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Time Course of Linguistic Information Extraction From Consecutive Words During Eye Fixations in Reading

Albrecht W. Inhoff and

Department of Psychology, Binghamton University, State University of New York

Brianna M. Eiter

Department of Psychology, Binghamton University, State University of New York

Ralph Radach

Department of Psychology, Florida State University

Abstract

Sequential attention shift models of reading predict that an attended (typically fixated) word must be recognized before useful linguistic information can be obtained from the following (parafoveal) word. These models also predict that linguistic information is obtained from a parafoveal word immediately prior to a saccade toward it. To test these assumptions, sentences were constructed with a critical pretarget–target word sequence, and the temporal availability of the (parafoveal) target preview was manipulated while the pretarget word was fixated. Target viewing effects, examined as a function of prior target visibility, revealed that extraction of linguistic target information began 70–140 ms after the onset of pretarget viewing. Critically, acquisition of useful linguistic information from a target was not confined to the ending period of pretarget viewing. These results favor theoretical conceptions in which there is some temporal overlap in the linguistic processing of a fixated and parafoveally visible word during reading.

Keywords

reading; attention; parafoveal preview; alternating case; parallel processing

Written language consists of a spatially ordered sequence of symbols, many of which are concurrently available to a reader. High-acuity vision is confined to a relatively small retinal area at any point in time that roughly corresponds to the fovea and immediately adjacent parafovea, so that only a limited amount of visual detail can be discerned when the eyes gaze at (fixate) a particular text location. Hence, readers need to move the eyes at or near a word to recognize it. Normal reading thus requires the development of a task-specific skill, that is, the dynamic coordination of eye movement (saccade) programming with successful visual word recognition and text comprehension.

Effects of this coordination are evident in the general progression of eye movements with word order and in robust effects of a word's spatial and linguistic properties on its viewing pattern (see Radach & Kennedy, 2004, and Rayner, 1998, for reviews). The coordination of eye movement programming with linguistic processes does not require, however, that the eyes are always moved from one word to the next. Although interword saccades to consecutive words

in the text are the most common type of eye movement during skilled reading, there is a relatively large proportion of other saccades (Hogaboam, 1983) that move the eyes to a different location within the same word (refixations), to a word beyond the next word in the text (skipping), or to a previously read word (interword regressions). The frequency with which these saccades are executed is a function of word and text properties.

A considerable number of studies that examined the relationship between the fixation of a word and its recognition have shown that skilled readers generally extract orthographic and phonological information from a word before it is directly fixated and that this parafoveally obtained information facilitates recognition of the word when it is subsequently fixated (this is referred to as *parafoveal preview benefit*; see Rayner, 1998).¹ Successful use of parafoveally available information also contributes substantially to the decision about which word to fixate next, and the skipping of the next word in the text is quite common when it is relatively short and easy to recognize (see Brysbaert, Drieghe, & Vitu, 2005, for a comprehensive review). Effective extraction of information from a parafoveally visible word is essential to skilled reading, because reading rate decreases substantially, up to one third, when useful parafoveal word previews are denied (Rayner, Well, Pollatsek, & Bertera, 1982).

Models of eye movement control during reading seek to explain how saccade programming is coordinated with ongoing perceptual and linguistic processes (for recent discussions, see Grainger, 2003; Jacobs, 2000), and a number of models have been proposed to explain basic oculomotor phenomena and parafoveal preview effects. Several of these models provide remarkably successful simulations of a wide range of oculomotor effects even though they are predicated on radically different processing assumptions (see Reichle, Rayner, & Pollatsek, 2003, for a review). In the current study we examine the time course of linguistic information use in the parafovea to provide insight into one of the most controversial issues in research on eye movements in reading: whether lexical processing of consecutive words is confined to just one word at a time and strictly serial or whether linguistic processing is spatially distributed (Starr & Rayner, 2001). One influential class of models, sequential attention shift (SAS) models, maintain that lexical processing is confined to one word at a time such that lexical information from a word can be obtained only after the lexical processing of the prior word is completed (Henderson & Ferreira, 1990; Inhoff, Pollatsek, Posner, & Rayner, 1989; Morrison, 1984; Reichle, Pollatsek, & Rayner, in press; Reichle et al., 2003; Reichle, Pollatsek, Fisher, & Rayner, 1998). Several theoretical alternatives maintain, by contrast, that the lexical processing of a word can begin before the prior word's lexical processing is completed, as is the case in Kliegl and Engbert's (2003; Engbert, Longtin, & Kliegl, 2002) SWIFT model, in Legge's (Klitz, Legge, & Tjan, 2000; Legge, Hooven, Klitz, Mansfield, & Tjan, 2002; Legge, Klitz, & Tjan, 1997) Mr. Chips model, and in Reilly and Radach's (2003, in press) Glenmore model.

According to all SAS models, including the recently developed family of E-Z Reader models, allocation of attention enables the acquisition of useful linguistic information one word at a time, and successful recognition shifts attention to the next word in the text. Because the programming of a saccadic eye movement is relatively time consuming, attention can generally be shifted from one word to the next before a corresponding saccade to the next word is executed. In recently proposed versions of the E-Z Reader model (Rayner, Ashby, Pollatsek, & Reichle, 2004; Rayner, Reichle, & Pollatsek, in press; Reichle et al., in press), for example, word recognition involves three stages, and saccade programming involves two stages. Word

¹Interword regressions, which direct the eyes to the word to the left of fixation (Hogaboam, 1983; Radach & McConkie, 1998), appear to be related to the success with which the previously fixated word to the left could be recognized (Vitu & McConkie, 2000) and to occasional corrections of oculomotor error (Rayner, 1998). Larger regressions appear to support repair of sentence meaning (e.g., Daneman & Stainton, 1991; Folk & Morris, 1995; Frazier & Rayner, 1982; Inhoff & Weger, 2005).

recognition starts out with preattentive visual processing, which segments text into spatially distinct word objects and achieves some feature extraction. The next stage, L1, determines a word's global familiarity, and the final stage, L2, determines specific word form(s) and word meaning. L1 and L2 involve attention-dependent linguistic processing, and factors that influence L1, such as word frequency and predictability, also influence L2, although the influence of predictability on L1 is scaled down so that the duration of L2 is a constant fraction of L1.

Lexical processing and eye movements are coordinated in the E-Z Reader model so that completion of L1 of a word initiates the programming of a saccade to the next word, and subsequent completion of L2 initiates a corresponding spatial shift of attention. In this scenario, the programming of a saccade takes place while the L2 processing of a fixated word is in progress, and a parafoveal preview benefit emerges when the L2 processing of a fixated word and the shift of attention to the next word in the text are completed before the concurrently programmed saccade is launched.

Computational implementations of the model (Reichle et al., 1998, 2003, in press) provide estimates for each one of the hypothesized stages of word recognition and saccade programming. In recent E-Z Reader model versions (Reichle et al., in press), the duration of early visual processing has an estimated duration of approximately 50 ms. L1 is assumed to range from 0–136 ms, and L2 is a constant fraction of that, with a range from 0 ms to 68 ms.² The durations of the first (labile) and second (nonlabile) stages of saccade programming are set to 183 ms and 53 ms, respectively, and actual execution of the saccade is assumed to consume approximately 25 ms. Preview benefits are thus common because completion of the two oculomotor stages of saccade programming generally consume more time than completion of L2, so that processing of the next word can commence before it is fixated.

Because extraction of linguistic information from a parafoveally visible word is confined to the interval between the completion of a fixated word's L2 processing and the completion of saccade programming, acquisition of useful linguistic information from a parafoveal word preview is strictly time locked. Specifically, acquisition of such information must occur during the final period of a word's fixation, immediately prior to the execution of the saccade to the previewed word.

The time course of linguistic information extraction from a parafoveally visible word is less transparent in competitor models, which assume that the linguistic processing of consecutive words is not strictly serial. The SWIFT and Glenmore models share the assumption that useful linguistic information can be obtained from more than one word, although visual constraints generally favor the processing of the directly fixated word over the processing of the next word in the text, at least during the initial period of a fixation. Consequently, these two alternatives will be referred to collectively as *processing gradient* (PG) models. According to the Mr. Chips model, visual information is obtained from a specific number of letters, irrespective of whether they belong to one or two words in the text. Similar to SAS models, the Glenmore and SWIFT models assume that use of linguistic information from the next word will generally lag the linguistic processing of the fixated word. However, in contrast to SAS models, extraction of parafoveal linguistic information should begin relatively soon after fixation onset, irrespective of the success with which the current word is recognized.

