EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY, 2004, *16* (1/2), 104–127

Do frequency characteristics of nonfixated words influence the processing of fixated words during reading?

Jukka Hyönä and Raymond Bertram
University of Turku, Finland

Are readers capable of lexically processing more than one word at a time? In five eye movement experiments, we examined to what extent lexical characteristics of the nonfixated word to the right of fixation influenced readers' eye behaviour on the fixated word. In three experiments, we varied the frequency of the initial constituent of two-noun compounds, while in two experiments the whole-word frequency was manipulated. The results showed that frequency characteristics of the parafoveal word sometimes affected eye behaviour prior to fixating it, but the direction of effects was not consistent and the effects were not replicated across all experiments. Follow-up regression analyses suggested that foveal and parafoveal word length as well as the frequency of the word-initial trigram of the parafoveal word may modulate the parafoveal-on-foveal effects. It is concluded that low-frequency words or lexemes may under certain circumstances serve as a magnet to attract an early eye movement to them. However, further corroborative evidence is clearly needed.

One key issue in eye movement research on reading has been to determine the span of effective vision among competent adult readers. In other words, how much textual information can a reader process during an eye fixation? Adherents of speed reading contend that with adequate practice, readers could acquire semantic information during a single fixation from a whole line of text (or at least from several words). Recent eye movement research has convincingly shown that this estimate is clearly too optimistic. The span of effective vision does not extend more than up to about 20 characters around the fixation and is strongly asymmetric to the right, at least for Indo-European languages like

---

Correspondence should be addressed to J. Hyönä, Dept. of Psychology, University of Turku, FIN-20014 Turku, Finland. Email: hyona@utu.fi

The financial support of Suomen Akatemia (the Academy of Finland) is gratefully acknowledged. We also thank Annu Haapakangas and Tuomo Häikiö for their help in the data analyses. We thank Wayne Murray and two anonymous reviewers for their insightful comments on an earlier version of this article.

http://www.tandf.co.uk/journals/pp/09541446.html DOI:10.1080/09541440340000132

English or Finno-Ugric languages like Finnish (see Rayner, 1998, for a review). The area from which semantic or lexical information may be extracted is clearly smaller than this.

According to the highly influential E-Z Reader model (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, in press), words are typically attended one at a time during reading, and lexical-semantic properties of the following word are not assumed to affect the processing of the fixated word. There is one exception to this. The word to the right of current fixation may sometimes be identified. This most likely happens when that word is short, frequent and highly predictable. As a consequence, the word to the right of fixation is skipped, and the duration of fixation prior to skipping is inflated (Pollatsek, Rayner, & Balota, 1986; but see Radach & Heller, 2000). Recently, Kennedy (1998, 2000; Kennedy, Pynte, & Ducrot, 2002) reported evidence that contradicts the view that words are attended sequentially one at a time. More precisely, Kennedy has provided evidence for what he calls a parafoveal-on-foveal effect: Lexical and orthographic features of the parafoveal (i.e., non-fixated) word influence the eye behaviour on the currently fixated word. This effect suggests that attention may not only incorporate the fixated word but may also spread to the adjacent word. It should be noted, however, that none of the Kennedy studies involved normal reading, but laboratory tasks were used (e.g., readers were asked to decide whether or not two words were synonymous).

Kennedy (1998) demonstrated that fixation time on word N was affected by features of word N+1. He reported an inverted frequency effect: Gaze duration on N was shortened when word N+1 was a low-frequency word (no such effect was observed in Exp. 2 of Kennedy, 2000). He also observed an inverted effect of the length of the parafoveal word. When the parafoveal word was long, the gaze duration on the foveal word was shortened. This effect was replicated in Kennedy's (2000) Experiment 2, but not in Experiment 1. Kennedy interpreted these rather surprising effects to reflect difficulties of parafoveal processing. When a parafoveal word is long or infrequent, its parafoveal processing is made more difficult, which results in the reader spending less time on the foveal word. It is as if a long or infrequent word attracts an early saccade to it. Kennedy et al. (2002) observed a similar result: Less fixation time was spent on short five-letter words, when the parafoveal word was low-frequency and possessed highly constraining (i.e., infrequent) initial letters. When the foveal word was long (i.e., nine letters), the nature of the parafoveal-on-foveal effect was qualitatively different. Now the low-frequency parafoveal words possessing highly constraining initial letters increased the time spent on the foveal word (this was true only, when the parafoveal word was short).

Inhoff, Radach, Stark, and Greenberg (2000a) reported a semantic parafoveal-on-foveal effect in a reading study. They found that when two adjacent words were semantically related, gaze duration on the previous word was shorter than when the two adjacent words were not related. A similar parafoveal-on-foveal effect was observed by Murray (1998). It should be noted that in these two reading studies parafoveal processing difficulty slowed down foveal processing. In other words, the nature of the effect is opposite to what Kennedy typically has observed (with one exception; see also Kennedy, Murray, & Boissiere, 2004). The inconsistency and nonreplicability cast doubt on the generalisability of the parafoveal-on-foveal effects. Recently, Rayner, White, Kambe, Miller, and Liversedge (2003) reviewed the evidence in favour and against the effect and concluded that the wealth of the available evidence speaks against parafoveal-on-foveal lexical-semantic effects, and thus it would be premature ''to accept that there is any strong evidence obtained from a natural reading task to suggest that semantic information is obtained from the parafovea, except in those cases when the parafoveal word is subsequently skipped'' (pp. 229–230). Specifically, among other things, they pointed out four reading studies (Carpenter & Just, 1983; Henderson & Ferreira, 1993; Inhoff, Starr, & Shindler, 2000b; Rayner, Fischer, & Pollatsek, 1998), none of which found evidence in support of a parafoveal-on-foveal effect of frequency.

In the present study, we set out to examine if parafoveal-on-foveal effects may indeed be observed in normal reading. We were particularly interested in whether lexical characteristics of the word to the right of the currently fixated word would influence the processing of the fixated word. Such an observation may be taken as evidence for the view that lexical processing is not only confined to the fixated word but also includes the parafoveal word. Word and constituent frequency were used as a tool to study parafoveal lexical processing. It should be noted that the present study departs from previous studies in that it deals with normal reading, while employing a relatively large database and items that are perfectly matched (the foveal word is identical for each matched pair of parafoveal words).

