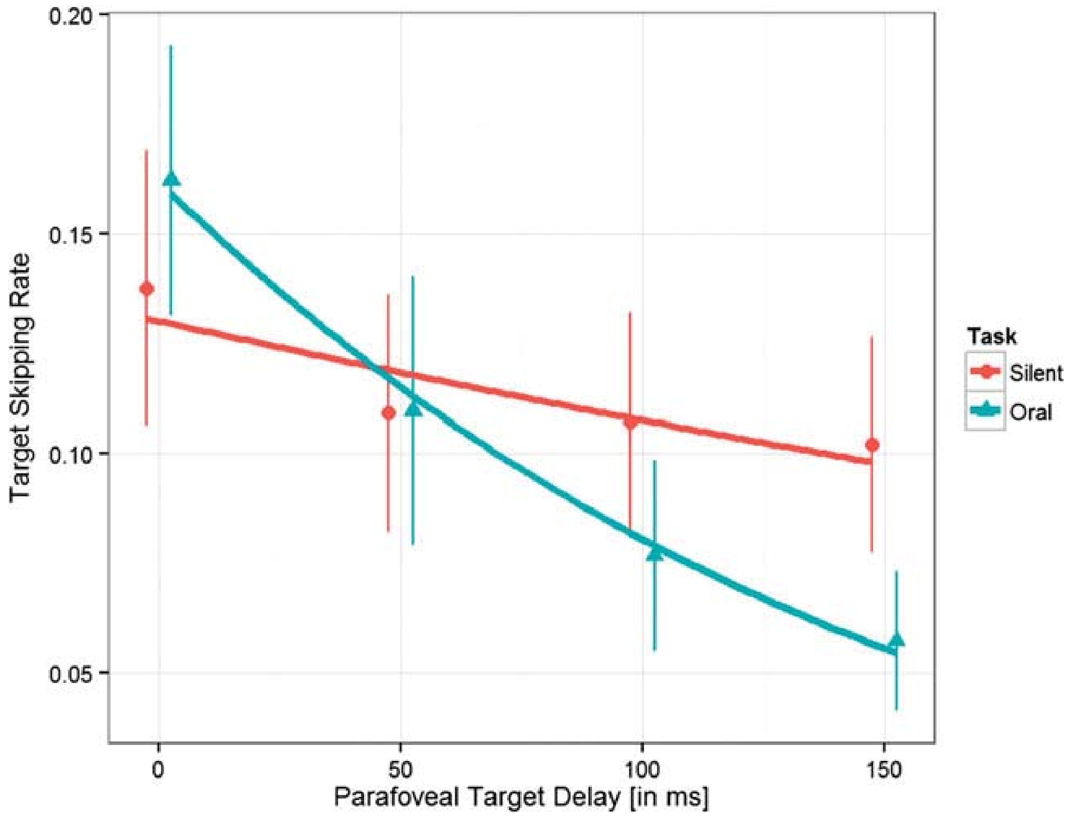


**Figure 4.** Mean target skipping rates as a function of parafoveal target delay and reading task with associated standard errors (computed over subjects). The figure also shows model-estimated values. To view this figure in colour, please see the online issue of the Journal.



$p$ = .13. Delays in the onset of a parafoveally visible target word diminished skipping from 14% in the 0 ms delay condition to 8% in the 150 ms delay condition, respectively, and the corresponding main effect was reliable, $b = 0.006$ (for each 1 ms increase in target delay), $SE = 0.00015$, $z = 3.86$, $p < .001$. The delay effect was numerically smaller during silent than during oral reading, and the corresponding interaction, shown in Figure 4, approached significance, $b = -0.005$, $SE = 0.003$, $z = -1.78$, $p < .08$. Together, the two sets of data show that even short delays in the onset of a related parafoveal target diminished the size of incoming saccades and rate of target skipping.