²In Rayner et al.'s (in press) recent E-Z Reader model, the duration of L1 for word n can be determined using the following function: $L1 = \alpha_1 - [\alpha_2 \ln(\text{freq}_n)] - (\alpha_3 \text{pred}_n)$, with $\alpha_1 = 136$ ms, $\alpha_2 = 3$ ms, and $\alpha_3 = 30$ ms. $\ln(\text{freq}_n)$ denotes the natural logarithm of word n 's frequency of occurrence and pred_n is word n 's cloze test predictability. The duration of L1 can also be zero, which occurs when the predictability of word n exceeds a certain probability value. The function for $L2 = \Delta L1$ (with Δ being generally 0.5). There is also some inherent variability in the durations of L1 and L2, and effects of frequency and predictability are modified by the retinal eccentricity of available information.

Discussion and testing of the strict seriality assumption have taken two major routes. First, the question has been raised of whether it is possible to carry out all necessary stages of word processing and oculomotor programming in a strictly sequential framework during the relatively short viewing period of individual words (e.g., Brysbaert & Vitu, 1998; Deubel, O'Regan, & Radach, 2000; Findlay & White, 2003; Radach, Deubel, & Heller, 2003; Sereno, O'Donnell, & Sereno, 2003). Second, there are a number of studies showing that linguistic properties of a parafoveally visible word can influence oculomotor behavior, especially viewing time on the fixated word (e.g., Inhoff, Starr, & Schindler, 2000; Kennedy, 2000; Kennedy & Pynte, 2005; Schroyens, Vitu, Brysbaert, & d'Ydewalle, 1999; Starr & Inhoff, 2004; Underwood, Binns, & Walker, 2000), which should not be the case if the saccade to the next word was programmed before any linguistic information was obtained from it.

Both lines of critique of the strict seriality assumption are not without problems, however. Current estimates of the minimum time necessary for word recognition (Sereno, Rayner, & Posner, 1998) and saccade reprogramming (Deubel et al., 2000) have been obtained in paradigms that do not correspond to a dynamic reading situation. Moreover, the estimated duration of the word recognition process is much shorter in more recent SAS models than in older models. Parafoveal-on-fovea effects, which appear to provide more direct evidence against the strict seriality assumption, have not always been consistent across experiments, and they were difficult to replicate in some cases (see Rayner et al., 2003, for a discussion). Given this state of affairs, specification of the time course of parafoveal processing during fluent reading is perhaps the most critical empirical issue in the discussion of current models of eye movement control in reading.

Studies with eye-movement-contingent control of parafoveal word previews sought to determine the time course of parafoveal information use by manipulating the temporal interval during which useful information was available in the parafovea (Morris, Rayner, & Pollatsek, 1990; Morrison, 1984; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner & Pollatsek, 1981). In these experiments, sentence reading was impeded when the onset of useful parafoveal information was delayed by as little as 50 ms relative to the onset of a fixation, a finding that on the surface seems to contradict SAS models and also appears difficult to reconcile with gradient models. For example, in one condition of Morris et al.'s (1990) study, a fixated word and all words to its left were visible throughout each fixation but each letter of all parafoveally visible words to the right of fixation was replaced with a length-matched string of lowercase *x*s for 50 ms to 250 ms after fixation onset, and the full line was visible during the remainder of the fixation (the full line was shown throughout a fixation in a control condition). Under these conditions, masking of the parafoveal word with a homogeneous string of letters decreased reading rate even at the shortest masking duration.

In defense of SAS models, it could be argued that the experimental manipulation by Morris et al. (1990) hampered more than the extraction of parafoveally available linguistic information. A homogeneous string of *x*s is perceptually salient, and its replacement with an appropriate word during a fixation involves a visually distinct change in the configuration of the preview that occurred in a consistent and predictable manner during each word viewing throughout sentence reading. These factors could have conspired to force a shift of attention to a parafoveally available useful word preview whenever it became available. Similar concerns apply to all other studies that manipulated the temporal availability of parafoveal information. Consequently, acquisition of useful linguistic information from the parafovea may generally be confined to the ending period of a fixation in the absence of a salient configurational change in the parafovea, as maintained by SAS models. To test the sequential linguistic word-processing assumption of SAS models, we examined the time course of parafoveal information use under conditions in which the configurational and visuospatial properties of a parafoveal target preview and of the target itself were relatively similar. As such, the present study provides

the first direct assessment of the time course of linguistic information extraction from a parafoveally visible word prior to its fixation in the absence of confounding configurational changes.

Experiment 1

Experiment 1 consisted of two related investigations. Similar to the study by Morris et al. (1990), Experiment 1B manipulated the temporal availability of parafoveal word previews by delaying the onset of a target word relative to the onset of a fixation on the preceding word. Experiment 1B differed from the earlier study (Morris et al., 1990) in several significant aspects, however, so that experimental effects could be attributed neither to a disruption of configurational processing nor to the premature attraction of attention to the parafoveal preview. Instead of masking the preview of each word of a sentence with a length-matched string of homogeneous letters, we manipulated the preview of just one (target) word during sentence reading by masking it with a visuospatially and linguistically nondistinct pseudoword for some duration after the onset of the first fixation on the pretarget word. Critically, high configurational similarity between the uninformative target preview and the target was achieved by using text written entirely in alternating case, so that the uninformative preview shared a prominent configurational characteristic, alternating case, with the actual target. To distract the reader from a change in the content of a parafoveal target preview during a fixation, all changes at the target location were implemented under the cover of a concurrent display change at the fixated pretarget location.

In the control condition, onset of the first fixation on the pretarget word was accompanied by the onset of the visibility of the parafoveal target word. In the experimental conditions, onset of the first fixation on the pretarget word was accompanied by the presentation of an uninformative sequence of letters at the target location that formed an orthographically legal pseudoword. Uninformative pseudoword previews were shown for a controlled duration, 70 ms to 350 ms, after which the preview was replaced with the target. To distract readers from the change in the content of the parafoveal target preview, onset of the parafoveal target was accompanied by the reversal of the alternating case of the fixated pretarget word, where each uppercase letter was switched to lowercase, and vice versa.

Although the use of alternating case text provided important methodological benefits, it also had the potential of incurring significant costs. Studies of isolated word recognition and reading have shown that it is more difficult to identify words written in alternating case than words written in lowercase (Besner & Johnston, 1989; Coltheart & Freeman, 1974; Heller & Radach, 1999; Herdman, Chenecki, & Norris, 1999). Nevertheless, other findings also suggest that parafoveal preview effects obtained with alternating case text may generalize to normal reading. In McConkie and Zola's (1979) study, there was no disruption of eye movements during sentence reading when a different alternating-case format was shown during successive fixations, and Rayner, McConkie, and Zola (1980) obtained full parafoveal preview benefits in a naming task when the case of a parafoveally visible letter string was changed during an eye movement to its location. To further increase the familiarity of alternating case text, participants in our study were asked to practice reading text in this format prior to the experiment. A supplemental inquiry, Experiment 1A, showed that this attempt was successful.

Experiment 1A: Practice Reading Alternating-Case Text

In Experiment 1A we determined the effect of practice on the reading of alternating text. We expected that, initially, reading of text written in alternating case would be more difficult than the reading of the same text written in lowercase. Practice should level the difference, however, so that visual word recognition may no longer be a function of case type.

Method

Participants: Ten undergraduate students at the State University of New York at Binghamton participated for course credit in the experiment. All were naïve about the purpose of the experiment.

Material: The material consisted of an essay describing the discovery and the symptoms of aphasia, taken from an undergraduate-level scholarly book. It contained a total of 1,820 words of a wide range of lengths and word frequencies and with various syntactic and lexical properties. For the experiment, the passage was partitioned into 48 four-line segments, half of which were written in lowercase and half of which were written in alternating case. Case type changed across successive segments, so that a segment written in lowercase was followed by a segment written in alternating case, and vice versa. Two lists were constructed to counterbalance case-type order, that is, a segment written in one type of letter case on one list was written in the other type of letter case on the other list.