It is well established that word frequency significantly contributes to the ease with which words are recognised during reading (see Rayner, 1998, for a review). For long, two-noun Finnish compounds (e.g., *joukkuehenki* = team spirit) it has been shown that not only word frequency, but also the frequency of the constituents as separate words (i.e., *joukkue* and *henki*) influence the time it takes to read these words when they are embedded in sentences (Hyönä & Pollatsek, 1998; Pollatsek, Hyönä, & Bertram, 2000). For the present study, we analysed the data from five experiments (previously published or submitted for publication), in which whole-word frequency or constituent frequency of compounds were manipulated. The experimental sentences, in which the target compounds appeared, were constructed so that the sentence frame up to target word was identical for each high- and low-frequency word pair. Thus, any differences in the eye behaviour on word N, the word before the target may be readily ascribed to the frequency difference in the target word pairs.

In the first three experiments reported below, the first-constituent frequency of compounds was manipulated while controlling for whole-word frequency, and in the last two experiments we varied the whole-word frequency while controlling for constituent frequency. Two opposite predictions can be made concerning the direction of possible parafoveal-on-foveal effects of frequency. If we were to replicate Kennedy (1998, 2000), we should find a paradoxical inverted frequency effect: Low-frequency compounds should attract an early saccade to them resulting in shorter processing time for the preceding word. On the other hand, if the effect manifests in a more orthodox manner, as was the case in Inhoff et al. (2000a), in Murray (1998), and in a subset of data of Kennedy et al. (2002), low-frequency target words should produce longer gazes on word N than high-frequency words.

As regards the possibility of finding a parafoveal-on-foveal effect of constituent vs. whole-word frequency, two alternative predictions seem plausible. First, given the acuity limits of foveal vision, it may be hypothesised that it would be more probable to find a parafoveal-on-foveal effect for the constituent frequency than for the whole-word frequency manipulation. On the other hand, exactly an opposite prediction may be made by assuming that it is easier to attend parafoveally to words separated by spaces than to morphological constituents that are visually less salient.

METHOD

Participants

The number of participants was 24, 30, 26, 30, and 24 for Experiments 1 through 5, respectively. All participants were university students recruited from the introductory course of psychology; participants spoke Finnish as their native language.

Apparatus

Eye movements were collected by the EYELINK eyetracker manufactured by SR Research Ltd (Canada). The eyetracker is an infrared video-based tracking system combined with hyperacuity image processing. There are two cameras mounted on a headband (one for each eye) including two infrared LEDs for illuminating each eye. The headband weighs 450 g in total. The cameras sample pupil location and pupil size at the rate of 250 Hz. Registration is monocular and is performed for the selected eye by placing the camera and the two infrared light sources 4–6 cm away from the eye. The spatial accuracy is better than 0.5°. Head position with respect to the computer screen is tracked with the help of a head-tracking camera mounted on the centre of the headband at the level of the forehead. Four LEDs are attached to the corners of the computer screen, which are viewed by the head-tracking camera, once the participant sits directly facing the screen. Possible head motion is detected as movements of the four LEDs and is compensated for online from the eye position records.

The target sentences were presented in Courier one at a time starting from the centre-left on the computer screen. The sentences extended a maximum of three lines of text; the critical word never appeared as the initial and final word of a text line. With a viewing distance of about 65 cm, one character space subtended approximately 0.5° of visual angle. A line of text comprised a maximum of 50 characters.

Materials

In all experiments matched sentence pairs were created for the low- and high-frequency condition. The matched sentence frames were identical up to the word after the manipulated word. Thus, word N was identical between the low- and high-frequency conditions. All experiments were carried out in Finnish. An example sentence pair (from Bertram & Hyönä, 2003) is given below (the manipulated word appears in bold and word N in italics).

Low-frequency condition:
''Muistin samassa, *että* **sivuovi** oli jäänyt lukitsematta.''
''I suddenly remembered that the sidedoor was left unlocked.''

High-frequency condition:
''Muistin samassa, *että* **pesukone** oli vielä tyhjentämättä.''
''I suddenly remembered that the washing machine was still not emptied.''

There were a few sentence pairs, in which word N appeared as the initial word of the sentence; these sentence pairs were excluded from the analyses. Below we present further details about the materials of each experiment. The frequencies were computed on the basis of an unpublished newspaper corpus of 22.7 million words that was accessed by the WordMill software (Laine & Virtanen, 1999).

Experiment 1: First-constituent frequency manipulation. The manipulated targets consisted of two sets of two-noun compounds (12–14 characters long): One set had a frequent initial constituent (average lemma frequency of 551 per million) and the other set had an infrequent initial constituent (average lemma frequency of 9 per million). The constituent frequency refers to the frequency the constituent has as a separate word in Finnish. There were 22 words of each kind. The two sets were equated for length and rated familiarity (for more information, see Exp. 2 of Hyönä & Pollatsek, 1998). The average initial trigram frequency (per thousand occurrences) of low-frequency compounds was 0.70 and that of high-frequency compounds was 1.24. These are absolute values that were computed with the help of the WordMill software (Laine & Virtanen, 1999). The mean length of word N was 6.3 characters for the 22 words included in the analysis; their mean lemma frequency was 3452 per million.

Experiment 2: First-constituent frequency manipulation for short and long compounds. A set of short (7–9 characters) and long (12–15 characters) two-noun compounds were chosen that either had a relatively low- or a high-frequency initial constituent. The average frequency values (per million) were 23 and 25 for low-frequency long and short compounds, respectively; the respective values were 472 and 468 for the high-frequency conditions. There were 19 words in each of the four conditions. The conditions were equated for word frequency, second constituent frequency, average bigram frequency, and length of the first constituent (for further details, see Exp. 1 of Bertram & Hyönä, 2003). The average initial trigram frequencies (per thousand) were 0.95 and 0.96 for the low- and high-frequency long compounds; the respective means for the short compounds were 0.43 and 0.86. The N words in the long and short compound conditions were matched on length (7.0 characters); the average lemma frequency of N was 5780 per million for the long and 4727 per million for the short compound condition.

Experiment 3: First-constituent frequency manipulation for semantically transparent and opaque compounds. A set of 40 semantically transparent and 40 opaque compounds was selected. The words were two-noun compound words (12–15 characters long). For both sets, the frequency of the first constituent was manipulated: One set had a frequent first constituent and the other set had an infrequent first constituent. There were 19 words of each kind both for transparent and opaque words (for more information, see Exp. 1 of Hyönä & Pollatsek, 2003). By definition, a semantically transparent compound is one whose meaning can be directly derived from the constituent meanings by simply ‘‘gluing’’ them together. On the other hand, a compound word is semantically opaque, when its meaning cannot be computed by simply gluing together constituent meanings. In our set of opaque compounds either the meaning of the whole word was opaque (e.g., *kompastuskivi* = stumbling block), or the meaning of the first constituent was opaque (e.g., *verivihollinen* = blood enemy). The average initial trigram frequencies (per thousand) were 0.36 and 0.90 for the low- and high-frequency opaque compounds and 0.85 and 0.67 for the low- and high-frequency transparent compounds, respectively. The mean length of N was 5.5 and 6.8 for the transparent and opaque condition, respectively; the respective mean lemma frequencies were 4434 and 3020.

