the following word; second, however, in cases where difficulty is detected in accessing the current word, the saccade may be replaced by a saccade targeted on the same word. The model would then posit two types of refixation, one driven only by low-level factors, the other guided by cognitive constraints.

Regressions and eye movements: Where and when

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Abstract: Reichle et al. argue that the mechanism that determines where to fixate the eyes is controlled mostly by low-level processes. Therefore, unlike other competing models (e.g., the SWIFT model), the E-Z Reader model cannot account for "global" regressions as a result of linguistic difficulties. We argue that the model needs to be extended to account for regressive saccades.

Two basic assumptions of the E-Z Reader model are that the mechanism responsible for *where* to fixate the eyes is controlled mostly by low-level processes, whereas the mechanism responsible for *when* to move the eyes is controlled mostly by cognitive processes. Although the model accounts for fixation durations, refixation/skipping probabilities, and initial landing positions in normal silent reading, it leaves regressive saccades unaccounted for. It is worth noting that a competing model, the SWIFT model (Engbert et al. 2002), can capture both short- (*local*) and long-range (*global*) regressions. Normal silent reading involves not only forward saccades, but also a number of regressions back to the previous word(s) when readers experience some difficulties with linguistic processing (or with oculomotor processes). Bear in mind that regressions represent around 14% of saccades for adults (and around 25% for children; Starr & Rayner 2001). The point we raise here is that, in regressions, the signal of where to send the eye does not seem to be controlled solely by oculomotor variables. Instead, cognitive processes can signal where to fixate the eyes next in order to resolve conflicting information from the text or to finish processing partially encoded information. We present two examples from recent research: one with sentences involving a target word with (or without) higher frequency *neighbors* (the neighborhood frequency effect; "local" regressions) and the other with sentences that include a mild garden path ("global" regressions).

Several eye movement experiments have shown that the number of regressions back to the target word in a sentence increases when the target word has higher frequency neighbors (see Perea & Pollatsek 1998; Pollatsek et al. 1999a). For example, in the sentence "The store didn't sell John's favourite [spice, sauce] any more," readers make more regressions back to the target word *spice* than to the target word *sauce.* (Note that *spice* has *space* or *spite* as higher frequency neighbors; *sauce* does not have any higher frequency neighbors.) Under these conditions, the target word may have been misidentified as the higher frequency candidate (*space* instead of *spice*) or, alternatively, the higher frequency neighbor could have slowed down the final stage of lexical processing (e.g., in an interactive activation system). This actually provokes an increased number of regressions back to the target word for words with higher frequency competitors. In the E-Z Reader model, the signal that word recognition is imminent (*L1* stage) causes the preparation of the saccadic movement on the word$_{n+1}$ before lexical access (*L2* stage) is completed. A regressive saccade may occur when the *L2* stage is long and the reader is still processing the target word. In that case, the target of this saccade is the difficult-to-process word$_n$. Thus, the E-Z Reader model, despite not having a specific mechanism for regressive saccades, can predict the presence of these "local" regressions as a special type of refixation. It is important to note that the SWIFT model (Engbert et al. 2002), which borrows the two word identification stages from the E-Z Reader model, can also capture these local regressions as a result of incomplete lexical processing.

The E-Z Reader model can accommodate short, local regressive saccades as a special type of refixations. But what about global regressive saccades? Are they simply triggered by high-level processes blindly, in the sense that they do not indicate exactly which part of the sentence the eyes should be directed to? This does not seem to be the case. The pattern of regressive eye movements while reading mild garden-path sentences strongly suggests that readers perform an overt selective reanalysis process (see Meseguer et al. 2002). This process seems to direct the regressive saccade to specific points of the sentence in which relevant information can be picked up (see also, Kennedy et al. 2003). In other words, the reader's eye seems to be intelligently led to the critical part of the sentence. In the E-Z Reader model, only one word can be attended to at a time, and the model has no straightforward means to redirect the eye to the relevant area of the information in the sentence. (These regressive saccades are beyond the scope of the current implementation of the model.) One possible way to accommodate these regressions is to assume that readers have access to some form of spatially coded information (Kennedy 2001). Alternatively, in the framework of a "guidance by gradient" model (i.e., more than one word can be attended to at a time) like SWIFT, it is possible to send the eye back to the critical point of the sentence where the reader experienced some linguistic difficulties (global regressions; see Engbert et al. 2002, Fig. 7).

Therefore, one challenge of a sequential attention-shift model like the E-Z Reader is to specify in detail how regressions are made without violating the "when/where" principle. We agree with Reichle et al. that it may be difficult to make precise predictions in parsing experiments. However, inclusion of an explicit mechanism for regressions is not an obstacle. As stated above, the SWIFT model captures the presence of global regressive saccades by assuming that the gradient of attention is not confined to individual words, but rather, to a wider attentional window. We should also note that this issue may be linked to the fact that readers seem to extract information from more than a word at a time (see Inhoff et al. 2000). Whether these are critical limitations for attention-shift models (note that these models can be considered extreme cases of "guidance by gradient" ones) is a matter for future research.

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Attention, saccade programming, and the timing of eye-movement control

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Abstract: E-Z Reader achieves an impressive fit of empirical eye movement data by simulating core processes of reading in a computational approach that includes serial word processing, shifts of attention, and temporal overlap in the programming of saccades. However, when common assumptions for the time requirements of these processes are taken into account, severe constraints on the time line within which these elements can be combined become obvious. We argue that it appears difficult to accommodate these processes within a largely sequential modeling framework such as E-Z Reader.

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