The time spent fixating target words was of particular theoretical interest, as parafoveally obtained information was presumably integrated with linguistic target word information during this period. All three measures yielded significant effects of reading mode with longer durations during oral reading, $b = 9.5$ ms, $SE = 4.31$, $t = 2.21$, for first fixation duration; $b = 25.5$ ms, $SE = 5.52$, $t = 4.62$, for gaze duration; $b = 30.0$ ms, $SE = 6.9$, $t = 4.35$, for total viewing duration (all $p$s < .05). The delay of a target preview also influenced target viewing duration. The linear delay component was significant, $b = 0.19$ ms (for each

1 ms increase in target delay), $SE = 0.036$, $t = 5.06$, for first fixation duration; $b = 0.22$ ms, $SE = 0.05$, $t = 4.55$, for gaze duration; $b = 0.28$ ms, $SE = 0.06$, $t = 4.68$, for total viewing duration (all $p$s $< .001$). Inclusion of a quadratic delay component did not improve statistical models.

Across all three measures, viewing duration differences between oral and silent reading were largest in the 0 ms delay condition (when the onset of a useful target preview was not delayed and when extraction was not impeded) and smallest in the 150 ms delay condition (when the least amount of parafoveal information could be extracted). The corresponding interaction was reliable for all three measures, $b = 0.21$, $SE = 0.076$, $t = 2.76$, $p < .01$, for first fixation duration; $b = 0.18$, $SE = 0.098$, $t = 1.86$, $p < .07$ ($p < .01$, with log transformed data), for gaze duration; and $b = 0.24$, $SE = 0.123$, $t = 1.97$, $p < .05$, for total viewing duration.

The interaction of reading mode with target delay indicates that the slope of the linear delay effect differed between silent and oral reading. However, as can be seen in Figure 5, the interaction was primarily due to reading mode differences in the 0 ms delay condition. When this condition was excluded, reading mode and delay still yielded robust effects (all $t$s $> 2$) but their interaction was negligible across the three viewing time measures (all $t$s $< .8$, $p$s $> .5$).

Together, three sets of target viewing durations show that a delay in the onset of a useful parafoveal target preview diminished preview benefits when the target was subsequently fixated, and that the cost of a delayed preview onset was larger during silent than oral reading condition. Importantly, parafoveal information use in the two reading mode conditions differed primarily in the 0 ms delay condition. After a 50 ms delay in the onset of a useful parafoveal target preview, any further delay influenced the use of parafoveal target preview equally in the two reading mode conditions.

The time course of parafoveal information use during subsequent target viewing was examined with survival analyses. The 0 ms (baseline) and 50 ms delay conditions were of primary theoretical interest, as parafoveal information during oral and silent reading differed primarily during this period. In addition, we compared the 0 ms with the 150 ms delay condition, but not the 0 ms and 100 ms conditions, to determine the time course of parafoveal information usage during oral and silent reading when parafoveal information extraction was maximally impeded. The silent reading condition showed lower survival probabilities in the 0 ms than the 50 ms delay condition (Figure 6, left panel), $b = 0.026$, $SE = 0.002$, $z = 12.63$, $p < .001$, and the estimated divergence was at 265 ms. The oral reading data, by contrast, did not show survival differences between the 0 ms and 50 ms delay conditions (Figure 6, right panel), $b = 0.0018$, $SE = 0.0012$, $z = 1.50$, $p > .1$, and there was no significant divergence in survival probability between the 0 ms and 50 ms delay conditions. This indicates that a parafoveal target preview that was available during the beginning 50 ms of a