Experiment 4: Whole-word frequency manipulation for short and long compounds. A set of high- and low-frequency two-noun compounds were selected that were either short (7–9 characters) or long (12–15 characters). The frequency values (per million) for the frequent compounds were 23 and 22 for the long and short compounds, respectively; the respective values for the two low-frequency conditions were 2.4 and 2.3. There were 20 words of each kind in the short compound and 18 in the long compound condition. The words were equated across conditions for first-constituent frequency, second-constituent frequency, average bigram frequency, word length, and length of the first constituent (for further details, see Exp. 2 of Bertram & Hyönä, 2003). The average initial trigram frequencies (per thousand) were 0.69 and 0.74 for the long low- and high-frequency compounds and 0.66 and 0.63 for the short low- and high-frequency compounds, respectively. The mean length of N was 6.0 for the long compound and 5.2 for the short compound condition, respectively; the respective mean lemma frequencies were 6708 and 4833 per million.

Experiment 5: Whole-word frequency manipulation for compound and monomorphemic words. Whole-word frequency was manipulated separately for two-noun long compounds (11–15 characters) and length-matched monomorphemic words. The frequency values (per million) of the two low-frequency word sets were 0.4 and 0.7 for the compounds and monomorphemic words, respectively; the respective means for the high-frequency word sets were 41 and 45. There were 12 words in the compound word set and 13 words in the monomorphemic word set. Most of the monomorphemic words were loan words (e.g., *identiteetti* = identity). The four word sets were matched for word length, average bigram frequency, and beginning and final trigram frequency. Moreover, the two compound word sets were matched on both first constituent length and frequency as well as on second constituent frequency and length (for further details, see Exp. 2 of Pollatsek et al., 2000). The average initial trigram frequencies (per thousand) were 0.63 and 0.70 for the low- and high-frequency compounds and 0.84 and 0.81 for the low- and high-frequency monomorphemic words, respectively. The average length of N was 6.6 characters and that of monomorphemic words was 7.2. The mean lemma frequencies of N were 2335 and 1079 for the compound and monomorphemic word condition, respectively.

Procedure

Prior to the experiment, the eyetracker was calibrated using a 9-point calibration grid that extended over the entire computer screen. Prior to each sentence, the calibration was checked by presenting a fixation point in a centre-left position of the screen; if needed, calibration was automatically corrected, after which a sentence was presented to the right of the fixation point.

Subjects were instructed to read the sentences for comprehension at their own pace. They were further told that periodically they would be asked to paraphrase the last sentence they had read to make sure that they attended to what they read. It was emphasised that the task was to comprehend, not to memorise, the sentences.

RESULTS

We analysed readers' eye fixation patterns of word N as a function of the frequency characteristics of words that appeared immediately to the right of N. The following eye fixation measures were employed: gaze duration, duration of final fixation, probability of refixation, and probability of skipping. Gaze duration is the summed duration of fixations on N prior to fixating the frequency-manipulated word to the right. The final fixation is the fixation made on N immediately before fixating the word to the right. When there is only one fixation on N, gaze duration and the duration of final fixation are equal. In addition to these two fixation time measures we also employed a measure of the probability of refixating N. Kennedy (2000) has shown that refixation rate may be a sensitive measure of parafoveal-on-foveal effects. It may be noted that refixation rate typically correlates quite strongly with gaze duration; when the probability of refixation increases, so does gaze duration. As the final measure we used the probability of skipping N, which is the rate of leaving the N word unfixated. Thus, this measure indexes possible processing done of the manipulated word N+1 when fixating on the N word (provided, of course, that properties of N+1 exert an effect).

We first report the results of three experiments, where the frequency of first constituent (or lexeme) was manipulated, followed by the results of two experiments, where whole-word frequency effects were examined. These analyses are followed by regression analyses computed on the pooled data set of all five experiments. It should be noted that in all experiments the N word was identical between the matched pairs of low- and high-frequency words.

Experiment 1: Effects of first-constituent frequency

The experiment included a set of long compounds with a low-frequency initial constituent and another set of compounds with a high-frequency initial constituent. Pairwise *t*-tests (both by participants and by items) were computed for the N words that appeared adjacent to the target compounds.[1] The data for N are presented in Table 1.

In order to be sure that a frequency manipulation can in principle exert an effect, a necessary requirement is that the parafoveal word exerts an effect when it is foveally inspected. In the present experiment this was clearly the case; gaze duration on low-frequency first constituent compounds was 87 ms longer than that on high-frequency first constituent compounds—a highly significant difference both by participants and by items (for more information, see Exp. 2 of Hyönä & Pollatsek, 1998).

---

[1] Items that were fixated less than 50% of the time and their matched pair word were excluded from the item analyses of gaze duration across all experiments, because their average would be based on too few observations.

TABLE 1
Gaze duration (in ms), duration of final fixation (in ms), probability of skipping, and probability of refixations for the N word, as a function of type of parafoveal compound word in Experiment 1 (standard deviations in parentheses)

Eye movement measure	*High-frequency first constituent*	*Low-frequency first constituent*
Gaze duration	222 (54)	220 (58)
Duration of final fixation	180 (30)	181 (29)
Probability of refixation	.15 (.08)	.14 (.11)
Probability of skipping	.19 (.13)	.22 (.14)

Gaze duration. Gaze duration was practically identical for the N word preceding a compound with a low- or high-frequency first-constituent ($t_{1,2} < 1$).

Duration of final fixation. The duration of final fixation prior to fixating the compound word did not differ between the two compound word types ($t_{1,2} < 1$).

Probability of refixation. The tested difference remained clearly non-significant ($t_{1,2} < 1$).

Probability of skipping. The probability of skipping N was greater in the low-frequency first-constituent compound condition, but the difference proved significant only in the participant analysis, $t_1(23) = 3.45$, $p = .002$; $t_2(21) = 1.46$, $p > .1$.

Experiment 2: Effects of first-constituent frequency for short and long compounds

In the next experiment, we examined first-constituent frequency effects separately for short (7–9 characters) and long (12–15 characters) compounds. It should be noted that there was a significant frequency effect in gaze duration for the compound words themselves, when they were foveally inspected (a 47 ms effect for long and a 20 ms effect for short compounds; the latter effect was significant only in the participant analysis; see Exp. 1 of Bertram & Hyönä, 2003). The data for N appear in Table 2. ANOVAs were computed using frequency of N+1 as a within-participant and a within-item variable and length of N+1 as a within-participant but a between-item variable.

