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Decision and metrics of refixations in reading isolated words

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Abstract

Eye movements were recorded during the reading of long words presented in isolation. Overall, the decision to refixate was found to depend on both length and frequency of the word, while refixation amplitude depended only on word length. This finding corroborates the assumption that most refixation saccades are preplanned on the basis of the parafoveal word length. However, cancellation of such a plan is possible and could be linked to the lexical processing during the first fixation into the word. Finally, a small proportion of refixations are corrective saccades, related to an oculomotor error. Theoretical implications for models of eye movement control during reading are discussed.

Keywords: Saccade; Eye movement; Refixation; Landing position; Word frequency

1. Introduction

During reading, words often receive more than one fixation. If it is now well known that the probability of refixating increases with word length, word frequency and when first fixations land far from the word center (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; Vitu, O'Regan, & Mittau, 1990), many questions about the mechanisms producing refixations on words are still subject to debate. For instance, when is the decision to refixate a word taken? What is the target for the refixation saccade? How are its metrics computed? With the recent development of computational models of eye movement control during reading, the understanding of what causes refixation has become a new challenge for researchers.

Several explanations of what causes a second saccade on the fixated word have been provided in the literature. Refixation saccades may be due to oculomotor errors, the eyes landing on a nonoptimal position on the word. This is the view of the oculomotor models such as the strategy-tactics model (O'Regan, 1990) which posits that only low-level factors affect the decision and the metrics of refixations. The oculomotor system computes a refixation saccade if the first saccade lands far from the center of the word, the optimal viewing position (O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984; Reilly & O'Regan, 1998). Such a mislocated first fixation generally is of short duration and is followed by a progressive or regressive corrective saccade directed to the other part of the word. In other words, the refixation saccade metrics—direction and amplitude—would be function of the first fixation position. In such a framework, the lexical properties of the word play a minor role. They may influence only the duration of the single fixation or of the second fixation in refixation cases, the first fixation being too short and devoted to the corrective saccade computation.

However, refixation saccades may also be due to cognitive processing difficulty during the first fixation. One argument in favour of the cognitive models relies on data showing that low-frequency words are more often refixated than high-frequency words (Rayner, Sereno, & Raney, 1996; Vitu, 1991). One of the most recent cognitive models is the E–Z Reader model which assumes that word recognition and saccade programming are both the results of two stages (Reichle, Pollatsek, Fisher, & Rayner, 1998). In the latest version of the model, the authors propose that the probability of

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preparing a refixation saccade program depends on the length of the word that is to be fixated (Reichle, Rayner, & Pollatsek, in press). The labile program of refixation is then initiated as soon as the eyes land in the word and as a function of the speed of the first stage of lexical processing, the program can be either cancelled and replaced by a saccade landing on the next word or executed. A frequency effect is expected on refixation probability when there is cancellation or on the first fixation duration in refixation cases when refixations are executed. In its current version, the E–Z Reader model does not provide any information about the metrics of the refixation saccade but simply assumes that the center of the word is the target for all saccades on the word (Reichle, Rayner, & Pollatsek, 1999). However, recent evidence suggests that the internal structure of long words influences where a refixation is directed (Bertram & Hyönä, 2003; Pollatsek, Hyönä, & Bertram, 2000; Pynte, 1996).

Although the oculomotor and cognitive models differ on their explanation of the refixation saccade occurrence, they share several assumptions: in both types of model, the decision to initiate a refixation is taken during the first fixation and the metrics of inter-word and refixation saccades are assumed to be identical (Radach & McConkie, 1998). Recent studies using isolated word or letter-string reading argue for an alternative view in which the refixation saccade may be preplanned before the word is fixated (Beauvillain, Vergilino, & Dukic, 2000; Vergilino & Beauvillain, 2000, 2001; Vergilino-Perez & Beauvillain, in press). In 2001, Vergilino and Beauvillain examined the planning of a sequence of two saccades directed to two short words (a 5-letter word followed by a 4-letter or a 6-letter words) or a single long word (9 or 11 letters). By looking at the relationship between first and second fixation position, the authors demonstrate different coding for inter-word and refixation saccades (Vergilino & Beauvillain, 2001). Whereas the inter-word saccade is found to be directed to a spatial location within the newly selected word, the refixation saccade can be described as a constant motor vector applied irrespective of the initial landing position on the word. Even when eye movement contingent changes were introduced during the first fixation, i.e. disappearance or displacement of the target word by one or two characters during the first saccade directed to it, the refixation fixed-motor vector is still applied without any correction of errors on the initial landing position (Beauvillain et al., 2000; Vergilino & Beauvillain, 2001). A second argument for the refixation saccade preplanning hypothesis comes from an experiment in which the length of a target letter string was changed during the first saccade directed to it or at different times during the first fixation on it (Vergilino & Beauvillain, 2000). Indeed, any influence of the initial length presented only in periphery should support the idea that the refixation saccade was preplanned. The authors found that the refixation saccade was computed on the initial length encoded only in periphery, even if the saccade could be updated on the final length if first fixation was long enough. Such results argue strongly in favour of a preplanning of the refixation saccade at the same time as the initial saccade.

However, the authors also show that the saccadic system is flexible, even if the decision to refixate and the computation of the metrics of the refixation saccade may both be planned before the word is fixated. Notably, whereas an artificial error does not involve a correction of the refixation saccade preprogram, the length change occurring during the first fixation permits a modification of the refixation program if the new information is provided sufficiently early, 150–200 ms before the end of the first fixation (Vergilino & Beauvillain, 2000). On the other hand, the cancellation of the refixation program followed by a planning of a saccade directed to another item requires more than 220 ms (Vergilino-Perez & Beauvillain, in press).

These experiments provide evidence that the planning of the refixation saccade can be modified or cancelled to take into account low-level properties such as word length. The question arises as to whether linguistic variables such as word frequency can influence the metrics of refixation saccades. The goal of the present study is to provide a detailed description of the refixation saccade metrics by manipulating word length and frequency. We examine this question by using a paradigm in which subjects had to read high- and low-frequency words of 8-, 10- and 12-letters. Words were presented in isolation in order to hold constant both the launch site and the foveal processing before landing into the target word. Our data argue in favour of the hypothesis that the decision to refixate and the computation of the metrics of the refixation saccade may both be planned before the word is fixated. We show that refixation saccade amplitude is calculated on the basis of the word length and is not affected by word frequency. However, the decision to execute the refixation saccade program can be cancelled during the first fixation due to lexical processing. Finally, we propose that the preplanning of the refixation includes not only the computation of the refixation saccade amplitude as a function of the word length but also of the initial landing position close to the word beginning.

2. Method

2.1. Participants

Eight 3rd- and 4th-year psychology students at the University of René Descartes Paris 5 participated in the experiment. All were skilled readers, native speakers of