In this commentary, we address three aspects that are relevant for the time line of word processing and eye-movement control in continuous reading: (1) the time it takes to lexically process a word, (2) the reprogramming time needed to alter the amplitude of a saccade, and (3) the question of whether "attention shifts" may also take time to be prepared and executed.

(1) Sereno et al. (1998) found in event related potential (ERP) studies on single-word recognition that N150 responses are sensitive to differences in word frequency. The responses for low and high frequency words start to diverge at about 130 msec, providing an indication for the minimal time required for any substantial lexical analysis. This roughly corresponds with the figure given in the target article "that the mean time needed to identify the word 'the' (the most frequent word in English text) when it is centrally fixated and in a completely predictable context is 148 msec" (sect. 3.1.2, last para.). In this specific case the time for L_2 is assumed to be zero, hence 150 msec is the time needed for L_1 under the most favourable circumstances.

(2) Looking at the other end of the time line, the question arises: How long, minimally, does it take to program or reprogram a saccade to a specific target word? This question can be discussed on the basis of the findings from the so-called double-step paradigm (Becker & Jürgens 1979), which have laid the foundation for the distinction between a labile and a nonlabile stage of saccade preparation (Morrison 1984). In a typical double-step experiment, a fixation target is shown at an eccentric location and, before a saccade can be executed, a second target is presented while the first disappears. Depending on the size and direction of the second target step, two basically different types of responses can be observed (Ottes et al. 1984). In the first, *averaging* mode, there is a continuous transition of the primary saccade amplitude from landing positions near the first target to positions close to the second target. This amplitude transition is a function of the available reprogramming time between the occurrence of the second target and the execution of the primary saccade. Importantly, the critical temporal window for saccade modification closes at 70–90 msec before saccade execution. The second response mode is characterized by *bistable* responses, which can be observed when the distance between the two stimuli is large or the direction of the saccade needs to be changed. In this case, landing positions of primary saccades cluster at both target locations. The succession of progressive saccades in reading appears consistent with the averaging response mode (note that sentences with regressions are removed from the data base E-Z Reader is tested with), suggesting that the absolute minimum time for the nonlabile stage of saccade programming is 70 msec. Alternatively, interpreting the nonfixation of words (skipping) in analogy of a bistable response mode would be consistent with the fixation duration on the origin word being increased (see below). In this response mode, the minimum reprocessing time is assumed to be 120 msec (see Deubel et al. 2000 for further detailed discussion).

Empirically, the question of whether fixation durations before word skipping are inflated is under dispute. It appears that some studies have found this effect and others have not. Critically, Radach and Heller (2000), in addition to reanalysing a sentence reading experiment, examined a very large corpus of reading data. Carefully controlling for factors like the fixation pattern on the origin word and launch site relative to the target word, they found no evidence in favour of such a phenomenon. It may thus appear premature to list the effect in Table 1 of the target article. Reichle et al. have noted with respect to the Glenmore model by Reilly and Radach (2003a) that "it remains an open question as to whether the model can predict the costs that have been observed for skipping" (target article, sect. 4.6). It is true that the phenomenon would not fit well with the mechanics of Glenmore. However, given the present state of affairs, we see no need to account for it in the model and look forward to seeing how the empirical debate on the issue will develop.

(3) We are in sympathy with the addition of a preattentive processing stage to the architecture of E-Z Reader and welcome the clear separation of visual selection for the purpose of saccade generation from selection preceding cognitive (lexical) processing (see Schneider & Deubel 2002 for a recent discussion in a more general context). Specifically, Reichle et al. reserve the term "attention" for "the process of integrating features that allows individual words to be identified" (sect. 3.1.3). In the description of the model, the authors have asserted many times that attention shifts from word to word as a result of completing lexical access. This raises a fundamental question. If the shifting constitutes a *movement* of attention, would this movement itself not need to be programmed, and would its preparation and execution not take a certain amount of time? If the answer to this question is that the shifting is merely equivalent to starting the lexical processing of a new word, then using the term *attention* in this context becomes rather meaningless. If however, the shift is seen as an obligatory stage that constitutes a precondition for the start of linguistic processing, then this process will have a latency and it will need time to be executed. Indeed, this is a major issue in the attention literature. The respective time interval is often referred to as *attentional dwell time,* and usual estimates of its duration are on the order of at least 50 msec (Duncan et al. 1994; Treisman & Gelade 1980).