Gaze duration. The main effect of frequency was significant in the participant analysis, $F_1(1, 29) = 5.02$, $p < .05$; $F_2(1, 33) = 1.19$, $p = .28$, and the effect of word length was close to significant in the participant analysis, $F_1(1, 29) =$

TABLE 2
Gaze duration (in ms), duration of final fixation (in ms), probability of skipping, and probability of refixations for the N word, as a function of type of parafoveal compound word in Experiment 2 (standard deviations in parentheses)

	Long compounds				*Short compounds*			
Eye movement measure	*High*		*Low*		*High*		*Low*	
Gaze duration	241	(47)	245	(73)	244	(55)	252	(69)
Duration of final fixation	196	(15)	195	(17)	198	(20)	201	(24)
Probability of refixation	.16	(.17)	.17	(.21)	.20	(.20)	.20	(.21)
Probability of skipping	.22	(.24)	.24	(.26)	.18	(.24)	.18	(.25)

High = high-frequency first constituent; Low = low-frequency first constituent.

3.41, $p < .08$; $F_2 < 1$. Target words preceding compounds with a high-frequency first constituent were gazed upon for less time than those preceding compounds with a low-frequency first constituent. Moreover, targets preceding long compounds were gazed upon for somewhat less time than those preceding short compounds. The Frequency × Length interaction was clearly nonsignificant ($F_{1,2} < 1$).

Duration of final fixation. There was no main effect of frequency ($F_{1,2} < 1$), but the main effect of length proved significant in the participant analysis, $F_1(1, 29) = 5.81$, $p = .02$; $F_2 < 1$. Targets preceding long compounds elicited somewhat shorter final fixations than those preceding short compounds. The Frequency × Length interaction remained nonsignificant ($F_{1,2} < 1$).

Probability of refixation. The main effect of length proved significant in the participant analysis, $F_1(1, 29) = 6.57$, $p < .02$; $F_2 < 1$, indicating that words prior to short compounds elicited somewhat more second fixations than words prior to long compounds. The main effect of frequency and the Frequency × Length interaction remained nonsignificant (for both, $F_{1,2} < 1$).

Probability of skipping. The main effect of frequency was not significant ($F_{1,2} < 1$), but the main effect of word length turned out to be significant in the participant analysis, $F_1(1, 29) = 16.66$, $p < .001$; $F_2 < 1$, indicating that words prior to long compounds elicited slightly more skips than words prior to short compounds. The Frequency × Length interaction was far from significant ($F_{1,2} < 1$).

Experiment 3: Effects of first-constituent frequency for transparent and opaque compounds

In this experiment, first-constituent frequency was manipulated separately for semantically transparent and opaque long compounds. It should be noted that the frequency effect was comparable in size for the transparent and opaque compounds, when they were foveally inspected (a 46 ms effect for transparent and a 47 ms effect for opaque compounds; see Exp. 1 of Hyönä & Pollatsek, 2003). ANOVAs were computed for N treating frequency and transparency of N+1 as within-participant variables, while in the item analyses transparency was a between-item and frequency a within-item variable. The data are presented in Table 3.

Gaze duration. The main effect of frequency proved significant, $F_1(1, 24) = 5.36$, $p = .03$; $F_2(1, 21) = 4.25$, $p = .05$. Gazes on N were shorter when the adjacent compound was low-frequency.

Duration of final fixation. No effect approached significance ($F_{1,2} < 1.1$).

Probability of refixation. The main effect of frequency approached significance in the participant analysis, $F_1(1, 24) = 3.18$, $p = .09$; $F_2(1, 36) = 1.92$, $p = .17$. There was a lower tendency for refixating N when the adjacent compound was low frequency.

Probability of skipping. A reliable frequency effect emerged, $F_1(1, 24) = 9.35$, $p = .005$; $F_2(1, 36) = 7.04$, $p = .01$. The probability of skipping word N was higher when the compound word to the right was low-frequency.

TABLE 3
Gaze duration (in ms), duration of final fixation (in ms), probability of skipping, and probability of refixations for the N word, as a function of type of parafoveal compound word in Experiment 3 (standard deviations in parentheses)

	Transparent compounds		*Opaque compounds*	
Eye movement measure	*High*	*Low*	*High*	*Low*
Gaze duration	214 (53)	208 (47)	234 (47)	221 (45)
Duration of final fixation	183 (33)	183 (32)	188 (28)	185 (28)
Probability of refixation	.12 (.11)	.09 (.10)	.18 (.10)	.16 (.12)
Probability of skipping	.27 (.15)	.32 (.16)	.21 (.14)	.23 (.12)

High = high-frequency first constituent; Low = low-frequency first constituent.

Summary of results for the first-constituent frequency experiments

Across the three experiments there was some evidence for a parafoveal frequency effect due to first-constituent frequency. There were five significant or marginally significant (typically the item analysis did not reach significance) effects; all except one was a negative frequency effect. In two experiments, the data on skipping probability demonstrated an inverted frequency effect; N was skipped more often when the initial constituent of the following compound word was infrequent. An analogous effect was observed once in gaze duration (i.e., gaze was shorter for the low-frequency condition). The reversed effect in gaze duration was accompanied by an analogous, but a statistically marginal effect in the probability of refixating N. Only once a marginal tendency for an orthodox frequency effect (i.e., gaze duration was somewhat longer for the low-frequency condition) was observed. The inverted frequency effects are compatible with the idea that low-frequency constituents attract the eyes toward them (see the Discussion).

In Experiment 2, in which the length of the parafoveal word was also manipulated, the participant analyses showed some indication for a parafoveal-on-foveal effect of length in all four measures. Long parafoveal words increased the probability of skipping N and decreased the probability of refixating N. In addition, they elicited shorter final fixations and gaze durations on N than short parafoveal words. These effects converge on the view that long parafoveal words attract an early saccade towards them. It should be born in mind, however, that only a subset of items was responsible for these effects, as indexed by nonsignificant item analyses.

Experiment 4: Effects of whole-word frequency for short and long compounds

We now move to the examination of whole-word frequency effects. In the experiment presented below, word frequency was separately manipulated for short and long compounds. ANOVAs for N were computed treating frequency and length of N+1 as within-participant variables, while in the item analyses length was a between-item and frequency a within-item variable. It should be noted that there was a reliable frequency effect in gaze duration both for short (a 48 ms effect) and long (a 64 ms effect) compounds, when they were foveally inspected (see Exp. 2 of Bertram & Hyönä, 2003). The eye fixation data for N are presented in Table 4.