Apparatus: All sentences were displayed in black on a gray background on a 21-in. Liyama Vision Master 510 monitor with 0.28-mm dot pitch and a 1028×768 resolution at a screen refresh rate of 160 Hz. All text was shown in a Courier-type font, so that each character occupied the same horizontal area of text, with a maximum of 12 horizontal pixels per character. The distance between readers' eyes and the monitor was set at approximately 85 cm, but head movements were not restrained and the distance was somewhat variable. At a typical distance of 85 cm, each letter of text subtended approximately 0.44° of visual angle laterally.

Eye movements and head position were recorded via an SR Research Eyelink (Mississauga, Ontario, Canada) video-based tracking system. Viewing was binocular but eye movements were recorded from the right eye only. A video camera was used for pupil recording at 250 Hz. The camera was positioned underneath the monitored eye and was held in place by head-mounted gear. A separate camera sampled head position at the same rate. The system achieved a relative spatial resolution of a few minutes of arc, and its output was linear over the vertical and horizontal ranges of the display. Continuously monitored fixation locations, sampled every 4 ms, were used offline to compute different measures of pretarget word and target processing.

Procedure: The experiment started with a two-dimensional calibration of the eye-tracking system, which was initiated by the reader by pressing the space bar on the keyboard. This was followed by the sequential presentation of nine fixation markers for 1 s each, three of which occupied horizontal locations near the left, center, and right side near the top, middle, and bottom areas of the monitor. The order in which fixation markers were presented at these spatial locations was randomized. A calibration was considered successful when all of the fixations were within 0.5° of visual angle of their respective fixation marker. Successful calibration was followed by the presentation of a fixation marker, consisting of a plus sign that was shown at the left side of the screen. A second pressing of the space bar replaced the fixation marker with a four-line segment of text that remained visible until the trial was terminated by another space bar pressing. This self-paced text presentation procedure was used throughout the experiment. To maintain a high degree of tracking accuracy, the system was recalibrated after every other four-line segment was read. A multiple-choice test that probed passage content was administered after passage reading. All participants answered at least 8 of the 10 questions correctly.

Data selection, measurement, and design: The data of 1 participant were excluded because of excessive drift during passage reading. The recorded sequence of fixations could thus not be mapped onto corresponding word locations. Five of the remaining readers showed a relatively high rate of rereading for the first and last line of most segments, perhaps because

these lines were related to unavailable (prior and following) text. To remove potential effects of segment integration, data from Lines 1 and 4 were excluded from analyses. Included in the analysis were all words with four letters or more, yielding a total of 4,273 eligible words. Two orthogonal factors were entered in all analyses of variance (ANOVAs): case type (alternating vs. lowercase) and practice (low vs. high). Practice was considered low when the beginning 24 segments were read and high when the following 24 segments were read.

Measures: As in other studies on continuous reading, we used gaze duration as the primary word-processing measure (for a discussion of oculomotor measures, see Inhoff & Radach, 1998; Inhoff & Weger, 2003; Rayner, 1998). Gaze duration consisted of the time spent viewing a word until the eyes moved to another word. It thus included the time spent refixating a word when it was fixated more than once and the time spent moving the eyes from one intraword location to another. Supplementary oculomotor measures of pretarget and target processing that are typically reported in the literature were also computed. These included skipping rate, the size of the saccade that was used to reach a word when it was fixated, the duration of the first fixation on a word (FFD), and the word's total viewing duration (TVD), which included the time spent rereading a particular word after another word had been fixated.

Results—Table 1 shows the effects of practice on the reading of alternating case and lowercase segments. Gaze durations and first fixation durations showed that practice decreased the time spent reading text written in alternating case but not the time spent reading text written in lowercase. The corresponding interaction was reliable for gaze durations, $F(1, 8) = 5.80$, $p < .05$, and marginally reliable for first fixation durations, $F(1, 8) = 4.30$, $p < .08$. Effects of practice and case type were absent in the TVDs (all $F_s < 1$). The time spent rereading words that was included in this particular measure obscured case-type effects that were present when the word was initially encountered.

Saccade size and skipping rates were influenced by case type but not by practice, with saccades being larger and skipping being more common for lowercase text, $F(1, 8) = 10.42$, $p < .01$, and $F(1, 8) = 37.83$, $p < .01$, respectively.

Discussion—Practice significantly decreased the time spent viewing words written in alternating case during first pass reading. With practice, gaze durations and first fixation durations for words written in alternating case and in lowercase became virtually identical, indicating that alternating case no longer impeded visual word recognition. Practice did not influence saccade size and word skipping. This does not compromise the use of alternating text to study the time course of linguistic information acquisition, however, because the targeting of the eyes to a parafoveally visible word is primarily determined by its visuospatial configuration (Rayner, 1998).

Experiment 1B: The Onset of Linguistic Information Extraction in the Parafovea

Method

Participants: Thirty-six students at the State University of New York at Binghamton participated in the experiment for course credit or payment. None of the students were familiar with the purpose of the experiment and all had normal or corrected-to-normal vision.

Materials: Sixty-six sentences were constructed, each containing two manipulated words: a pretarget word and a subsequent target word. Each sentence was written in alternating case, for example,

I lIkE tO dRiNk My mOrNiNg CoFfEe at HoMe RaThEr ThAn in ThE oFFlCe.

To increase the likelihood that readers obtained useful information from a parafoveally visible target preview, each pretarget to target pair was related, for example, *MoRnInG* and *cOfFeE* (see also Inhoff, Radach, Starr, & Greenberg, 2000). This was confirmed by ratings of 16 independent participants who determined (on a scale of 1 [low] to 7 [high]) the degree of semantic relatedness of each word pair (*morning-coffee*). Stimuli were eliminated if the overall mean relatedness rating for the two words was lower than 4. Pretarget and target words had mean word frequencies of 43 ($SD = 58$) and 66 ($SD = 120$) words per million, respectively (CELEX, Version 2.5 of the English corpus, 1995). These means were not significantly different ($p > .09$). The length of the pretarget word ranged from 3 to 9 letters, with a mean of 5.82 ($SD = 1.37$); parafoveal target lengths ranged from 3 to 9 letters, with a mean of 5.32 ($SD = 1.47$). Each word pair was embedded in a sentence that did not contain any punctuation or any lexical or syntactic ambiguities so that it was relatively easy to comprehend. Each sentence occupied a single line of print, and the manipulated critical word pair never occupied the first or last two positions in a sentence.

Six viewing conditions were created for each word pair of the experimental sentences. In the control condition (Delay 0, or D0), both words were continuously visible during sentence reading, although their case pattern was reversed when the eyes traversed the blank space that preceded the pretarget word. The target location was occupied by an uninformative case- and length-matched pseudoword at the onset of sentence reading in the five experimental conditions. In the sample sentence, the pseudoword *VaTtId* initially occupied the location of *CoFfEe*. This uninformative pseudoword was replaced with the target after delays of either 70 ms (D70), 140 ms (D140), 210 ms (D210), 280 ms (D280), or 350 ms (D350) after the onset of pretarget viewing. The replacement of the pseudoword with the target was accompanied by a case change for each letter position of the pretarget and target word, for example, *mOrNiNg* changed to *MoRnInG* when *VaTtId* changed to *cOfFeE*. An example of the viewing conditions is shown in Figure 1.

Apparatus and viewing conditions: The same apparatus was used as in Experiment 1A. A boundary technique (Rayner, 1975) was used to initiate eye-movement-contingent display changes when the measured visual axis of the right eye crossed the blank space preceding the pretarget word. When this occurred, the system either waited 0 ms, 70 ms, 140 ms, 210 ms, 280 ms, or 350 ms (in the D0 to D350 conditions, respectively) before display changes at the pretarget and target locations were executed. This involved a case change at the currently fixated pretarget location after the interval had elapsed, where one alternating case format was replaced with another, and a change at the target location, where a parafoveally visible uninformative pseudoword was replaced with the target (also involving a case change). The display change occurred during the first fixation on the target, provided its duration exceeded the delay period. It occurred on a subsequent pretarget fixation when the delay period exceeded the duration of the first fixations.³ Implementation of display changes required approximately 13 to 16 ms, which involved data transfer, signal averaging, and waiting for the next monitor refresh cycle. All viewing conditions thus involved a pretarget and target word change, which occurred typically during the saccade to the pretarget word (or roughly with the onset of the pretarget fixation) in the D0 control condition and after specified delays in the five other delay conditions. The display changes were latched to the first crossing of the change boundary, and no additional changes were applied when the pretarget word was reread at a later point in time.