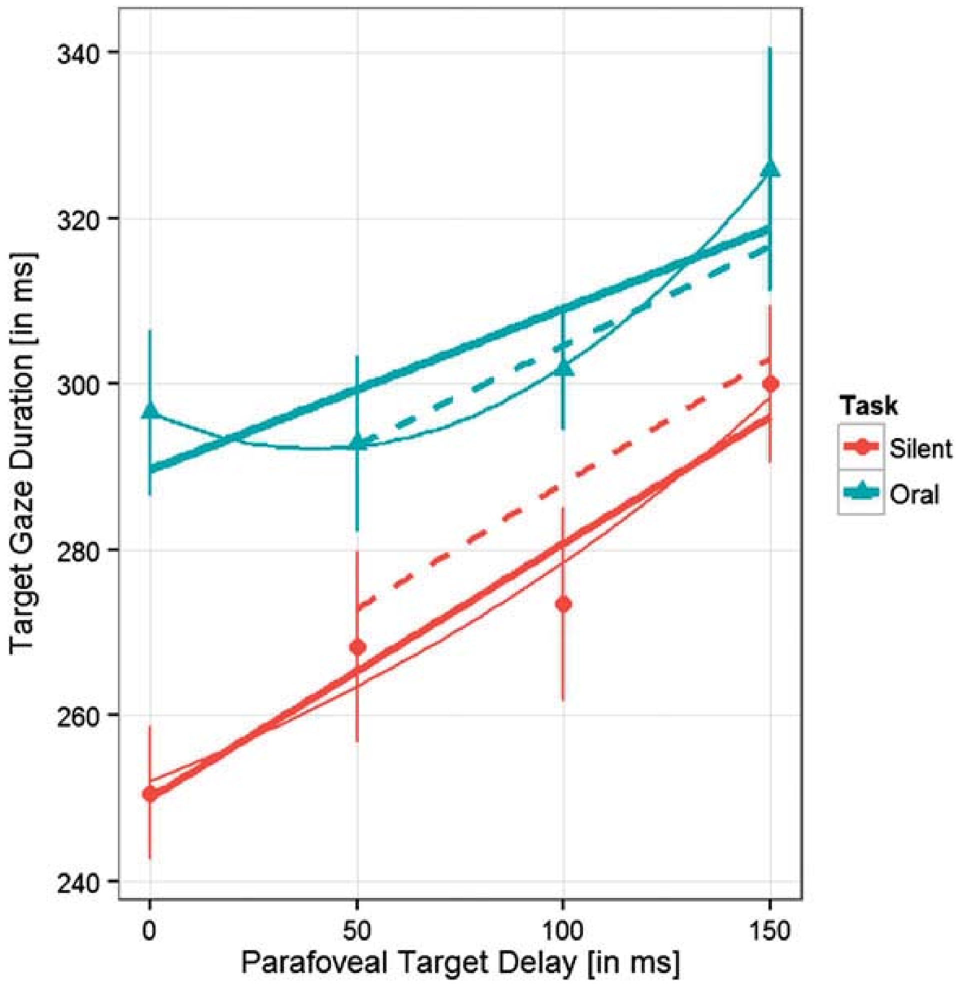


**Figure 5.** Target gaze duration as a function of prior parafoveal target delay and reading mode. Condition means (in ms) are shown with associated standard errors (computed over subjects). Full lines show linear effects of target delay and task type, as estimated from the full statistical model; dashed lines show model-estimated linear effects when the 0 ms delay condition was excluded. Thin lines show loess functions. To view this figure in colour, please see the online issue of the Journal.



pretarget viewing was used when the target was subsequently fixated during silent reading but not during oral reading.

Figure 7 shows the corresponding survival probability functions for the 0 ms and 150 ms delay conditions. Now, silent and oral modes showed delay-dependent survival differences, $b = 0.0085$, $SE = 0.005$, $z = 17.05$, $p < .001$, and $b = 0.001$, $SE = 0.0004$, $z = 2.20$, $p < .05$, respectively, indicating that parafoveal target previews were more useful in the 0 ms than the 150 ms delay condition. The divergence point was earlier during silent reading (Figure 7, left panel), at approximately 125 ms, than during oral reading (Figure 7, right panel), at approximately 240 ms, suggesting that a parafoveally available target preview was used earlier during subsequent target viewing in the silent than the oral reading condition.