Gaze duration. There was no main effect of frequency ($F_{1,2} < 1$), but the effect of length was significant in the participant analysis, $F_1(1, 29) = 23.85$, $p < .001$; $F_2 < 1$, indicating that words preceding the short compounds were gazed

TABLE 4
Gaze duration (in ms), duration of final fixation (in ms), probability of skipping, and probability of refixations for the N word, as a function of type of parafoveal compound word in Experiment 4 (standard deviations in parentheses)

	Long compounds		*Short compounds*	
Eye movement measure	*High*	*Low*	*High*	*Low*
Gaze duration	200 (40)	206 (44)	193 (30)	187 (35)
Duration final fixation	181 (22)	169 (12)	167 (12)	169 (14)
Single fixation duration	188 (27)	177 (21)	169 (13)	171 (17)
Probability of refixation	.07 (.11)	.13 (.17)	.12 (.13)	.10 (.15)
Probability of skipping	.32 (.26)	.30 (.25)	.30 (.22)	.26 (.22)

High = high-frequency compound; Low = low-frequency compound.

upon for somewhat shorter time than words preceding the long compounds. The Frequency × Length interaction was not significant, $F_1(1, 29) = 2.97$, $p > .09$; $F_2(1, 30) = 2.76$, $p > .1$.

Duration of final fixation. There was a main effect of frequency in the item analysis, $F_1(1, 29) = 1.60$, $p = .22$; $F_2(1, 30) = 4.52$, $p < .05$, and the effect of word length was significant in the participant analysis, $F_1(1, 29) = 12.46$, $p < .001$; $F_2(1, 30) = 2.13$, $p = .16$, indicating that the duration of final fixation on N prior to fixating a short compound was somewhat shorter than that prior to fixating a long compound. The Frequency × Length interaction was significant, $F_1(1, 29) = 9.89$, $p < .005$; $F_2(1, 30) = 7.71$, $p < .01$. Subsequent *t*-tests showed a significant effect of frequency for the long compounds, $t_1(29) = 2.86$, $p < .01$; $t_2(26) = 2.62$, $p < .02$, but not for the short ones, $t_1(29) = 1.54$, $p = .14$; $t_2(34) < 1$. The frequency effect for long compounds was an inverted effect with longer final fixation durations for the high-frequency than for the low-frequency condition.

The effects observed in final fixation duration may be confounded by the number of fixations made; when two fixations are made on the word, the second of the two is typically shorter than a single fixation (e.g., Hyönä, 1995; Kliegl, Olson, & Davidson, 1983; Underwood, Clews, & Everatt, 1990). Therefore, a separate analysis was conducted for the single-fixation trials.

Single fixation duration. There was a tendency for a frequency effect in the item analysis, $F_1(1, 29) = 1.19$, $p = .28$; $F_2(1, 30) = 3.51$, $p = .07$, and the effect of word length was significant in the participant analysis, $F_1(1, 29) = 17.71$, $p < .001$; $F_2(1, 30) = 3.64$, $p < .07$, indicating that the duration of final fixation on N prior to fixating a short compound was somewhat shorter than that prior to fixating a long compound. The Frequency × Length interaction was significant,

$F_1(1, 29) = 9.98$, $p < .005$; $F_2(1, 30) = 6.12$, $p < .02$. Subsequent *t*-tests showed a significant effect of frequency for the long compounds, $t_1(29) = 3.52$, $p = .001$; $t_2(26) = 2.23$, $p = .03$, but not for the short ones, $t_1(29) = 1.40$, $p = .17$; $t_2(34) < 1$. The frequency effect for long compounds was an inverted effect with shorter single fixation durations for the low-frequency than for the high-frequency condition.

Probability of refixation. Both the main effect of frequency, $F_1(1, 29) = 1.78$, $p = .19$; $F_2(1, 36) < 1$, and the main effect of length, $F_1(1, 29) = 1.04$, $p = .32$; $F_2 < 1$, remained nonsignificant. On the other hand, the Frequency × Length interaction proved significant, $F_1(1, 29) = 12.13$, $p < .005$; $F_2(1, 36) = 6.69$, $p < .02$. Subsequent *t*-tests revealed a significant frequency effect for long compounds, $t_1(29) = 3.49$, $p < .005$; $t_2(34) = 2.53$, $p = .02$, indicating that the word to the left of a high-frequency compound elicited less refixations than the word to the left of a low-frequency compound. Such a frequency effect was not observed for the short compounds, $t_1(29) = 1.47$, $p =.15$; $t_2 < 1$.

Probability of skipping. Probability of skipping N was not reliably affected by frequency, $F_1(1, 29) = 2.82$, $p > .10$; $F_2(1, 36) = 3.74$, $p > .06$, or by length ($F_{1,2} < 1$) of the adjacent compound, nor did the Frequency × Length interaction prove significant ($F_{1,2} < 1$).

Experiment 5: Effects of whole-word frequency for compound and monomorphemic words

In the final experiment, word frequency was manipulated separately for long compounds and for length- and frequency-matched monomorphemic words. Both word types exerted a reliable frequency effect in gaze duration (a 82 ms effect for compounds and a 34 ms effect for monomorphemic words) when the words were foveally inspected (see Exp. 2 of Pollatsek et al., 2000). ANOVAs for N were computed treating frequency and word type of N+1 as within-participant variables, while in the item analyses word type was a between-item and frequency a within-item variable. The data for N are presented in Table 5.

Gaze duration. No effect approached significance ($F_{1,2} < 1.1$).

Duration of final fixation. The main effect of frequency approached significance $F_1(1, 24) = 3.03$, $p = .09$; $F_2(1, 18) = 3.07$, $p < .10$. The main effect was qualified by a Frequency × Word type interaction that remained marginal in the item analysis, $F_1(1, 24) = 5.35$, $p = .03$; $F_2(1, 18) = 3.11$, $p < .10$. The frequency effect was apparent only for compound words, $t_1(24) = 2.75$, $p < .02$; $t_2(14) = 1.94$, $p = .07$, but not for monomorphemic words ($t_{1,2} < 1$); the final fixation on N was shorter when the adjacent compound word was low-frequency.

TABLE 5
Gaze duration (in ms), duration of final fixation (in ms), probability of skipping, and probability of refixations for the N word, as a function of type of parafoveal word in Experiment 5 (standard deviations in parentheses)

	Compound word		*Monomorphemic word*	
Eye movement measure	*High*	*Low*	*High*	*Low*
Gaze duration	208 (36)	208 (37)	214 (43)	216 (48)
Duration final fixation	182 (25)	172 (23)	188 (30)	189 (28)
Single fixation duration	190 (27)	180 (26)	193 (30)	196 (35)
Probability of refixation	.12 (.12)	.14 (.11)	.12 (.13)	.12 (.14)
Probability of skipping	.25 (.14)	.23 (.11)	.09 (.09)	.08 (.07)

High = high-frequency word; Low = low-frequency word.