Together, these considerations imply the following constraints to a tentative time line: Take 130 msec as a conservative estimate for the duration of L_1 on word$_n$ and 70 msec as a conservative estimate for the minimal duration of the non-labile stage of saccade programming. Given a fixation duration of 250 msec, the summed duration of these two stages in a sequential time line leaves a time of only 50 msec for all remaining processes. In the case of skipping word$_{n+1}$ this time would have to include the attention shift to $n+1$, the completion of some lexical processing (L_1) of this word, and the reprogramming of a saccade to word$_{n+2}$. Given the commonly observed phenomenon of skipping words that are relatively difficult to process, it is hard to conceive a scenario such as in Figure 5C of the target article, where word$_{n+2}$ becomes the target of the next saccade after less then 150 msec. Finally, in the case depicted in Figure 5B where word$_{n+2}$ becomes the target of the saccade after less than 100 msec, the question arises how this pattern could have emerged in the computational implementation of E-Z Reader. In any case, it appears incompatible both with the verbal description of the model and the time line constraints discussed above.

E-Z Reader 7 provides a platform for explaining how low- and high-level linguistic processes influence eye movements

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Abstract: E-Z Reader 7 is a processing model of eye-movement control. One constraint imposed on the model is that high-level cognitive processes do not influence eye movements unless normal reading processes are disturbed. I suggest that this constraint is unnecessary, and that the model provides a sensible architecture for explaining how both low- and high-level processes influence eye movements.

Reichle et al. describe E-Z Reader 7 as a processing model of eye-movement control in reading. This reflects the assumption that ongoing cognitive processes influence when and where the eyes are moved. Despite this assumption, Reichle et al. make the strong claim that "higher-order processes intervene in eye-movement control only when 'something is wrong'" (sect. 3.1). The justification for this claim is that the process of integrating semantic and syntactic elements of a text occurs too late in the processing stream to influence decisions about when and where to move the eyes. This claim seems inconsistent with the word identification process within E-Z Reader 7, and, if anything, understates the capabilities of the model. Here I discuss what I believe is a minimized strength of E-Z Reader 7, namely, that the model provides a natural framework for explaining how high-level cognitive processes influence eye-movement control. I begin by addressing the question: What is a high-level process? I then discuss how high-level processes might be explained within E-Z Reader 7.

What constitutes a high-level process is partly an issue of definition. High-level processes may be defined as processing based on information not contained within the lexical representation of a word. This is similar to the description of top-down processes in models of word processing (e.g., McClelland & Rummelhart 1981). Note that E-Z Reader 7 includes predictability as an element of word identification. Processes based on word predictability qualify as high-level processing in the sense that predictability accumulates across words and sentences. Monitoring predictability to enhance word identification appears to be a normal component of reading. I suspect that Reichle et al. would agree given that the predictability is a component of both the L_1 and L_2 stages of word identification in E-Z Reader 7. Based on the above definition, predictability represents an example of high-level information that directly influences eye-movement control during normal reading. Therefore, the conclusion that high-level processes influence eye movements only when "something is wrong" seems inconsistent (and unnecessary) with the structure of the model.