³No parafoveal display change was initiated when the gaze duration on the pretarget word was shorter than the delay period. In these cases the changes occurred during subsequent target viewing. All trials in which this occurred were excluded from subsequent analyses, and the 280-ms and 350-ms conditions were not analyzed to the paucity of trials in which the display change occurred during target viewing.

Procedure: Participants were tested individually. Each experiment started with the reading of the practice passage printed on sheets of paper. The practice passage was identical to the passage used in Experiment 1A, except that text was not broken up into four-line segments and that all words were now written in alternating case. This took 10–15 min on average to complete. As in Experiment 1A, passage reading was followed by a multiple-choice test, and participants had to answer at least 8 of the 10 questions correctly to participate in the experiment.

A one-dimensional, horizontal calibration of the eye-tracking system began the experiment. During this calibration, the reader was asked to fixate a sequence of four fixation markers as they appeared in random order for 1 s at the right, left, and center locations of the screen (the left-side location corresponded to the position of the first letter of a sentence). The initial calibration was followed by a validation routine that determined the stability and accuracy of the calibration. To encourage reading for meaning, participants were asked to report the previously read sentence on approximately every 10th trial. All readers were able to report sentence content upon questioning with an accuracy rate greater than 95%. The reading of 10 practice sentences preceded the experiment. After the experiment was completed, we asked each participant whether any visual display changes had been noticed. All reported the presence of changes, but participants generally attributed display changes to the fixated pretarget word.

Design: Six lists were created, all of which contained an identical sequence of sentences. The lists differed in that the relevant two-word sequence shown in one condition was presented in a different condition on another list. Each list contained 11 items in each of the six conditions, and condition order was randomized within each list. The assignment of list to participants was counterbalanced.

Measures, selection criteria, and data analyses: The same dependent measures were used as in Experiment 1A. In addition, we examined cases in which pretarget and target words received a single fixation to determine whether intraword refixations determined the effect pattern. ANOVAs were applied to the data, with error terms for participants and items (F1 and F2, respectively). Differences between specific delay conditions were examined with supplementary *t* tests. To avoid an overly redundant reporting of statistical effects, we report detailed analyses for gaze durations only. Analyses of other measures are reported only when their effect patterns differed from those of the gaze data.

All trials were considered for the computation of pretarget and target skipping rates. A number of criteria had to be fulfilled, however, before a trial was included in the viewing duration and saccade analyses. Because SAS models seek to explain the processing of consecutive words, only those trials were considered in which pretarget and target words were fixated in sequence. In addition, the saccade to each word and the saccade leaving it had to be right-directed so that the reading of this sentence segment was strictly unidirectional. This resulted in the initial exclusion of approximately 20% of the trials. Reichle et al. (1998) used a similar movement sequence criterion for the selection of sentence data that were used for the testing of computational implementations of the E-Z Reader model, which resulted in the exclusion of approximately 40% of the trials.

We also determined the proportion of trials in which the experimental manipulation of the target preview could not be fully implemented during word viewing because the eyes left the word before the parafoveal target became visible. This occurred on 0%, 3%, 3%, 19%, 55%, and 61% of the trials in the D0 to D350 conditions, respectively. Target delay was thus confounded with the successful implementation of the experimental manipulation, the likelihood of which decreased as the delay of the parafoveal target presentation increased. To remove this confound, we excluded all cases in which the display change could not be

implemented during pretarget viewing. Because this resulted in the exclusion of the vast majority of trials from the D280 and D350 conditions, data from these two conditions were not subjected to statistical analyses. To equate all remaining conditions for the duration of the shortest eligible pretarget viewing duration, which was 210 ms in the D210 condition, we adopted a lower level cutoff of 210 ms for all analyzed conditions. This resulted in the exclusion of approximately 40% of the total number of trials in the D0 to D210 conditions. Data from eligible trials were then used to determine two critical events: first, the earliest point in time at which the effect of the pretarget word's case change started to subside and, second, the earliest point in time at which the delay of useful orthographic information at the parafoveal target location hampered subsequent target reading.

Results—Figure 2 shows gaze durations on the pretarget and target for the D0 to D210 conditions.

Pretarget reading: The effect of the pretarget's case change on gaze duration followed an inverted v-shape function. Gaze duration was roughly 300 ms in the control condition, then increased substantially, by 59 ms, in the D70 condition, and then gradually decreased, first by 18 ms in the D140 condition and then by another 21 ms in the D210 condition. Statistically, this was expressed in a main effect of delay, $F(3, 105) = 7.20$ and $F(3, 183)^4 = 10.27$, both $ps < .01$, and by significant differences between the control condition and the D70 and the D140 conditions: $t(35) = 4.66$ and $t(61) = 5.18$, and $t(35) = 2.78$ and $t(61) = 4.62$, respectively, all $ps < .01$. The 18-ms drop-off between the D70 and the D140 conditions was not reliable, $t(35) = 1.33$ and $t(61) = 0.48$, both $ps > .2$, but the total drop-off, the difference between the D70 to the D210 conditions, was highly reliable, $t(35) = 2.72$ and $t(61) = 3.41$, both $ps < .01$.

First fixation durations, single fixation durations, and TVDs on the pretarget word, shown in Table 2, also followed an inverted v-shape function, with relatively long durations in the D70 condition. The skipping rate of the pretarget word was approximately 10% in all four conditions, $F(3, 105) < 1$ and $F(3, 183) = 1.48$, $p > .2$, and mean saccade size was approximately 6.9 letter spaces, $F(3, 105) = 1.12$ and $F(3, 183) = 1.30$, both $ps > .2$. The pretarget's case change was not expected to have a systematic influence on skipping rate or saccade size, as the experimental manipulation was implemented after the execution of the saccade that moved the eyes onto or across the pretarget boundary word was initiated.

Target reading: With one exception, target gaze durations increased with the prior delay of the target preview, $F(3, 105) = 15.67$ and $F(3, 183) = 23.30$, both $ps < .01$. The exception was virtually identical gaze durations in the D0 and D70 conditions, $t(35) = 0.17$ and $t(61) = 0.37$, both $ps > .5$. The increase was approximately linear for all further delays of the target preview. Paired comparisons, with the D0 condition as baseline, revealed significant differences with the D140 and D210 conditions: $t(35) = 3.02$ and $t(61) = 5.27$, and $t(35) = 5.48$ and $t(61) = 5.86$, respectively, all $ps < .01$.

Single fixation durations, also shown in Table 2, matched the pattern of gaze durations. First fixation durations and total viewing duration showed a small cost of the target delay in the D70 condition that was not reliable in either measure: $t(35) = 1.15$ and $t(61) = 1.32$, both $ps > .19$, and $t(35) = 0.92$, $p > .3$ and $t(61) = 1.89$, $p < .07$, respectively. Skipping, which occurred on approximately 9% of the eligible trials, was not systematically influenced by the experimental manipulation, $F(3, 105) = 1.01$, $p > .3$ and $F(3, 183) = 1.62$, $p > .18$. Saccades were slightly larger in the D0 condition than in the other conditions, but the effect was not

⁴Four of the items were removed from the analyses because the display change boundary was not accurately set.

robust over participants, $F(3, 105) = 1.45, p > .3$, and was only marginally reliable over items, $F(2, 183) = 2.76, p < .06$. Because word length and other configurational cues are the primary sources of information for saccade programming during reading (see Rayner, 1998, for a review), the presence of relatively minor target delay effects on target skipping and saccade size that were not statistically reliable suggests that pseudoword previews did not disrupt the visual and configurational processing of a parafoveal target preview.

Discussion—Experiment 1B revealed virtually identical target viewing durations when the preview of the target was available at the onset of the pretarget word's fixation and when useful linguistic information was delayed for 70 ms. Further delays in the availability of useful linguistic information yielded near linear increases in subsequent target viewing duration. In the absence of distinct configurational changes in the parafovea, extraction of effective linguistic information from a parafoveal target word thus does not begin with the onset of a fixation but begins 70 ms to 140 ms after that.