To unconfound final fixation duration from fixation frequency, a separate analysis was conducted for the single fixation duration.

Single fixation duration. The main effect of frequency was significant in the item analysis, $F_1(1, 24) = 1.49, p = .23$; $F_2(1, 18) = 5.70, p < .03$. The main effect was qualified by a Frequency × Word type interaction analysis, $F_1(1, 24) = 6.74, p < .02$; $F_2(1, 18) = 5.56, p = .03$. The frequency effect is apparent only for compound words, $t_1(24) = 2.58$, $p < .02$; $t_2(14) = 3.29$, $p < .01$, but not for monomorphemic words ($t_{1,2} < 1$); the final fixation on N was shorter when the adjacent compound word is low-frequency.

Probability of refixation. No effect approached significance ($F_{1,2} < 1.3$).

Probability of skipping. Only the main effect of word type proved significant, $F_1(1, 24) = 96.76, p < .001$; $F_2(1, 23) = 4.14, p = .054$, but the effect is not readily interpretable, because the N words were not matched across the two word types.

Summary of results for the whole-word frequency experiments

In both whole-word frequency experiments, the duration of final fixation demonstrated an inverted parafoveal frequency effect (low-frequency parafoveal words were associated with shorter final fixations on N than high-frequency words). This inverted effect emerged only for long compound words. It was also observed for the single fixation duration, thus confirming that it was not confounded by refixation probability. The inverted frequency effect is compatible with the view that low-frequency words are capable of attracting an early saccade to them. We also observed the refixation probability to be increased when the following word was a long low-frequency compound, compared to the case when the following word was a long high-frequency compound (i.e., the effect is an orthodox frequency effect). This effect may be explained by the magnet view outlined in the Discussion. It should be noted, however, that this effect was not replicated in the other experiment.

Experiment 4, in which length of parafoveal word was also varied, showed some indication for a parafoveal-on-foveal length effect; gaze duration and single fixation duration on N was longer when the parafoveal word was long (it was only significant in the participant analysis). It may be noted that the effect is in the opposite direction to what was observed in Experiment 2, and it is compatible with a view that long words cause a parafoveal processing difficulty.

Follow-up regression analyses

To further examine the admittedly inconsistent pattern of effects, we conducted a set of regression analyses to see what factors might predict the size of the parafoveal-on-foveal effects of frequency. We tried to predict the difference in each dependent measure between the low- and high-frequency condition using the following predictor variables: the length of N, the difference in the initial trigram frequency of N+1 (i.e., high[N+1] – low[N+1]), and the frequency difference in N+1 (i.e., high[N+1] – low[N+1]); for the two last predictors, logarithmic values were used.[2] The Kennedy studies (1998, 2000; Kennedy et al., 2002) suggest that length of N and initial trigram frequency of N+1 are variables that may potentially modulate the parafoveal-on-foveal effects. The frequency difference in N+1 was included to see whether the size of the parafoveal effect may be predicted by the relative magnitude in the manipulated frequency. Separate regression analyses were computed for the constituent frequency (Experiments 1–3) and word frequency experiments (Experiments 4 and 5), and they were computed using the word items as cases.[3]

Constituent frequency experiments (Experiments 1–3)

Separate regression analyses were computed for short and long compounds.

Long compounds. The three-predictor model did not reach significance for any of the dependent variables. For the difference in skipping rate, the model proved statistically marginal, $F(3, 75) = 2.29$, $p = .085$. The regression coeffi-

---

[2] We also considered using frequency of N as a predictor, but as it correlated highly ($r = -.77$) with the length of N it was left out (length of N was a better predictor than frequency of N).

[3] We are aware that in these analyses subject variability is not taken into consideration. Lorch and Myers (1990) point out that, in the analysis based on item means, the estimates of the percentage of variance accounted for by the predictor variables may be inflated, but estimates of the population regression coefficients are unbiased.

cient was only significant ($p = .02$) for length of N; its semipartial correlation was $-.26$. The shorter the word, the more probable it was that there was a positive frequency effect in skipping rate.

Short compounds. Although the number of short compounds was considerably smaller than the number of long compounds, the three-predictor model proved much more successful for short compounds. First, the difference in gaze duration between the low and high frequency condition was reliably predicted by the model, $F(3, 15) = 10.90$, $p < .001$. The regression coefficients proved significant for initial trigram difference ($p = .002$) and constituent frequency difference ($p = .026$) and was marginal for length of N ($p = .063$). The respective semipartial correlations were .53, $-.36$, and .29. Thus, the likelihood of finding a positive frequency effect in gaze duration was increased, the higher the initial trigram frequency was for high-frequency words in comparison to low-frequency words. In other words, a constituent-frequency effect is boosted by initial trigram frequency. Second, there was a greater tendency for observing a negative frequency effect when constituent frequency difference in N+1 increased. Finally, it was more likely to find a positive frequency difference in N+1 for long than short words. The analysis conducted on the difference in refixation probability demonstrated a similar pattern, $F(3, 16) = 4.77$, $p = .015$, except that the regression coefficient for length of N did not reach significance. The semipartial correlations were .49, $-.34$, and .13, for initial trigram difference, frequency difference, and length, respectively. With the other measures, skipping rate and final fixation duration, the model remained nonsignificant.

Word frequency experiments (Experiments 4 and 5)

As with the constituent frequency experiments, the regression analyses were conducted separately for long and short parafoveal words. In all analyses, the regression model remained clearly nonsignificant; this was true even when pooled analyses were computed for short and long words.

Summary of the regression analyses

Our three-predictor model did a considerably better job in predicting the relative size of the parafoveal frequency effect for the experiment, in which constituent frequency of relatively short compounds was manipulated, compared to the experiments with long initial constituents and to experiments where whole-word frequency was manipulated. This may be ascribed to visual acuity: Whole-word and constituent frequency of long compounds are more difficult to pick up from the parafovea than short (typically four letters) constituent morphemes, because words and long constituents extend further to the periphery.

The specific results of the regression analyses for the compounds with short initial constituents may be summarised as follows. First, a negative correlation was established between the relative constituent frequency difference in N+1 and the size of the parafoveal frequency effect, which was seen in gaze duration and refixation probability. Thus, the greater the frequency difference, the more likely it was to find a negative frequency effect. This suggests that a clearly low-frequency parafoveal constituent attracts an early saccade to it thus reducing the fixation time on N. In the Discussion we offer an explanation for this finding based on the idea that properties of the parafoveal word may serve as ''magnets'' to draw the eyes to them.

