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# Parafoveal-on-foveal effects on eye movements in text reading: Does an extra space make a difference?

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**Abstract**

Schiepers [Schiepers (1980). Response latency and accuracy in visual word recognition. *Perception & Psychophysics, 27*, 71–81] proposed that in text reading, the currently fixated word and the next word are processed in parallel but with a time delay of 90 ms per degree of eccentricity. In his model, the benefit of seeing the upcoming word is due to the fact that the parafoveal information from fixation $n$ is combined with the foveal information from fixation $n + 1$ to boost word recognition, at least when the fixation on word $n$ is of an optimal duration (between 210 and 270 ms). We tested this assumption by adding an extra blank space between the foveal and the parafoveal word. According to the model, this should result in a 30 ms longer processing time for the foveal word. However, reading time was shorter for a word followed by a double space than for a word followed by a single space. An effect of parafoveal word length was also observed with a longer word in the parafovea leading to shorter fixation times on the foveal word. Implications of these low-level parafoveal-on-foveal effects are discussed.



*Keywords:* Reading; Parafoveal-on-foveal effects

## 1. Introduction

When people are reading, their eye movements are characterized by a sequence of saccades and fixations. The main purpose of the saccades is to bring new information into the center of the visual field, where visual acuity is highest. However, there is a large body of evidence that, in addition to foveal word processing, information from the word to the right of the fixation is extracted and used in reading as well (see Rayner, 1998; for a review). Two of the most important findings in this respect are the phenomenon of word skipping and the so-called parafoveal preview benefit. About one third of the words in a text are skipped during first-pass reading. This is particularly so for short words and words that lie close to the previous fixation location (i.e., when the saccade is launched from the second half of the word prior to the target word). There is also a smaller influence of the difficulty of the target word (see Brysbaert, Drieghe, & Vitu, 2005; Brysbaert & Vitu, 1998, for a meta-analysis of the data). The parafoveal preview benefit refers to the finding that reading is slower when the letters of the word to the right of the currently fixated word are not visible than when they are visible (e.g. Blanchard, Pollatsek, & Rayner, 1989; Morris, Rayner, & Pollatsek, 1990; Rayner, 1975; Rayner, Well, Pollatsek, & Bertera, 1982). From these findings, it is clear that processing of parafoveal information plays a role in normal reading. There is, however, much more controversy over the question to what extent

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parafoveal information concerning word $n + 1$ influences the fixation duration and gaze duration[2] of the currently fixated word $n$. This latter possibility is referred to as parafoveal-on-foveal effects and several suggestions of such effects have been made.

A first way in which parafoveal processing of word $n + 1$ might influence the gaze duration on word $n$, was proposed by Pollatsek, Rayner, and Balota (1986). They reported that the fixation duration was longer before a saccade that skipped the next word than before a saccade that was targeted at the next word. They interpreted this finding as evidence for the hypothesis that words were skipped as a result of a two-stage process. First, a saccade was programmed to word $n + 1$, but if this word was recognized (or was likely to be recognized) before the saccade was initiated, the program could be cancelled and replaced by a new program for a saccade towards word $n + 2$ (see Reichle, Rayner, & Pollatsek, 2003; for the latest update of this model of eye movement control). The cancellation of the original program and the replacement by a new one were the origin of the longer fixation duration on word $n$. Unfortunately, this finding is a bit controversial with some studies finding the effect and others that do not (e.g., Drieghe, Brysbaert, Desmet, & Debaecke, 2004; but see Drieghe, Rayner, & Pollatsek, submitted). A recent study suggests that longer fixations before a skipping saccade are observed only when long and difficult words are being skipped (Kliegl & Engbert, in press). When short and easy words are skipped, fixation durations actually tend to be shorter than when these words are fixated. Although the latter finding is a problem for most theories of eye movement control in reading, if it can be replicated it still is an example of how processing word $n + 1$ may influence the gaze durations on word $n$.

Another suggestion of how parafoveal word $n + 1$ might affect the gaze duration on word $n$ was made by Kennedy and colleagues (e.g., Kennedy, 1998; Kennedy, Murray, & Boissiere, 2004; Kennedy & Pynte, 2005). Kennedy (1998) reported that the gaze durations on word $n$ were shorter when word $n + 1$ was a low-frequency word and when it was a long word. He interpreted this paradoxical parafoveal-on-foveal effect as evidence for a model of eye movement control (which has been referred to as the process monitoring hypothesis) in which word $n$ and word $n + 1$ are processed in parallel (with some time delay depending on the length of word $n$) and in which the resources are allocated as a function of the difficulty of both words. The harder word $n + 1$ is to process, the stronger it pulls the eyes towards it, in order to optimize the extraction of visual information from the page of text. Again, however, the evidence for this parafoveal-on-foveal effect is not unequivocal, with some studies failing to report an effect of the difficulty of word $n + 1$ on the gaze duration for word $n$ (e.g., White & Liversedge, 2004), and others reporting a lengthening of the gaze duration for difficult parafoveal words (e.g., Hyönä & Bertram, 2004, Experiment 2; see Rayner & Juhasz, 2004; for a critical review of the evidence).

A final suggestion about how processing of word $n + 1$ might affect the reading time of word $n$ was made by Schiepers (1980). Schiepers started from the observation that in a perceptual identification task it takes on average 90 ms longer per degree of eccentricity to identify a word, arguably because it takes that much time for the stimulus to activate the relevant letter and word representations in the brain. Given that one degree of visual angle roughly coincides with three letter positions[3] and that saccades usually are 7–9 letters long, Schiepers hypothesized that if word $n + 1$ was presented in foveal vision 210–270 ms after it had been presented in parafoveal vision, the parafoveal information from fixation $n$ could be merged with the foveal information on fixation $n + 1$. By combining both sources of information, the activation of the word representation could be faster than if it were based on the foveal information alone. This, argued Schiepers, could be the origin of the typical fixation durations of some 250 ms seen in text reading. When fixations are shorter or longer, part of the parafoveal preview benefit is lost, because the synchrony in the arrival of parafoveal and foveal information is less than optimal.

The ideas of Schiepers (1980) were utilized by Schroyens, Vitu, Brysbaert, and d'Ydewalle (1999) to provide a neat explanation of a puzzling finding. In their experiment, Schroyens et al. presented three alphabetic stimuli. The first one was a boundary stimulus, which either was a high-frequency word, a low frequency-word, or a homogeneous string of the letter z. There were two lengths of these boundary stimuli: 3 letters long (e.g., *now*, *tic*, *zzz*) and 5 letters long (e.g., *first*, *vaunt*, *zzzzz*). The second word was the target word and was a high-frequency or a low-frequency word of 7 letters (e.g., *because*, *judaism*). Finally, there was a third word with a length ranging from 4 to 8 letters. The task of the participants was to read the three stimuli and to indicate whether one of the words referred to an article of clothing (e.g., *cap*, *skirt*, *trousers*). The intriguing finding was that participants looked more than 20 ms longer at a *zzzzz* string than at a *zzz* string, even though there was no more information to be obtained from a 5-letter z-string than from a 3-letter z-string. Sch-

[2] The gaze duration is the sum of the fixations from the moment the eyes land on word n to the moment they move off again.

[3] Nowadays we know that in reading the numbers of letters are a more appropriate metric to use than degrees of eccentricity. The number of letters crossed by saccades is relatively stable, independent of the visual angle (Morrison & Rayner, 1981).