This finding is not in agreement with processing conceptions in which there is concurrent onset of foveal and parafoveal information extraction. SAS models, such as recent versions of the E-Z Reader model, by contrast, appear to offer a viable account. Specifically, acquisition of useful linguistic information from the parafovea could be delayed because linguistic processing was confined to the pretarget during the beginning 70 ms of its fixation. Recognition of the pretarget word and a shift of attention to the parafoveal target may have occurred shortly after that, so that further increases in the delay of useful linguistic information in the parafovea corresponded to instances in which attention was shifted to the parafoveal target location before the target was shown. In these cases, processing costs were incurred when the target was subsequently fixated. The complementary pattern of case-change effects on pretarget viewing, with the largest effect in the D70 condition and progressively smaller effects at longer delay conditions, also fits this account of the data. Attention appeared to be allocated to the pretarget word during the beginning 70 ms of a fixation, accounting for relatively large case-change effects for this condition, and the likelihood of a shift of attention to the parafoveal target during a fixation increased after that, accounting for the decline of case-change effects in these conditions.

Even though SAS models provide a cohesive account of the effect pattern, processing gradient models remain a viable alternative. This is because the delay in the acquisition of useful linguistic information from the parafoveal target does not imply that processing of the parafoveal target word occurred during the final period of interword saccade programming (the interval in between the completion of the pretarget word's L2 processing and the arrival of the eyes on the target), as must be assumed by SAS models. Acquisition of useful linguistic information from the parafoveal target preview could have commenced 70 ms to 140 ms after the onset of the pretarget word's fixation irrespective of when the pretarget word was recognized.

Furthermore, the temporal pattern of case-change effects during pretarget viewing may not be related to the allocation of visual attention to that word. Instead, some case changes may have delayed the execution of a modifiable saccade (Reingold & Stampe, 2000, 2003) that was still in its early (labile) stage in the D70 condition and progressively less so in the D140 and D210 conditions. That is, in the shortest delay condition, the D70 condition, the case change may have occurred while saccade programming was generally in a labile stage, before a point of no return was passed. Consequently, there was a general inhibition of saccade execution. As the delay duration increased, the proportion of saccades that reached the nonlabile stage increased. These saccades were already committed to move to the target word, thus yielding progressively smaller pretarget case-change effects.

The distributions of the pretarget word's gaze duration in the D0 to D210 conditions corroborate this account of pretarget effects. As can be seen in Figure 3, relative to the D0 condition, a case change in the D70 condition shifted the full distribution toward longer durations. The distribution of pretarget gazes in the D140 condition was bimodal. The frequency of short gazes up to 224 ms was virtually equivalent to the frequency of short gazes in the D0 condition, indicating that these saccades were committed to execution before the case change occurred. All longer gazes deviated substantially from the control condition, however, as the case change could influence the execution of these saccades. The distribution of gaze durations in the D210 condition yielded yet another pattern, one quite similar to the distribution of gazes in the control condition, as the case change in the D210 condition generally occurred after the saccade leaving the pretarget word was committed to action.

This account of case-change effects on pretarget viewing implies that the trade off between pretarget and target effects does not necessarily reflect a shift of linguistic information extraction from the pretarget word to the target. Readers could have obtained linguistic information from a parafoveally visible target preview shortly after the onset of pretarget viewing while the linguistic processing of the pretarget word was still in progress.

Experiment 2

In Experiment 2, we pursued the same general goal as in Experiment 1B, that is, the testing of the strictly serial word recognition assumption of SAS models, but we used a slightly different procedure. First, the procedure differed from that of Experiment 1B in that the case of the pretarget word was no longer changed during its fixation. Saccadic inhibition effects should thus have been avoided. That is, the pretarget case-change effects could no longer be carried over into target viewing, as may have occurred in Experiment 1 when a pretarget case change occurred in the D140 and D210 conditions after the saccade to the target word had been committed to action. Second, Experiment 2 differed from Experiment 1B in that it subjected the predictions of the SAS models to more stringent testing. Instead of determining when the uptake of useful linguistic information would begin in the parafovea, we tested whether the uptake of this information is confined to the time interval immediately prior to the execution of a saccade to a previewed parafoveal target, as maintained by SAS models.

For this experiment, we created a beginning-of-fixation preview condition in which a useful parafoveal target preview was available during the beginning 140 ms of the pretarget word's fixation but not after that, and a complementary end-of-fixation preview condition in which a useful parafoveal target preview was available 140 ms after the onset of the pretarget word's fixation but not before that. According to all SAS models, the benefit from a target's end-of-fixation visibility should be larger than the benefit from its beginning-of-fixation visibility. This is because only end-of-fixation previews are much more likely than beginning-of-fixation previews to reveal the parafoveal target during the effective parafoveal information extraction interval, that is, the period in between the completion of the pretarget word's L2 processing and the completion of the oculomotor task that moves the eyes onto the parafoveal target. In fact, the benefit of an end-of-fixation preview should approximate the benefit of a full target preview when the pretarget word's viewing duration is relatively long, as the end-of-fixation interval should now be as large or larger than the duration of the hypothesized parafoveal information extraction interval.

To ascertain the consequences of a target change 140 ms after the onset of the first pretarget fixation, we used two types of full preview and full mask conditions, one involving a case change of the informative or uninformative preview 140 ms after the onset of the first pretarget fixation and one in which the parafoveal preview remained unchanged throughout pretarget

viewing. Our working hypothesis was that the magnitude of the parafoveal preview effect should not be influenced by the occurrence of a parafoveal case change.

Method

Participants—Thirty-six undergraduate students at the State University of New York at Binghamton participated for experimental course credit or pay. All were naïve about the purpose of the experiment and none had participated in Experiments 1A or 1B.

Stimuli and procedure—The same stimuli were used as in Experiment 1B, and the experimental task involved the same sentence-reading procedure. Again, participants first read the practice essay (written in alternating case) and answered multiple-choice questions probing essay content prior to the experiment.

Viewing conditions and data selection—As in Experiment 1B, the parafoveal preview of a target word was manipulated during pretarget word viewing. In contrast to the earlier experiment, this was not accompanied by a pretarget case change. Six target preview conditions were created. In the beginning-of-fixation visibility condition, the parafoveal target was visible prior to the onset of the pretarget word's fixation and for 140 ms after that. After this interval, the target preview was replaced with an uninformative pseudoword. In a complementary end-of-fixation visibility condition, the parafoveal preview of the target consisted of an uninformative pseudoword during the beginning 140 ms of pretarget word viewing. The target was shown after that—until the eyes moved off of the pretarget word.

Four additional conditions provided baselines for the measurement of preview benefits and for the specification of parafoveal case-change effects. In Conditions 3 and 4, referred to as the *full preview change condition* and the *full mask change condition*, respectively, the target was either continuously visible during the viewing of the pretarget word or continuously masked. As in the beginning-of-fixation and end-of-fixation visibility conditions, the letter case of the preview was changed 140 ms after the onset of the first pretarget fixation. In Conditions 5 and 6, the *full preview constant condition* and the *full mask constant condition*, respectively, the target preview was also either continuously visible or fully masked, but no case change was applied to the preview during pretarget viewing. The four parafoveal case-change conditions are depicted in Figure 4.

Identical selection criteria were applied to the viewing duration (and saccade size) data as in Experiment 1B. Only those instances were included in which the experimental manipulation could be applied during pretarget viewing. This resulted in the exclusion of all trials with pretarget gaze durations of 140 ms or less, which occurred on approximately 7% of the trials. As in Experiment 1B, eligibility for viewing duration analyses required that the pretarget word and the target were read in sequence and that the saccade to the pretarget word and the saccade leaving the target were in harmony with word order. Together, the different selection criteria led to the exclusion of approximately one third of the trials.