Second, a positive first-constituent frequency effect was boosted by the low-frequency constituent having an initial trigram that was also of low frequency; this was observed both in gaze duration and refixation probability. The finding suggests that in order to observe a positive parafoveal frequency effect two different properties need to co-occur: The parafoveal lexeme (or word) needs to be short, and it needs to have an infrequent initial trigram.

Third, length of N correlated with the size of the parafoveal frequency effect in gaze duration. It was more probable to find a positive parafoveal frequency effect when the foveal word was long and a negative effect when the foveal word was short. This finding should be coupled with a length effect on skipping probability that was found for long compounds of the constituent frequency experiments. Here the parafoveal effect was reversed: It was more likely to find a positive frequency effect (i.e., word N is skipped more often in the low-frequency condition) with short foveal words. Taken together, these results suggest that for long foveal words the parafoveal effect may be observed while fixating on the word itself, whereas for short words the effect manifests itself while fixating on N. Visual acuity of parafoveal information most likely plays a relevant role here.

DISCUSSION

Table 6 summarises the results of the present study. As is apparent from the table, we did obtain parafoveal-on-foveal effects of frequency in reading, but the nature of effects is not consistent, and they do not replicate across experiments. First, in *skipping rate* we obtained an inverted frequency effect in two constituent frequency experiments, but the effect was not replicated in the experiments, in which word frequency was varied. The inverted effect suggests that N is skipped more often, when N+1 has an infrequent initial constituent. This is in line with a view that a low-frequency lexeme operates as a ''magnet'' that draws the eyes to it. By adopting this view, one may further assume that the magnet would operate more strongly, the lower the frequency is. In the follow-up regression analysis we did find evidence to support this: The relative constituent

TABLE 6
Summary of results of the five experiments

Experiment	*Word type*	*Frequency manipulation*	*Gaze*	*Final fixation*	*Skipping rate*	*Probability of refixation*
1	Long compounds	First constituent	No	No	Slightly negative	No
2	Long and short compounds	First constituent	Slightly positive	No	No	No
3	Long transparent and opaque compounds	First constituent	Negative	No	Negative	Slightly negative
4	Long and short compounds	Whole word	No	Negative (long compounds)	No	Positive (long compounds)
5	Long compounds and monomorphemic words	Whole word	No	Negative (compounds)	No	No

Positive = low-frequency condition greater than high-frequency condition; No = no frequency effect; Negative = high-frequency condition greater than low-frequency condition (in skipping rate this inverted effect takes the shape of the low-frequency condition producing more skips).

frequency difference in N+1 reliably predicted the effect size in gaze duration of N (but only when the parafoveal compound had a short initial constituent).

In *gaze duration*, we once observed a positive (nonsignificant in the item analysis), once a negative, and three times no parafoveal-on-foveal effect of frequency. A positive effect may be taken to suggest that readers allocate attention to lexical features of N+1 while fixating on N by spending longer time fixating N when N+1 comprises an infrequent beginning lexeme. Thus, this result is consistent with the idea that parafoveal processing difficulty slows down foveal processing. In contrast, a negative effect may be interpreted to support a magnet view, according to which an infrequent beginning lexeme would pull the eyes toward it resulting in a shorter gaze duration and a lower probability of refixating N (the latter finding was also borne out in Experiment 3).

Follow-up regression analyses provided some evidence that both length of the parafoveal lexeme as well as length of the foveal word are factors capable of modulating the nature and existence of parafoveal-on-foveal effects of frequency. First, the evidence supporting the magnet view came from trials in which either the parafoveal lexeme or the foveal word was short. When the foveal word was short, it was more probable that low-frequency parafoveal beginning lexemes attracted the eyes to them, thus shortening the gaze duration. On the other hand, when the foveal word was long, it was somewhat more probable to observe a positive frequency effect (i.e., N is gazed upon for longer time and/or refixated more often when there is a low-frequency word or lexeme to the right; see Kennedy et al., 2002, for a similar pattern of results). Finally, length of N also modulated the effect observed in skipping rate for long initial constituents. It was more probable to find an inverted parafoveal frequency effect in skipping (i.e., more skips in the low-frequency condition) when N was short. All these effects may be accounted for by the magnet view by further assuming that the magnetic force varies as a function of visual eccentricity. When the eyes are closer to the magnet (as is the case when N or initial lexeme of N+1 is short), the magnet is capable of pulling the eyes to it, whereas when the eyes are farther away from the magnet (as is the case when N is long), they are only attracted closer to the magnet (i.e., the eyes remain on N thus lengthening the gaze duration on N). Finally, the analyses also suggested that the magnetic force may be stronger for short parafoveal lexemes—a suggestion in line with the idea that magnetic force may vary as a function of eccentricity. It should be noted that the magnetic view bears a lot of similarity to the process monitoring account recently proposed by Kennedy et al. (2002).

In the constituent frequency experiment where also parafoveal word length was manipulated we found some evidence suggesting that long parafoveal words would serve as magnets in attracting the eyes to them. However, this finding was due to only a few items as indexed by nonsignificant item analyses. Moreover, in the corresponding whole-word frequency experiment we obtained an opposite effect; long parafoveal words were associated with longer gaze durations on the foveal word—a finding consistent with the notion of parafoveal processing difficulty. Thus, these data lent no consistent support for the magnet account when it comes to pure word-length effects.

The finding observed in the regression analyses that infrequent initial trigrams (coupled with low-frequency initial lexeme) appearing parafoveally are associated with increased foveal processing also runs counter to the magnet view according to which infrequent trigrams would attract an early saccade towards them. The idea that orthographic saliency is picked up from the parafovea and is subsequently used in guiding the eyes not only emerges in the Kennedy studies (e.g., Kennedy et al., 2002), but it may also be found in Hyönä (1995), Inhoff et al. (2000b), Underwood, Binns, and Walker (2000), and White and Liversedge (2004). Hyönä and White and Liversedge reported evidence demonstrating that word N may be skipped when N+1 hosts an irregular or illegal word-initial letter cluster, while Underwood et al. observed increased fixation times for the foveal word, when the parafoveal word had an infrequent as opposed to a frequent word-initial trigram. A similar finding was reported by Inhoff et al., who found increased fixation times for the foveal word when the parafoveal item was a nonword consisting of quasirandom letters (i.e., orthographically highly infrequent letter sequences). The findings of Underwood et al. and Inhoff et al. are in line with what we obtained in the regression analyses but at odds with a number of other studies and with the prediction that may be derived from the magnet account.