High-level processes may also be defined as based on later-occurring semantic processing, thereby excluding early-occurring visual processing. Determining whether high-level processes occur too late in the processing stream to influence eye movements becomes a critical issue. Although there is evidence for many high-level processes being slow, in the sense that they occur in late stages of word processing or even after a problematic word has been read (e.g., the garden path sentences used by Frazier & Rayner [1982]), there is growing evidence that high-level processes can influence early stages of word identification (Morris 1994; Sereno 1995; Wiley & Rayner 2000). This evidence again calls into question the necessity of the claim that high-level processes do not influence eye movements unless something goes wrong. My purpose here is not to resolve this definition issue but to suggest that Reichle et al. might be constraining their model unnecessarily. An untapped strength of E-Z Reader 7 is that it provides a transparent (i.e., definable) architecture for explaining how high-level processes influence eye movements (at least the decision of when to move the eyes). This contrasts with other models in which the architecture is not always transparent (such as, how hidden layers operate in connectionist models). Thus, my criticism of E-Z Reader 7 is that the architecture of the model is not fully utilized. Below I provide two examples of how the model may be applied.

Including a two-stage word identification system provides a natural architecture for separating the locus of low- and high-level processing influences on eye movements. Recent studies from my own lab support this conclusion. In one study (Raney et al. 2000), I recorded subjects' eye movements while they read a text once and then read either the same text a second time or a paraphrased version of the text. Paraphrases were created by replacing words with synonyms. For identically repeated target words, both first fixation duration and gaze duration were reduced during the second reading. For synonyms, only gaze duration was reduced during the second reading. For synonyms, early-occurring orthographic processing was not facilitated whereas later-occurring semantic processing was facilitated. This makes sense because no orthographic repetition occurs for synonyms, but semantic repetition does occur. In terms of the E-Z Reader model, the results for synonyms reflect no facilitation of the L_1 stage of word identification, but facilitation of the L_2 stage (a reduction in gaze duration, which reflects more later-occurring processes than first fixation duration).

In a similar study (Raney et al. 1996), fluent and nonfluent bilinguals read a text in one language and then reread either the same text or a translation. Embedded in the texts were cognate and noncognate target words. For fluent bilinguals, fixation durations were equivalent for cognates and noncognates during the second reading. For nonfluent bilinguals, fixation durations were shorter for cognates than for noncognates during the second reading. The low-level benefit of repeating the orthographic form (for cognates) interacted with high-level processes associated with comprehension level (fluency). These findings also map onto the model. Specifically, only semantic processes influenced fixation duration for fluent bilinguals (L_2), but both orthographic (L_1) and semantic processes (L_2) influenced fixation duration for nonfluent bilinguals.

To summarize, Reichle et al. describe E-Z Reader 7 as a processing model of eye-movement control. One constraint they impose on the model is that high-level cognitive processes do not influence eye movements unless normal reading processes are disturbed. This constraint makes the model conservative regarding what forms of information are allowed to influence eye movements. My own view is that there is enough evidence that high-level processes influence early and late stages of eye movements, for models of eye-movement control to incorporate these processes. E-Z Reader 7 provides a sensible architecture for explaining how high-level processes influence eye movements. Constraining the impact of high-level processes reduces the explanatory power of the model.

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Methodologies for comparing complex computational models of eye-movement control in reading: Just fitting the data is not enough

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Abstract: As the number of computational models of eye-movement control in reading increases, so too will their coverage and complexity. This will make their comparison and testing increasingly challenging. We argue here that there is a need to develop a methodology for constructing and evaluating such models, and outline aspects of a possible methodology.

In recent years, research on eye movements in reading has made substantial progress. A key new development in the field is the emergence of computational models of eye-movement control during reading. The target article is a timely evaluation of this branch of reading research. The modeling principles and algorithms that different computational models embody reflect the theoretical viewpoints of their authors. In the case of E-Z Reader, sequential lexical processing is proposed as the obligatory trigger for the generation of all eye movements made in normal reading.

In contrast, Reilly and O'Regan (1998), following the theoretical framework developed by O'Regan (1990), demonstrated that a good account for the positioning of fixations in reading can be achieved by using a set of rather simple oculomotor heuristics. We believe that both of these positions have their merits and can account for important aspects of eye behaviour during reading. On the other hand, both approaches also have serious limitations. Therefore, the question of interest is not whether eye movements are determined by visuomotor factors or by linguistic processing,