Design and statistical analyses—The distributions of the pretarget word's gaze duration in the six conditions were examined to determine the extent to which the target's change during pretarget viewing influenced the ensuing oculomotor activity. As can be seen in Figure 5, the two conditions without a parafoveal case change (the full preview constant and full mask constant conditions) showed typical unimodal frequency distributions, with a peak for the 225–299-ms interval. This distinct peak was absent in the four remaining conditions, in which the letter case of the target preview was changed 140 ms after the onset of the first pretarget fixation. Although the case change did influence pretarget viewing in the four case-change conditions, it did so to similar degrees. Consequently, 2×2 ANOVAs, with the variables target beginning-

of-fixation visibility (present vs. absent) and target end-of-fixation visibility (present vs. absent), were applied to analyze these data.

Supplementary analyses examined the influence of a parafoveal case change (constant vs. changed) on the magnitude of the parafoveal preview benefit (full preview vs. full mask). Because the distributions of pretarget gazes differed in the two no-change and change conditions, we sought to minimize potential pretarget-to-target spillover effects by using only those target trials in which prior pretarget gazes exceeded 300 ms. As can be seen in Figure 5, the distributions of pretarget gaze durations were quite similar for the two no-change and the two change conditions in this subset of trials. In the following section, we first report the consequences of a parafoveal case change on preview benefits. We then follow with a detailed report of the effects of the temporal availability of the parafoveal target on pretarget and target reading.

Results

The effect of the parafoveal case change on preview benefits—Target gazes for trials in which pretarget gazes exceeded 300 ms are shown in Table 3 as a function of prior target visibility (full preview vs. full mask) and target case change (no change vs. change).

The exclusion of trials in which pretarget gazes were shorter than 300 ms meant that not all readers were included in the statistical analysis. The 28 readers who contributed gaze-duration data to each one of the experimental conditions revealed a large and highly reliable preview benefit of 90 ms, $F(1, 27) = 30.65$, $p < .01$. Large benefits emerged in all other viewing-duration analyses as well. The effect of the case change was negligible ($F < 1$). More important, the results indicate that a parafoveal case change did not disrupt the use of parafoveally available linguistic information.

Pretarget reading as a function of the temporal availability of the target in the four preview change conditions—The effects of beginning- and end-of-fixation visibility of the target on pretarget viewing are shown in Figure 6 and Table 4. Pretarget gazes were 27 ms shorter when the end-of-fixation preview of the target was informative, $F(1, 35) = 7.26$, and $F(1, 61) = 6.73$, both $ps < .01$. The parafoveal preview of the target during the beginning 140 ms had no effect (F and $F_2 < 1$). A corresponding effect pattern was present in first fixation durations, single fixation durations, and total viewing durations (see Table 4). Pretarget skipping and saccade size did not reveal any effect (all $ps > .10$), presumably because the completion of the corresponding oculomotor control decisions preceded the implementation of the experimental manipulation.

Target reading—Target gaze durations as a function of prior preview type are shown in Figure 7. Beginning- and end-of-fixation preview effectively decreased target gaze durations: $F(1, 35) = 14.80$ and $F(1, 61) = 17.17$, and $F(1, 35) = 25.99$ and $F(1, 61) = 21.81$, respectively, all $ps < .01$. There was a tendency toward an interaction, with relatively short gazes in the full preview change condition, that is, when beginning- and end-of-fixation visibility of the target were provided. The corresponding interaction was marginally reliable over items, $F(1, 35) = 2.06$, $p < .18$ and $F(1, 61) = 3.96$, $p < .06$. As can be seen in Table 4, first fixation durations, single fixation durations, and TVD yielded an analogous effect pattern.

The theoretically important difference between the beginning- and end-of-fixation visibility conditions was examined by separate paired comparisons. Although these comparisons revealed numerically shorter target gazes in the end-of-fixation visibility condition, this advantage was not reliable in any of the first pass target viewing measures. Specifically, the advantage was 15 ms for the primary measure, gaze duration, $t(35) = 1.63$, $p > .11$ and $t(61) = 0.68$, $p > .3$; 12 ms for first fixation duration, $t(35) = 1.25$, $p > .2$ and $t(61) = 1.53$, $p > .$

10; and 21 ms for single fixation duration, $t_1(35) = 1.90, p = .07$ and $t_2(61) = 0.95, p > .3$. TVD, which included the time spent rereading the target, showed a somewhat larger effect of 27 ms, $t_1(35) = 2.69, p < .025$ and $t_2(61) = 0.60, p > .5$, that was robust across participants but not across items.

The target's skipping rate and the saccade to it were influenced by beginning-of-fixation visibility, with slightly more (3%) skipping and slightly larger (0.3 letter spaces) saccades in that condition, $F_1(1, 35) = 6.48, p < .025$ and $F_2(1, 61) = 2.80, p < .10$, and $F_1(1, 35) = 6.45$ and $F_2(1, 61) = 11.77$, both $ps < .01$, respectively. End-of-fixation visibility had no reliable effect (all $ps > .25$).

These results reveal robust effects of beginning-of-fixation previews on target viewing durations and on eye movements leaving the pretarget word. End-of-fixation previews also benefited subsequent target reading but they did not influence eye movements.

Discussion

As in Experiment 1, readers effectively obtained linguistic information from a parafoveal target preview within less than 140 ms of the onset of pretarget viewing. Moreover, the visibility of the parafoveal target at the beginning of pretarget viewing, but not during the ending period of pretarget viewing, had a relatively small but reliable influence on the size of the ensuing saccade to the target. In the absence of distinct configurational changes during a fixation, these two findings once more indicate that parafoveally available linguistic information was acquired relatively early in a fixation.

Independent of this, visibility of the target 140 ms after the onset of pretarget viewing also yielded a robust preview benefit during subsequent target viewing. As predicted by SAS models, the benefit of such an end-of-fixation target preview was numerically larger than the benefit of a beginning-of-fixation target preview. The difference between the two conditions was not robust, however, and the numeric disadvantage of beginning-of-fixation previews could have been due to the interjection of irrelevant information in between the availability of useful linguistic information in the parafovea and the target's subsequent fixation. End-of-fixation previews, by contrast, provided an uninterrupted transition from the parafoveal target preview to its subsequent fixation.

Because all SAS models postulate that linguistic information is acquired from a parafoveal target relatively late in a fixation, there is only one way by which they can accommodate the effective use of beginning-of-fixation previews and roughly similar preview benefits from beginning- and end-of-fixation previews. These models must assume that recognition of the pretarget word and the ensuing attention shift to the parafoveal target are completed within less than 140 ms of the onset of the first pretarget fixation on a large proportion of the trials, so that attention can be focused on the parafoveal target within less than 140 ms of the onset of pretarget viewing. As noted in the introduction, early visual processing and the linguistic processing of a word in Stages L1 and L2 can be sufficiently short to allow for a relatively large proportion of short-duration word identifications.

This account of parafoveal information use in the beginning-of-fixation visibility conditions yields two testable predictions. Beginning-of-fixation target visibility should provide reliable benefits primarily when the duration of pretarget viewing is short, as the shift of attention from the pretarget word to the parafoveal target should occur relatively quickly after fixation onset on these trials. Conversely, end-of-fixation visibility should yield a relatively large preview benefit when the pretarget word's viewing duration is relatively long. As noted earlier, preview benefits in these cases should now be roughly equivalent to preview benefits in the full-preview change condition.

Because the distributions of pretarget word gazes in all four case-change conditions tended to be bimodal, pretarget word gazes were considered short when they were members of the first subdistribution and long when they were members of the second subdistribution. This included 512 trials with short pretarget gazes ranging from 140 ms to 300 ms, and 1,033 trials with longer pretarget gazes. To test the first prediction, that beginning-of-fixation visibility should yield reliable preview benefits only when pretarget viewing is relatively short, the beginning-of-fixation visibility condition was contrasted with the full mask change condition as a function of the pretarget word's gaze duration (short vs. long). The partitioning of the eligible data yielded some cases in which at least one condition cell was left without data, but 31 out of 36 participants contributed full sets of condition means. There was also considerable variability in the available data, undermining the statistical power of this analysis, so that the main effect of the beginning-of-fixation preview was no longer robust, $F(1, 30) = 1.59, p > .2$. Nevertheless, examination of the numeric size of preview benefits showed that effects in the beginning-of-fixation visibility condition were not distinctly larger when pretarget gazes were short (preview benefit = 14 ms) than when they were long (preview benefit = 11 ms).