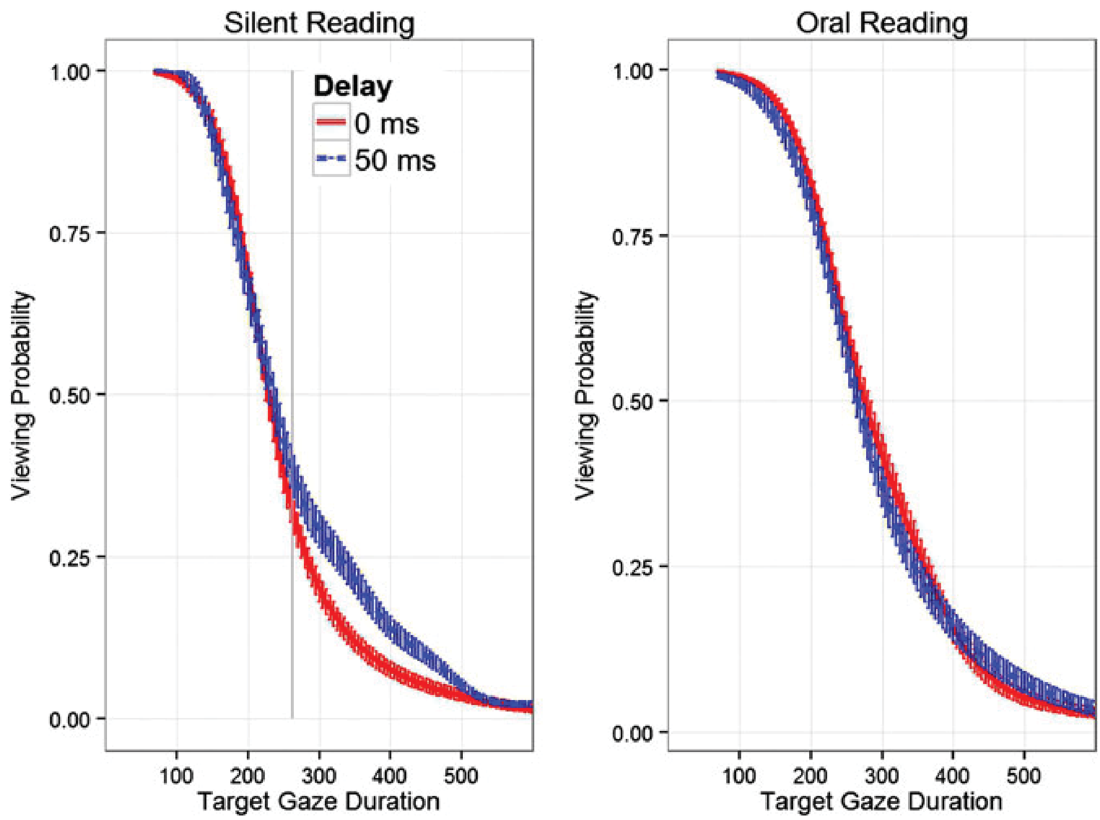


**Figure 6.** Survival functions for gaze durations in the 0 ms and 50 ms target delay conditions with associated standard errors (computed over subjects). The left panel shows smoothed survival probabilities during silent reading; the right panel shows smoothed survival probabilities during oral reading. The vertical line in the left panel marks the divergence point. To view this figure in colour, please see the online issue of the Journal.

## DISCUSSION

The main goal of the current study was to discern the source of parafoveal preview benefits, i.e., whether they are determined by the effectiveness with which parafoveally available information was extracted or by the integration of extracted information during subsequent word viewing. To achieve experimental control over parafoveal information extraction, the temporal availability of useful target information was manipulated so that preview of a target word was either available upon the onset of pretarget viewing or delayed for a variable time interval that ranged from 50 ms to 150 ms. This manipulation was implemented in two reading modes, silent and oral reading. Consistent with Ashby et al. (2012), the results showed that readers spent more time viewing individual words during oral than during silent reading, and target viewing duration measures revealed larger parafoveal preview benefits during silent than during oral reading. The use of the boundary rather than the window technique in the current study indicates that smaller parafoveal preview benefits during oral reading cannot be attributed to experiment-induced processing strategies, as the informative value of the parafoveal preview of a target word could not be anticipated.

