(Osaka et al. 2002). Thus, it is likely that "higher-level" visuospatial attention appears to control optimal eye movement. Phonological store and phonological loop (each assumed to be located in the supramarginal gyrus and inferior frontal gyrus [Broca's area BA44], respectively) are subcomponents of the central executive during sentence reading that could be "interfaced" with the cognitive components of working memory. "Interfacing" refers, in my opinion, to a resource-limited attentional mechanism with executive function (Osaka et al. 2003). Therefore, it is likely that the phonological loop influences eye movements. These data suggest that the eye movement might be influenced both by the writing system and by individual working memory capacity.

Linguistically guided refixations

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Abstract: I discuss evidence for direct linguistic control of refixations and argue that the E-Z Reader model's account of refixations requires elaboration or revision.

What are the proximal causes of consecutive fixations on a word in reading? Four suggestions have been advanced: (1) Refixations may be due to oculomotor error in saccades targeted at another word (e.g., McConkie et al. 1989; Pollatsek & Rayner 1990); (2) Refixations may be guided by low-level, nonlinguistic information such as word length (e.g., O'Regan 1992a; Vergilino & Beauvillain 2000); (3) Refixations may reflect a trade-off between linguistically guided decisions to maintain fixation on the current word and to move the eyes to another word (e.g., Henderson & Ferreira 1990; Pollatsek & Rayner 1990); (4) Refixations may be linguistically guided movements targeting another region of the word (Hyönä & Pollatsek 1998; Pynte 1996). The E-Z Reader model allows for only the first two of these possibilities, although the model can account for some of the evidence of linguistic influence on refixation patterns indirectly. This is because the model supposes that dumb refixation decisions are less likely to win a race against linguistically based decisions to saccade to another word when the currently fixated word is (initially) easy to access.

Other evidence of linguistic influence on refixations is less easily reconciled with the E-Z Reader model. One example is evidence from Finnish that properties of a word's morphemes affect refixation location (Hyönä & Pollatsek 1998). The difficulties posed by this finding have been acknowledged in previous expositions of the model, but Reichle et al. (1999) suggest that a homologous adaptation of the current model, adopting the morpheme rather than the word-form as the fundamental lexical unit, might be capable of accommodating this result – in this case, linguistically guided word-form refixations would be reconstrued as linguistically guided intermorphemic saccades. A similar finding, not mentioned in any exposition of the E-Z Reader model, is Pynte's (1996) demonstration (using polymorphemic French words) that refixations may be preferentially directed to whichever region discriminates the word from similar words of higher frequency.

Incidental findings I obtained in a reading experiment using the boundary technique (Rayner 1975), pose further difficulties for the E-Z Reader model. In the experiment, participants read Dutch sentences for comprehension while their eye movements were monitored. Each sentence contained a monomorphemic target word primed by a parafoveal preview of varying orthographic similarity to the target word: The preview was either a higher frequency orthographic neighbor (HFN) of the target word, overlapping with the target at all letter positions but one (e.g., *spier-spies*), or an unrelated word preview, overlapping at zero letter positions (e.g., *jacht-spies*). To guard against the possibility that preview effects would be attributable to something other than the manipulated variable, the two preview groups were equated in terms of predictability from the preceding context, number of syllables and morphemes, word class, word frequency, summed bigram frequency, neighborhood size, number of higher frequency neighbors, familiarity, age of acquisition, imageability, polysemy, and (because the Dutch orthography is highly transparent) regularity. In addition, launch site distributions and the distributions of landing sites on the target word did not differ as a function of preview type. The primary aim of the experiment was to test predictions derived from the results of previous experiments, concerning the interaction of perceptual and lexical factors in visual word recognition. As expected, clear inhibitory effects of orthographic preview similarity were found in eye-movement measures such as gaze duration and total time on the target word, once well-known perceptual constraints were taken into account. The findings have been reported at a number of conferences (e.g., Pacht et al. 1999) and form the basis of a manuscript in preparation.

For present purposes, the most relevant findings concern the pattern of preview effects on the first fixation of refixated target words (FFR) and on target word refixation rates. Many studies have found that target word processing may benefit from the availability of a parafoveal preview sharing the first two or three of the target word's letters (for a review, see Rayner 1998). Consistent with these findings, I found that FFR was facilitated by the HFN preview, provided that the HFN preview and target word overlapped at the first 2–3 letter positions (255 msec vs. 273 msec, $F1(1,50) = 4.24$, $p < .05$, $F2(1,62) = 4.57$, $p < .05$). The E-Z Reader model accounts for this result (and other findings of preview benefit) by assuming the HFN preview facilitated the initial phase of target word lexical access (*L1*). By the same token, the model predicts planned refixations on the target word should have been canceled more often, given the HFN preview, resulting in fewer refixations in that preview condition. However, this was far from being the case: If anything, there was a tendency for target words to be refixated *more* often, given the HFN preview (16% vs. 14%, $Fs < 1$).

A plausible account of these findings is that the HFN preview initially facilitated target word access, by priming representations or form-neighborhoods shared by the target, but subsequently interfered with target word access by activating (or adding to the activation of) its own higher-frequency lexical representation. The initial facilitation elicited a relatively fast decision to move the eye, while later-emerging lexical competition elicited a decision to fixate the current word, which might be construed as the initial "where" decision, or as a supervening "where" decision to maintain fixation or to refixate. Two implications for models of eye-movement control in reading are that the execution of refixations may *follow* execution of linguistically guided saccades (or at least, "when" decisions), and that refixations may themselves be *proximally* (and not only indirectly) controlled by linguistic variables. Both of these implications are at variance with the assumptions of the E-Z Reader model.

In sum, while some refixations may be planned without reference to linguistic information, others appear amenable to direct linguistic influence. I will close by suggesting one way in which my findings might be reconciled with the E-Z Reader model. If refixations are defined not as consecutive fixations on a word but as consecutive fixations during which the current word is processed, then according to the E-Z Reader model some refixations are indeed proximally controlled by linguistic variables and follow execution of linguistically guided "when" decisions. Specifically, the immediate regressions, which the model assumes arise when an intended interword saccade is executed before the current word is fully accessed, may be viewed as refixations following on the heels of a prior but improperly executed attempt to refixate. That is, in such cases, the "intended interword saccade" is in fact intended as a refixation at the moment the movement is executed. This amounts to a proposal that in its labile phase, the interword saccade destined for $word_{n+1}$ may be modified in two ways. First, as the current model allows, in cases where *L1* is completed on $word_{n+1}$, the saccade may be replaced by a saccade targeted on

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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.