The test of the second prediction, that the benefit of end-of-fixation visibility should be roughly equivalent to the benefit of full target change condition when pretarget gaze durations are relatively long, was based on data from 34 participants. In violation of the serial attention shift assumption, this supplementary analysis revealed significantly shorter target gazes in the full preview change condition than in the end-of-fixation change condition, $F(1, 33) = 9.70, p < .01$. It is critical to note that the advantage of the full preview change condition was not influenced by the duration of pretarget gazes, as can be seen in Figure 8. The corresponding statistical interaction of the effects of pretarget gaze duration and of target preview (full preview change vs. end-of-fixation preview) was negligible ($F < 1$).

Although it is difficult to determine the precise point in time at which attention should have been shifted from the pretarget word to the target according to SAS models, these models must predict that the shift of attention from the pretarget word to the parafoveal target and the subsequent acquisition of useful information from a parafoveal target are related to the pretarget word's viewing duration, which was not the case in both supplementary analyses.

General Discussion

The current study tested the strictly serial word recognition assumption of SAS models by examining the time line of linguistic information acquisition from a parafoveally visible target-word preview. The results of Experiments 1B showed that extraction of linguistic information from a parafoveally visible word begins 70 ms to 140 ms after the onset of the pretarget fixation. Experiment 2 replicated this finding, again showing that linguistic information is obtained from a parafoveal target preview during the beginning 140 ms of pretarget viewing and that effective linguistic information is also obtained after that.

The presence of a sizable delay of more than 70 ms in the acquisition of linguistic information from a parafoveally visible word in Experiment 1B differs from the results of previous experiments, according to which useful information is obtained from a parafoveal preview within less than 50 ms of fixation onset (e.g., Morris et al., 1990). One could argue that this discrepancy occurred because extraction of linguistic information from a parafoveal target preview was unusually slow in Experiments 1B and 2, perhaps because alternating case lacked the familiarity of lowercase previews. We explicitly tested this possibility in Experiment 1A. The results showed that text written in alternating case was initially more difficult to read than lowercase text. Practice, as provided in Experiments 1B and 2, increased the fluency of alternating-case text reading, however, indicating that word recognition was not noticeably impeded in these experiments.

A more viable alternative account for the earlier usage of parafoveal word-level information in previous experiments is that previews offered multiple sources of effective information. Specifically, these multiple sources appear to have conveyed useful linguistic information and effective configurational cues, and it may have been the use of parafoveally available configurational cues rather than of specific linguistic information that occurred within 50 ms of fixation onset. As noted before, uninformative previews were visuospatially distinct in earlier studies. In Morris et al. (1990), the replacement of a parafoveally visible sequence of *xs* with a length-matched word 50 ms after fixation onset consistently decreased saccade size relative to a 0-ms delay baseline condition. The effect of the 50-ms parafoveal preview delay on fixation durations was less clearcut, however. The delay increased fixation duration relative to the baseline in Experiment 2 of Morris et al.'s study but not in Experiment 1. Because parafoveal word length and other configurational cues have large effects on saccade programming, we take this particular effect pattern to mean that it was configurational information, rather than linguistic information, that was reliably extracted from the parafovea within 50 ms of fixation onset in that study (see Inhoff, Radach, Eiter, & Juhasz, 2003, for a detailed account of spatial vs. linguistic parafoveal information processing).

Was the acquisition of useful linguistic information from a parafoveally visible target preview delayed because the lexical processing of the fixated pretarget word had to be completed before attention was shifted to the adjoining target, as follows from the strict seriality assumption of SAS models? Other accounts appear equally plausible. There is a direct link between foveal cones (at the retina) and higher level neurons in the lateral geniculate nucleus and the visual cortex. Visual detail, critical for successful word identification, can thus be rapidly extracted. In contrast to this, activity is summed over receptors that are outside the fovea before the signal is conveyed to higher level neurons. Although summation of receptor activity improves the sensitivity to light, and probably to configurational information, it decreases visual acuity and thus hampers the acquisition of visual detail. Some delay in the use of linguistic information from the parafovea is thus expected on purely anatomical grounds (see Schiepers, 1980, for a similar view).

It is also possible that acquisition of useful linguistic information from the parafovea requires the prior shifting of attention to it and that this explains why no useful information was extracted from the preview within the beginning 70 ms of a fixation. However, even if acquisition of useful linguistic information from a parafoveal target preview required the allocation of attention to it, it is not clear that such a shift of attention was delayed relative to the onset of a fixation. Estimates of the minimal time needed for an attention shift from one location to another are in the vicinity of 50 ms (Posner, 1980; Treisman & Gelade, 1980; Wolfe, 1998), although there are other persuasive views that propose that it may take considerably longer than that (see Egeth & Yantis, 1997; Horowitz, Holcombe, Wolfe, Arsenio, & DiMase, 2004; Theeuwes, Godijn, & Pratt, 2004; Ward, 2001). For example, Horowitz et al. (2004) suggest that "attentional saccades" between objects may take as much as 300 ms. If the shifting of attention to the parafovea is not instantaneous but takes a measurable amount of time during reading, the delay in the uptake of linguistic information from a parafoveal target preview in Experiment 1 is consistent with the view that the transition of attention from the pretarget word to the target was underway at the very onset of the first pretarget fixation.

The strict seriality assumption of SAS models is also difficult to reconcile with key results of Experiment 2. End-of-fixation previews were not significantly more effective than beginning-of-fixation previews, as should be the case if the attention shift to the parafoveal word occurred relatively late during pretarget viewing. Supplementary analyses revealed that the viewing duration of a pretarget fixation did not influence linguistic information extraction from a parafoveal target during the beginning 140 ms of pretarget viewing, which should have been the case if completion of pretarget processing controlled the onset of parafoveal information

extraction. Supplementary analyses also showed that extraction of linguistic information from the parafoveal target was less effective in the end-of-fixation condition than the full preview condition even when pretarget viewing durations were relatively long, that is, when the end-of-fixation interval was as large or larger than the hypothesized parafoveal information-extraction interval. Together, these findings imply that extraction of linguistic information from a parafoveal target preview ensued some time after fixation onset and was typically continuous after that. A limited amount of concurrent linguistic processing of fixated and parafoveally visible words is thus typical in skilled reading.

The assumption of temporal overlap in the linguistic processing of spatially adjacent words was also used to explain the results of earlier findings from our laboratory according to which orthographic and configurational properties of a parafoveally visible target preview influenced the time spent viewing the fixated word (Inhoff, Starr, et al., 2000; Inhoff, Radach, et al., 2000; Starr & Inhoff, 2004). In Experiment 2, pretarget gazes were in fact significantly shorter when the end-of-fixation preview was informative. Notably, this occurred only in the end-of-fixation target preview condition but not the beginning-of-fixation preview condition. This particular time course of “counterdirectional” parafoveal-on-fovea effects is also consistent with the view that these effects develop only during the final period of a fixation. The same claim has recently been made by Yang and McConkie (in press). However, as noted before, parafoveal-on-fovea effects are subject to alternative accounts that are consistent with the serial word-processing assumption of SAS models (Rayner et al., 2003).⁵ Consequently, the current evidence for continuous parafoveal information extraction 70 ms to 140 ms after the onset of a fixation—which occurred irrespective of the duration of prior word viewing—assumes critical theoretical importance, in that it favors models that incorporate a gradient conception of consecutive word processing over models that assume that all linguistic processing is confined to one word at a time.

Two models, the SWIFT model (Engbert, Longtin, & Kliegl, 2002; Kliegl & Engbert, 2003; Richter, Engbert, & Kliegl, in press) and the Glenmore model (Reilly & Radach, 2003, in press), are based on the assumption of a gradient of linguistic word-recognition processes. Hence, they are consistent with the view that extraction of linguistic information from a parafoveal word is not confined to the interval that precedes the execution of a saccade to it. Both models successfully account for basic oculomotor phenomena such as word skipping, refixations, and regressions as a function of visual and linguistic variables, and they provide effective computational accounts for parafoveal preview benefits.