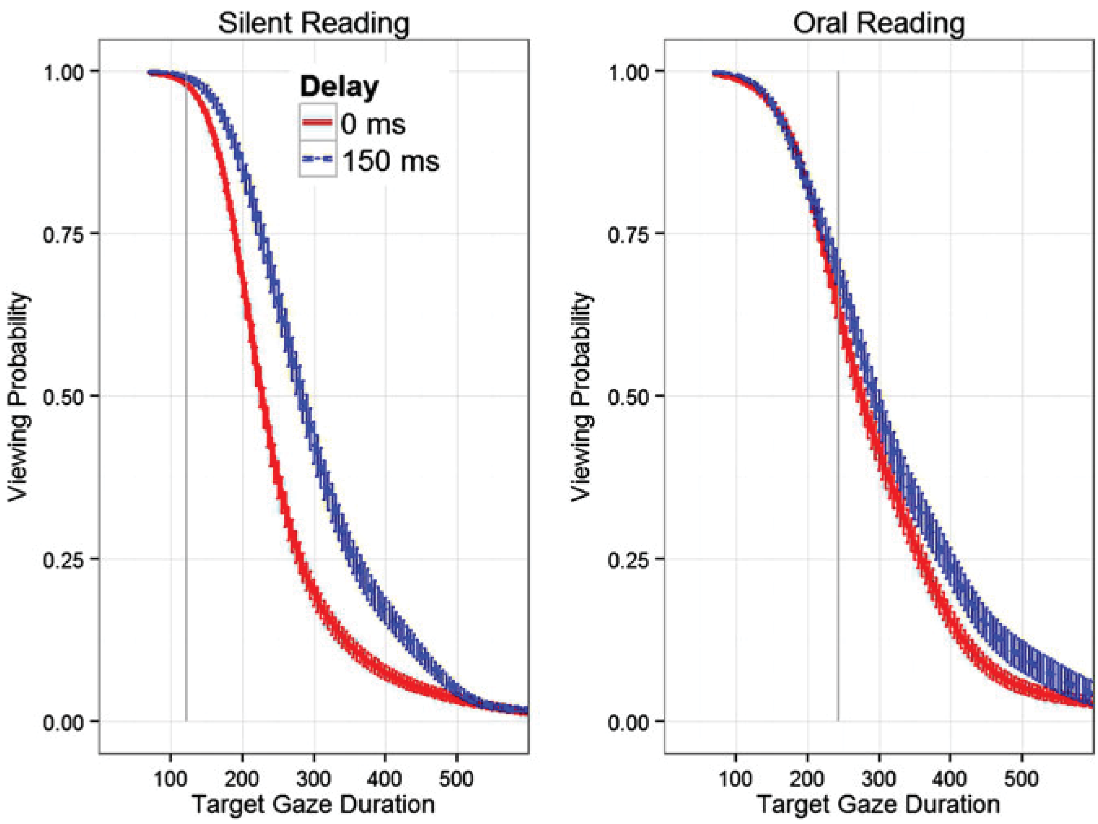


**Figure 7.** Survival functions for gaze durations in the 0 ms and 150 ms target delay conditions with associated standard errors (computed over subjects). The left panel shows survival probabilities during silent reading; the right panel shows survival probabilities during oral reading. Vertical grey lines mark divergence points during silent and oral reading. To view this figure in colour, please see the online issue of the Journal.

According to the parafoveal information extraction hypothesis, decreases in the temporal availability of parafoveal target preview should result in smaller benefits when the target is fixated. In agreement with the hypothesis, target viewing durations increased with the delay of a target, with a smaller effect size for the oral than the silent reading condition. Inspection of target viewing durations, shown in Table 2 and Figure 5, further indicates that these durations increased linearly with preview delay in the silent reading condition. Here, any change in the opportunity to extract parafoveally visible target information influenced subsequent target viewing durations.