When it comes to the magnet account, we readily admit that the evidence in support of it is at best suggestive, and it should thus only be regarded as a tentative hypothesis clearly in need of more empirical support. It makes a counterintuitive prediction in claiming that parafoveal processing difficulty should lead to shorter processing times for the foveal word. However, this does not necessarily imply that processing would be left uncompleted. What may be left uncompleted during one fixation, will most likely be completed during the next fixation. Moreover, Rayner, Inhoff, Morrison, Slowiaczek, and Bertera (1981) demonstrated in a foveal masking study that as little as 50 ms is needed at the beginning of each fixation in order for reading to proceed at a normal pace. If it were true, the magnet account would challenge all existing models of eye guidance in reading (see, e.g., Engbert, Longtin, & Kliegl, 2002; Inhoff et al., 2000; Reichle et al., in press; Reilly & Radach, 2003). Although most models would be capable of accommodating some parafoveal-on-foveal effects, as far as we can judge, no model would be able to account for the ‘‘magnetic’’ effects discussed above. We readily admit that the challenge is not a particularly serious one, and more converging evidence is needed to make the hypothesis more tenable.

The present study was motivated by the hope that we would be able to clarify the inconsistent pattern of results regarding possible parafoveal-on-foveal effects. Our hopes were not fulfilled. Instead, we fear our results may rather create further confusion than solve previous inconsistencies. Notwithstanding the inconsistencies, it is curious that parafoveal-on-foveal effects do pop up as often as they do in the present and other recent studies. Thus, we want to close by pointing to an apparent need for more empirical studies where parafoveal-on-foveal effects in reading are systematically studied. The present study and those of Kennedy (1998, 2000; Kennedy et al., 2002) suggest that when testing the possibility of two words being lexically attended at once factors such as length of the foveal word, length of the parafoveal word, and initial trigram frequency of the parafoveal word may have a significant impact on the probability of observing an effect. Thus, studies are needed in which one variable is manipulated at a time while controlling for the effects of other variables. It is left for future research to seek additional evidence bearing on our following tentative conclusions: (1) Low-frequency lexical items serve as magnets to attract the eyes either (a) directly to them when the previous word is short and easy to recognise, or (b) closer to them when the fixated word is long; (2) Parafoveal word (or lexeme) frequency may interact with initial trigram frequency in producing parafoveal-on-foveal effects in reading.

REFERENCES

Bertram, R., & Hyönä, J. (2003). The length of a complex word modifies the role of morphological structure: Evidence from reading short and long Finnish compounds. *Journal of Memory and Language*, *48*, 615–634.

Carpenter, P. A., & Just, M. A. (1983). What your eyes do when your mind is reading. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 275–307). New York: Academic Press.

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed processing. *Vision Research*, *42*, 621–636.

Henderson, J. M., & Ferreira, F. (1993). Eye movement control during reading: Fixation measures reflect foveal but not parafoveal processing difficulty. *Canadian Journal of Experimental Psychology*, *47*, 201–221.

Hyönä, J. (1995). Do irregular letter combinations attract readers' attention? Evidence from fixation locations in words. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 142–152.

Hyönä, J., & Pollatsek, A. (1998). Reading Finnish compound words: Eye fixations are affected by component morphemes. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1612–1627.

Hyönä, J., & Pollatsek, A. (2003). The role of semantic transparency in the processing of Finnish compound words. *Manuscript submitted for publication*.

Inhoff, A. W., Radach, R., Starr, M., & Greenberg, S. (2000a). Allocation of visuo-spatial attention and saccade programming during reading. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 221–246). Oxford, UK: Elsevier Science.

Inhoff, A. W., Starr, M., & Shindler, K. L. (2000b). Is the processing of words during eye fixations in reading strictly serial? *Perception and Psychophysics*, *62*, 1474–1484.

Kennedy, A. (1998). The influence of parafoveal words on foveal inspection time: Evidence for a processing trade-off. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 149–179). Oxford, UK: Elsevier Science.

Kennedy, A. (2000). Parafoveal processing in word recognition. *Quarterly Journal of Experimental Psychology*, *53A*, 429–455.

Kennedy, A., Murray, W. S., & Boissiere, C. (2004). Parafoveal pragmatics revisited. *European Journal of Cognitive Psychology*, *16*(1/2), 128–153.

Kennedy, A., Pynte, J., & Ducrot, S. (2002). Parafoveal-on-foveal interactions in word recognition. *Quarterly Journal of Experimental Psychology*, *55A*, 1307–1337.

Kliegl, R., Olson, R. K., & Davidson, B. J. (1983). On problems of unconfounding perceptual and language processes. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 333–343). New York: Academic Press.

Laine, M., & Virtanen, P. (1999). *WordMill lexical search program*. Center for Cognitive Neuroscience, University of Turku, Finland.

Lorch, R. F., Jr., & Myers, J. L. (1990). Regression analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 149–157.

Murray, W. S. (1998). Parafoveal pragmatics. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 181–199). Oxford, UK: Elsevier Science.

Pollatsek, A., Hyönä, J., & Bertram, R. (2000). The role of morphological constituents in reading Finnish compound words. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 820–833.

Pollatsek, A., Rayner, K., & Balota, D. A. (1986). Inferences about eye movement control from the perceptual span in reading. *Perception and Psychophysics*, *40*, 123–130.

Radach, R., & Heller, D. (2000). Relations between spatial and temporal aspects of eye movement control. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 165–191). Oxford, UK: Elsevier Science.

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

Rayner, K., Fischer, M., & Pollatsek, A. (1998). Unspaced text interferes with both word identification and eye movement control. *Vision Research*, *38*, 1129–1144.

Rayner, K., Inhoff, A., Morrison, R., Slowiaczek, M., & Bertera, J. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 167–179.

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). Amsterdam: Elsevier Science.

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

Reichle, E. D., Rayner, K., & Pollatsek, A. (in press). The E-Z Reader model of eye movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences*.

Reilly, R. G., & Radach, R. (2003). Foundations of an interactive activation model of eye movement control in reading. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 429–455). Amsterdam: Elsevier Science.

Underwood, G., Binns, A., & Walker, S. (2000). Attentional demands on the processing of neighbouring words. In A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 247–268). Oxford, UK: Elsevier Science.

Underwood, G., Clews, S., & Everatt, J. (1990). How do readers know where to look next? Local information distributions influence eye fixations. *Quarterly Journal of Experimental Psychology*, *42A*, 39–65.

White, S. J., & Liversedge, S. P. (2004). Orthographic familiarity influences initial eye fixation positions in reading. *European Journal of Cognitive Psychology*, *16*(1/2), 52–78.