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Parafoveal preview benefit in reading is not cumulative across multiple saccades

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Abstract

Two empirical predictions can be generated from recent parallel processing models of eye movement control in reading concerning the phenomenon of parafoveal preview benefit. These predictions derive from the assumption that lexical activation accumulates across more than one saccade. A large corpus of eye movement data was used to determine whether parafoveal preview benefit of a target word is modulated by (1) its distance from the penultimate fixation, and (2) the amount of time it spends in the 'perceptual span'. There was an unexpected inverse relationship between first fixation duration and distance: fixations were longer the closer the penultimate fixation was to the target word, and a positive relationship between fixation duration and time: fixations were longer the greater the summed durations of the ultimate and penultimate fixations. These findings represent a challenge for computational models of eye movements in reading.

Keywords: Reading; Fixation duration; Preview benefit

1. Introduction

An important, highly robust finding in reading research is *parafoveal preview benefit*: fixation durations are shorter when parafoveal visual information about the currently-fixated word was available on the previous fixation than when it was denied (see Rayner, 1998, for a review), suggesting that some level of preprocessing of the current word (word *n*) occurred when the eyes were fixating word $n-1$. There is also a positive linear relationship between mean fixation duration and the eccentricity of word *n* from the previous fixation position [1]; this Saccade Distance Effect (Radach & Heller, 2000; Vitu, McConkie, Kerr, & O'Regan, 2001) has been explained in terms of decreasing visual acuity from the centre of the fovea outwards: the further away the previous fixation, the more degraded the visual information, and therefore the less preprocessing possible (Vitu et al., 2001).

Two recent computational models of eye movement control in reading (SWIFT: Engbert, Longtin, & Kliegl, 2002; and Glenmore: Reilly & Radach, 2003) account for preview benefit by assuming that the processing of words within the perceptual span occurs in parallel. Both models incorporate the concept of *lexical activity* (or activation) to represent the degree of processing attained. The activity levels of both foveal and parafoveal words are determined by their eccentricity (reflecting visual acuity constraints; activation rises more slowly with increasing eccentricity) and time (activation increases as a function of time in the perceptual span; the longer the fixation, the greater the activity level). In Glenmore,

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[1] In a large-scale correlational analysis of six subjects reading text passages, Rayner and McConkie (1976) found essentially no relationship (Pearson *r*s ranged from −0.041 to 0.108) between progressive saccade amplitude and the duration of the fixation ending the saccade.

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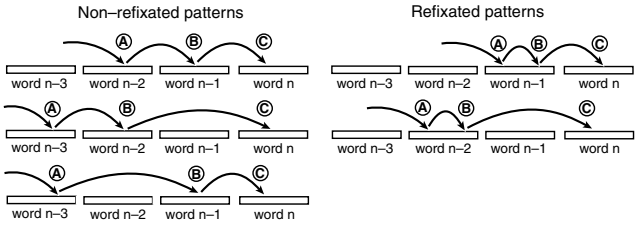

Fig. 1. The five fixation patterns selected for analysis from the Dundee corpus.

activation of a word's representation rises until a saccade is triggered targetting that word; in SWIFT, activation rises until a threshold level is reached after which activation decreases. Generally speaking, for both models variation in processing benefit due to parafoveal preview is attributed to variation in activation levels.

The well-specified mechanisms of these computational models permit specific empirical predictions to be made. Given a sequence of three fixations (A, B and C; see Fig. 1), two predictions can be derived from the assumptions that parafoveal preview benefit is proportional to lexical activation, and that activation levels directly depend on the parallel processing of the words occurring within the perceptual span. First, preview benefit for the word upon which Fixation C falls (the *target* word) should be greater when its distance from Fixation A is short, compared with larger eccentricities (all else being equal). Second, preview benefit for the target word should be modulated by the amount of time the target is located within the perceptual span; thus, the duration of Fixation C should decrease as the summed duration of Fixations A and B increases, but only when Fixation A is close to the target. [2] With respect to the first prediction, there should be an increase in the duration of Fixation C as the distance of the target from Fixation A increases. If preview benefit does not accumulate across successive fixations, then there should be no relationship between eccentricity and Fixation C duration.

Empirical support for the modulation of preview benefit by time is provided by a study by Schroyens, Vitu, Brysbaert, and d'Ydewalle (1999); using a reading-like task, they found that preview benefit effect size increased with the duration of the previous fixation (but see White, Rayner, & Liversedge, in press, for contradictory evidence from a sentence reading study). This paper reports the results of testing the above two predictions using a large eye movement corpus.

An important constraint on the observation of parafoveal preview effects is the size of the perceptual span. Using a eye-contingent display-change technique, McConkie and Rayner (1975) showed that perturbing the text beyond 14–15 characters to the right of the currently fixated character had no reliable influence on reading speed. Thus we can assume that the effective spatial window in which any modulation of preview benefit due to eccentricity could be observed is bounded by the perceptual span size. Note that in studies of eye movements in reading it is appropriate to measure the size of the perceptual span and eccentricity in character spaces; for instance, Morrison and Rayner (1981) demonstrated that mean saccade amplitude was constant over a range of viewing distances when measured in character spaces as opposed to visual angle.

2. Methods

As a source of reading data I utilised the Dundee English corpus (Kennedy, 2003), which consists of the eye movement data collected from 10 readers each reading approximately 50,000 words of newspaper text. Readers' eye movements were recorded using a Dr Bouis Oculometer eyetracking instrument. The position of the right eye was sampled every millisecond. The viewing distance was 500 mm and one character subtended approximately 0.3° of visual angle.

Data matching five common fixation patterns involving three successive forward saccades over two to four words (see Fig. 1) were extracted from the Dundee corpus. Constraints on data selection ensured that there was no intervening punctuation between critical words; the launch word (the word receiving Fixation A) was not the first word on the line of text, Fixation A was at least the second fixation made on the line, the target word (the word receiving Fixation C) was between four and seven letters in length, and the eccentricity of the target from Fixation A was 15 character spaces or less. After selection, 15,116 cases were available for analysis.

3. Results and discussion

Prediction (1), that preview benefit for the target word will be greater the nearer the penultimate fixation, was tested by varying the eccentricity of the target word from the penultimate fixation (Fixation A). If preview benefit is cumulative across saccades, then fixations on the target should be shorter the closer the penultimate fixation, because the target would have a greater chance of being preprocessed. Fig. 2 displays the mean duration of the first fixation on the target word (Fixation C) as a function of the eccentricity of the target from Fixation A (ECC_A), holding the eccentricity of the target from Fixation B small and constant ($ECC_B < 5$ character spaces), for four target word lengths. It was important to control

[2] This interactive prediction is similar to the assumption of the SWIFT model (Engbert et al., 2002) that lexical activity is a multiplicative function of time and eccentricity.