Target viewing durations in the oral reading condition showed a somewhat different pattern of target delay effects, however. In this mode, first fixation durations were even numerically shorter in the 50 ms than the 0 ms delay condition, and neither gaze durations nor total viewing durations were longer in the 50 ms than 0 ms delay condition, as if no useful information was obtained during the beginning 50 ms of a parafoveal target preview. Consistent with this, survival probabilities in the 0 ms and 50 ms delay conditions differed after 265 ms during silent reading, indicating that previewed influenced target viewing after this point in time, and the corresponding survival probabilities did not differ at any point in time during oral reading.

The finding that a 50 ms delay in the onset of useful target information did not diminish the parafoveal preview benefit relative to the 0 ms delay condition during oral reading can be reconciled with one version of the parafoveal information extraction hypothesis, according to which increased foveal processing difficulty *delayed extraction* of useful information from a parafoveal preview, as originally proposed by Henderson and Ferreira (1990). During silent reading, parafoveal information extraction may have started immediately with the onset of pretarget viewing, and it may have been delayed by approximately 50 ms when the task became more difficult through the overt articulation of identified words. After the short delay, parafoveal information extraction could have progressed normally; hence, similar rates of parafoveal information extraction during oral and silent reading when the 0 ms delay condition was excluded. Survival differences between the two reading modes are consistent with this delayed extraction account, as significant target delay effects emerged at a later point in time during oral than during silent reading.

Equivalent target viewing durations in the 0 ms and 50 ms delay conditions during oral reading and only later use of parafoveally extracted information with this task are also consistent with the information integration hypothesis, according to which differences in the size of the parafoveal preview benefit are not due to differences in the extraction of parafoveal information but its subsequent integration. According to this account, extraction of parafoveal target information may have started with the onset of pretarget viewing in both reading mode conditions, but parafoveally extracted information was integrated at a later point in time when the target was subsequently fixated during oral reading.

The integration hypothesis, but not the extraction hypothesis, can also explain the effect of parafoveal target delay on target skipping. As can be seen in Table 2 and Figure 4, target skipping probabilities decreased with increased target delay, and this occurred during oral and silent reading. In contrast to the viewing duration data, both the oral and the silent reading mode showed numerically higher skipping rates in the 0 ms delay condition (15% and 13%, respectively) than in the 50 ms delay condition (10% and 11%, respectively), and the difference between these two delay conditions was numerically larger during oral reading. These results have diagnostic value, because the target skipping data differ in an important aspect from the target viewing data: The decision to skip the target cannot be influenced by the integration of parafoveal information during subsequent target viewing, as the target is not fixated. Instead, a linguistically informed decision to terminate pretarget viewing with a skipping saccade must be based on parafoveally extracted information alone. Without the modulating effect of a subsequent target fixation, use of parafoveal information was not diminished in the oral relative to the silent reading condition. Saccades that moved the eyes from pretarget to target words showed similar effects of target delay (see Figure 3). Without the modulating effects of transsaccadic information integration, the programming of saccades to target words was influenced by target delay, but the delay effect was equivalent during oral and silent reading.

Furthermore, the integration hypothesis, but not the extraction hypothesis, can explain effects of a parafoveal target delay on pretarget viewing. The pretarget data are similar to the target skipping and saccade size data in that delay effects cannot be influenced by the time spent viewing the subsequent target word. As can be seen in Table 1 and Figure 2, pretarget viewing durations were influenced by the parafoveal delay of the target and by reading mode, but the target delay effect was similar during silent and oral reading during first pass pretarget viewing. In both reading modes, the effect of delay was relatively large for the 50 ms delay condition, which is similar to larger target delay effects in the 70 ms delay condition than in longer delay conditions in Inhoff et al. (2005), perhaps because a visual change shortly after the onset of pretarget viewing impeded saccade programming (Reingold & Stampe, 2000, 2003, 2004). Figure 2 shows that pretarget gaze durations also increased with target delay during oral and silent reading when the 50 ms delay condition was excluded, and the linear delay component was marginally significant in all three sets of pretarget viewing duration data. According to the integration hypothesis, these results indicate that parafoveal extraction and use of information was similar during oral and silent reading, except when parafoveally obtained target information was integrated with information that was obtained when the target was subsequently fixated.