As an example, the Glenmore model assumes that during each fixation, visual information is acquired from all letter positions within the perceptual span, which includes the fixated word and the next word in the text. This information is transferred to a linguistic processing module that controls processing on the letter and word levels within an interactive activation framework (Grainger & Jacobs, 1998). The processing dynamics resulting from the pattern of information acquisition therefore typically include a limited amount of concurrent foveal and parafoveal word processing (that codetermine the duration of a fixation). Parafoveal preview benefits emerge as an inherent property of this model architecture, as the activation values of parafoveal words are carried over to the next fixation. In the timeline of processing during a fixation, the peak of orthographic and lexical processing will gradually shift from the currently fixated word

⁵Another comparison of pretarget gazes also revealed the elusive nature of parafoveal-on-fovea effects. One Experiment 2 comparison examined pretarget gazes as a function of the parafoveal target preview (full visibility vs. full mask) for the two preview change conditions and a second comparison examined the influence of the parafoveal target preview on pretarget gazes for the two corresponding preview no-change conditions. The first contrast yielded significantly shorter pretarget gazes when the intact target was previewed (313 ms) than when it was masked (345 ms), $t(35) = 2.85$ and $t(61) = 2.66$, both $ps < .025$, presumably because a linguistically informative target preview was less disruptive to pretarget processing. Yet, comparison of the two preview constant conditions yielded virtually no parafoveal-on-fovea effect: 306 ms and 309 ms for the full preview and full mask conditions, respectively (both $t1$ and $t2 < 0.5$).

to more parafoveal letter positions, reflecting the fact that, on a general level, reading is a serial process. At any given point in time, the bulk of lexical processing will be centered on one particular word, but some degree of parallel processing of neighboring words is part and parcel of the model's dynamics.

The present experiments have provided evidence for the existence of temporal overlap in the processing of consecutive words in reading. Our results are based on a direct examination of the time course of parafoveal processing rather than inferences from more indirect data. We expect our study to stimulate more experimental research into the timeline of processing in continuous reading. A major task of this research will be to specify more precisely the scope and limits of concurrent word processing. If our conclusions gain further empirical support, the question will arise as to whether the temporal overlap between foveal and parafoveal processing can be better accounted for by future versions of SAS models or by alternative models that put more emphasis on parallel aspects of word processing.

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Sample Sentence with mOrNiNg as pre-target word and CoFfEe as target word:
 I lIkE tO dRiNk My mOrNiNg CoFfEe At HoMe RaThEr ThAn In ThE oFflcE.

Sentence visibility at the onset of the pre-target fixation in the D70 condition:
 I lIkE tO dRiNk My mOrNiNg VaTtId At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Sentence visibility 70 ms after the onset of the pre-target fixation in the D70 condition:
 I lIkE tO dRiNk My MoRnInG cOfFeE At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Sentence visibility during target viewing and thereafter:

I lIkE tO dRiNk My MoRnInG cOfFeE At HoMe RaThEr ThAn In ThE oFflcE.

* * * *

Figure 1.

An illustration of the pretarget words and the target's change in the D70 condition (delay = 70 ms) of Experiment 1B.

Figure 2.

Mean gaze durations for pretarget words and targets in the four analyzed delay (D) conditions, D0 to D210, in Experiment 1. Vertical lines depict standard errors of the mean.

Figure 3.

The distribution of pretarget word gaze durations as a function of target delay (D) in Experiment 1.

Full Preview Change Condition during the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg CoFfEe At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Full Preview Change Condition after the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg cOfFeE At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Beginning-of-fixation condition during the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg CoFfEe At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Beginning-of-fixation condition after the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg VaTtId At HoMe RaThEr ThAn In ThE oFflcE.

* * *

End-of-fixation condition during the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg VaTtId At HoMe RaThEr ThAn In ThE oFflcE.

* * *

End-of-fixation condition after the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg CoFfEe At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Full Mask Change Condition during the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg VaTtId At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Full Mask Change Condition after the beginning 140 ms of pre-target viewing:

I lIkE tO dRiNk My mOrNiNg vAtTiD At HoMe RaThEr ThAn In ThE oFflcE.

* * *

Figure 4.

An illustration of the target preview in the four parafoveal change conditions in Experiment 2.

Figure 5.
The distribution of pretarget word gaze durations in the six preview conditions of Experiment 2.

Figure 6.
Pretarget gaze duration as a function of beginning- and end-of-fixation previews.

Figure 7.
Target gaze duration as a function of beginning- and end-of-fixation previews.

Figure 8.
Target gaze duration in the beginning-of-fixation visibility condition and the full preview change condition.

Table 1
The Five Oculomotor Measures of Word Viewing During Essay Reading as a Function of Case Type and Practice

Measure	Low practice				High practice			
	Alternating		Lowercase		Alternating		Lowercase	
	M	SE	M	SE	M	SE	M	SE
FFD	267	7	251	9	260	8	259	8
Gaze	304	18	270	11	286	10	293	8
TVD	340	23	325	22	337	30	327	17
SacTo	9.0	0.6	9.5	0.6	9.0	0.6	9.3	0.6
Skip	29	3	34	3	27	3	31	3

Note. First fixation duration (FFD), gaze duration (Gaze), and total viewing duration (TVD) are reported in milliseconds. The size of the saccade reaching the word (SacTo) is measured in letter units, and skipping rate (Skip) consists of the relative frequency with which the eyes moved over a word without fixating it.

Table 2
Pretarget and Target Reading as a Function of the Delay of the Parafoveal Target Preview

Measure	Target delay											
	D0			D70			D140			D210		
	M	SE		M	SE		M	SE		M	SE	

Note. First fixation duration (FFD), gaze duration (Gaze), single fixation duration (SF), and total viewing duration (TVD) are reported in milliseconds. The size of the saccade reaching the word (SacTo) is measured in letter units, and skipping rate (Skip) consists of the relative frequency with which the eyes moved over a word without fixating it.

Target Reading as a Function of the Parafoveal Visibility of the Target and the Occurrence of a Case Change 140 ms After the Onset of the First Pretarget Fixation

Table 3

Measure	Target constant			Target case change		
	Full preview		Full mask	Full preview		Full mask
	M	SE	M	SE	M	SE
FFD (<i>n</i> = 28)	255	9	342	23	268	12
SF (<i>n</i> = 25)	263	10	338	16	274	15
Gaze (<i>n</i> = 28)	277	13	365	29	288	15
TVD (<i>n</i> = 28)	290	15	397	30	301	17
SacTo (<i>n</i> = 28)	6.4	0.41	6.2	0.26	6.3	0.22
Skip (<i>n</i> = 31)	11	3.2	10	3.5	9	3.6
					9	0.24
					9	3.4

Note. Only those target trials were included in which pretarget gazes exceeded 300 ms. First fixation duration (FFD), single fixation duration (SF), gaze duration (Gaze), and total viewing duration (TVD) are reported in milliseconds. The size of the saccade reaching the word (SacTo) is measured in letter units, and skipping rate (Skip) consists of the relative frequency with which the eyes moved over a word without fixating it.

Table 4
Pretarget and Target Reading as a Function of the Temporal Availability of a Parafoveal Target Preview in the Parafovea

Measure	Beginning-of-fixation visible			Beginning-of-fixation masked				
	End-of-fixation visible (full preview change)		End-of-fixation masked (beginning-of-fixation visible)	End-of-fixation visible		End-of-fixation masked (full mask change)		
	M	SE	M	SE	M	SE		
Pretarget								
FFD	290	10	294	13	277	9	295	12
Gaze	313	11	336	15	312	11	345	15
SF	295	10	306	14	282	10	299	13
Gaze	313	11	334	15	312	11	345	15
TVD	331	11	367	17	349	130	399	21
SacTo	7.1	2.1	7.2	0.21	6.9	0.19	7.3	0.23
Skip	9	1.5	9	2.0	12	1.6	11	1.8
Target word								
FFD	262	7	305	10	293	9	319	8
Gaze	288	13	363	17	347	18	387	21
SF	268	9	318	10	297	10	330	8
TVD	304	14	394	1.9	367	19	402	16
SacTo	6.5	0.21	6.3	0.15	6.1	0.14	6.2	0.16
Skip	11	2.1	12	2.1	8	1.7	10	1.7

Note. First fixation duration (FFD), gaze duration (Gaze), single fixation duration (SF), and total viewing duration (TVD) are reported in milliseconds. The size of the saccade reaching the word (SacTo) is measured in letter units, and skipping rate (Skip) consists of the relative frequency with which the eyes moved over a word without fixating it.