Parafoveal-on-foveal effects are often spurious and somewhat controversial (see Drieghe, Rayner, & Pollatsek, 2008; Kennedy, 2008; Rayner, White, Kambe, Miller, & Liversedge, 2003; Wang & Inhoff, 2013), and, according to Rayner et al. (2003), the effect is due to saccadic error. In the current study, the eyes may have been directed at a parafoveally visible target word but landed on the pretarget word instead; hence, target delay effects on pretarget viewing could have been "misplaced" preview benefits. According to this account, parafoveal-on-foveal effects should have matched parafoveal preview benefits, which was not the case. Furthermore, more recent work has provided a principled alternative account for parafoveal-on-foveal effects according to which they do reflect extraction of parafoveally available information. According to Risse and Kliegl (2012, in press), parafoveal-on-foveal effects are often small and unreliable because they emerge late during pretarget viewing, and because they often spill over into subsequent target viewing.

The transsaccadic information integration hypothesis thus provides a theoretical framework that accommodates the effects of a delayed target preview on pretarget fixation durations, target skipping rate, the size of saccades to target words, and target fixation durations. The theoretically significant aspect of the current findings is the dissociation of parafoveal information extraction from subsequent information integration, which challenges prior accounts and current theoretical conceptions according to which parafoveal preview benefits are solely a function of parafoveal information extraction (Engbert et al., 2005; Henderson & Ferreira, 1990; Reichle et al., 2006; Reilly & Radach, 2006). As originally proposed by McConkie and his colleagues (e.g., Blanchard et al., 1984; McConkie & Zola, 1987), extracted linguistic information appears to be used when needed, and this occurs at a later point in time during oral than during silent reading.

The present work also adds to the small but growing body of literature on eye movements in oral reading (e.g., Ashby et al., 2012; Huestegge, Radach, Corbic, & Huestegge, 2009; Hyönä & Olsen, 1995). It indicates that the demands of concurrent speech production represent not just an addition to silent reading but may cause substantial and systematic changes in the transsaccadic integration of parafoveally extracted information.



## REFERENCES

Ashby, J., Yang, J., Evans, K. H. C., & Rayner, K. (2012). Eye movements and the perceptual span in silent and oral reading. *Attention, Perception, and Psychophysics*, *74*, 634–640.

Baayen, H. (2008). *Analyzing linguistic data*. Cambridge: Cambridge University Press.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*, 390–412.

Bates, D., Maechler, M., & Bolker, B. (2013). lme4: Linear mixed-effects models using S4 classes R package version 1.0-4 (Computer software). Available from: http://CRAN.R-project.org/package=lme4

Blanchard, H. E., McConkie, G. W., Zola, D. E., & Wolverton, G. S. (1984). Time course of visual information utilization during fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(1), 75–89.

CELEX Database. (1995). Release D2.5 (Computer software). Nijmegen: Centre for Lexical Information.

Drieghe, D., Rayner, K., & Pollatsek, A. (2008). Mislocated fixations can account for parafoveal-on-foveal effects in eye movements during reading. *Quarterly Journal of Experimental Psychology*, *61*, 1239–1249.

Engbert, R., Nuthmann, A., Richter, E., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review*, *112*, 777–813.

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

Huestegge, L., Radach, R., Corbic, D., & Huestegge, S. M. (2009). Oculomotor and linguistic determinants of reading development: A longitudinal study. *Vision Research*, *49*, 2948–2959.

Hyönä, J., & Olson, R. K. (1995). Eye fixation patterns among dyslexic and normal readers: Effects of word length and word frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *6*, 1430–1440.

Inhoff, A. W., Eiter, B. M., & Radach, R. (2005). The time course of linguistic information extraction from consecutive words during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 979–995.

Inhoff, A. W., & Radach, R. (1998). Definition and computation of oculomotor measures in the study of cognitive processes. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 29–54). Oxford: Elsevier.

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

Inhoff, A. W., Solomon, M., Radach, R., & Seymour, B. (2011). Temporal dynamics of the eye voice span and eye movement control during oral reading. *Journal of Cognitive Psychology*, *23*, 543–558.

Inhoff, A. W., & Wang, (1992). The encoding of text, manual movement planning, and eye-hand coordination during copytyping. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 437–448.

Inhoff, A. W., & Weger, U. (2003). Advancing the methodological middle ground. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 335–344). Oxford: Elsevier.

Kennedy, A. (2008). Parafoveal-on-foveal effects are not an artifact of mislocated saccades. *Journal of Eye Movement Research*, *2*, 1–10.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception and Psychophysics*, *17*, 578–586.

McConkie, G. W., & Zola, D. (1979). Is visual information integrated across successive fixations in reading? *Perception and Psychophysics*, *25*, 221–224.

McConkie, G. W., & Zola, D. (1987). Visual attention during eye fixations while reading. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 385–401). Hove: Lawrence Erlbaum Associates.

Radach, R., & Kennedy, A. (2004). Theoretical perspectives on eye movements in reading: Past controversies, current issues, and an agenda for the future. *European Journal of Cognitive Psychology*, *16*, 3–26.

Radach, R., & Kennedy, A. (2013). Eye movements in reading: Some theoretical context. *Quarterly Journal of Experimental Psychology*, *66*, 429–452.

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

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*, 372–422.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology*, *62*(8), 1457–1506.

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

R Development Core Team. (2013). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, *105*(1), 125–157.

Reichle, E. D., Pollatsek, A., & Rayner, K. (2006). E-Z Reader: A cognitive-control, serial-attention model of eye-movement behavior during reading. *Cognitive Systems Research*, *7*, 4–22.

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

Reingold, E. M., Reichle, E. D., Glaholt, M. G., & Sheridan, H. (2012). Direct lexical control of eye movements in reading: Evidence from a survival analysis of fixation durations. *Cognitive Psychology*, *65*, 177–206.

Reingold, E. M., & Stampe, D. M. (2000). Saccadic inhibition and gaze contingent research paradigms. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 119–149). Oxford: Elsevier Science.

Reingold, E. M., & Stampe, D. M. (2003). Using the saccadic inhibition paradigm to investigate saccadic control in reading. In J. Hyona, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movements* (pp. 347–360). Amsterdam: Elsevier Science Publishers.

Reingold, E. M., & Stampe, D. M. (2004). Saccadic inhibition in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 194–211.

Risse, S., & Kliegl, R. (2012). Evidence for delayed parafoveal-on-foveal effects from word n+2 in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(4), 1026–1042.

Risse, S., & Kliegl, R. (in press). Dissociating preview validity and preview difficulty in parafoveal processing of Word n+1 during reading. *Journal of Experimental Psychology: Human Perception and Performance*.

Schotter, E. R., Angele, B., & Rayner, K. (2012). Parafoveal processing in reading. *Attention, Perception, and Psychophysics*, *74*, 5–35.

Sheridan, H., Rayner, K., & Reingold, E. M. (2013). Unsegmented text delays word identification: Evidence from a survival analysis of fixation durations. *Visual Cognition*, *21*, 38–60.

Sheridan, H., & Reingold, E. M. (2012). The time course of contextual influences during lexical ambiguity resolution: Evidence from distributional analyses of fixation durations. *Memory and Cognition*, *40*, 1122–1131.

Slattery, T. J., Angele, B., & Rayner, K. (2011). Eye movements and display change detection during reading. *Journal of Experimental Psychology: Human Perception and Performance*, *37*, 1924–1938.

Wang, C.-A., & Inhoff, A. W. (2013). Extraction of linguistic information from successive words during reading: Evidence for spatially distributed lexical processing. *Journal of Experimental Psychology: Human Perception and Performance*, *39*, 662–677.

Wood, S. N. (2006). *Generalized additive models: An introduction with R*. London: Chapman & Hall/CRC.

Yang, S.-N., & McConkie, G. W. (2004). Saccade generation during reading: Are words necessary? *European Journal of Cognitive Psychology*, *16*, 226–261.