syntactic processing strategies used by listeners and readers would be the same." This assumption has had a profound effect on theories of reading and has played a part in the evolution of models of eye-movement control that assign a significant role to an attentional spotlight, deployed sequentially across "word objects." It is, nonetheless, fallacious. Written text is normally continuously available as a spatially extended object on the page or screen, and, unlike the speech signal, can be inspected at will (Kennedy 2000a). This bestows unique advantages on the reader because, as noted by Reichle et al., re-inspection is typically deployed as a reprocessing option. The cost of incorrect initial structural analysis is far higher when processing speech, where no process equivalent to visual re-inspection is available (Watt & Murray 1996).

It should be noted, however, that the equivalence between *reinspection* and *reanalysis* is itself in need of careful justification: It can be drawn only because readers compute and retain enough spatially coded information to make saccades to specific locations possible. This point needs to be stressed, because saccades made in the service of reanalysis are often very large and cannot be controlled accurately by physical identification of their correct landing site (Murray & Kennedy 1988). For readers of English, the relationship between initial landing position and launch site for progressive saccades is linear over the whole range of launch positions likely to be found in normal reading, with one character shift in launch position producing a corresponding shift of about a third of a character in landing position. However, the equivalent analysis of inter-word regressive saccades shows a virtually flat relationship between extent and accuracy. Landing position is close to the target word's centre, regardless of launch position, an outcome that strongly implies spatial control over saccades to "already-inspected" sites. The fact that readers know where previously inspected words lie (Radach & McConkie 1998) means that their temporal order of fixation need bear no relationship at all to their spatial succession. Indeed, the fact that the reader, unlike the listener, can afford to adopt a single "preferred" structural analysis rests on the fact that a repair process is readily available, underpinned by this spatially coded information (Kennedy et al. 2003; Kennedy & Murray 1987; Pynte et al. 1988).

The E-Z Reader model takes as a theoretical given the concept of *word object,* an idea which found its place in the literature because it neatly captured the idea of a visually-presented word functioning as a cognitive *event,* bounded by the time spent inspecting it (McConkie 1979). Processing could thus mimic the (temporal) sequence of events that would obtain if the word were heard rather than seen. It is hardly surprising, therefore, that the claim that text presented without inter-word spaces can be read quite well (Epelboim et al. 1993) should have been seen as peculiarly subversive and rejected with vigour (Rayner & Pollatsek 1996; see also Epelboim et al. 1996). What else but inter-word spaces could underpin the notion that the "primitive object level" in reading is the word (McConkie & Zola 1987)? Inter-word spaces are the visual equivalent of auditory segmentation, defining the boundary of attention. They allow the notion of an attentional spotlight, switched to each word in turn, to smuggle into any model of reading that employs it the plausible, but questionable, belief that reading is a form of surrogate listening. From this point of view, properties of a word in the parafovea *cannot* influence current foveal processing, because it is obviously not possible to hear the next word before it is uttered. The irony is, of course, that the serial-sequential nature of speech is precisely the property that a writing system avoids.

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How tight is the link between lexical processing and saccade programs?

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Abstract: We question the assumption of serial attention shifts and the assumption that saccade programs are initiated or canceled only after stage one of word identification. Evidence: (1) Fixation durations prior to skipped words are not consistently higher compared to those prior to nonskipped words. (2) Attentional modulation of microsaccade rate might occur after early visual processing. Saccades are probably triggered by attentional selection.

Two core assumptions of the E-Z Reader model are: (1) attention is shifted across the text in a strictly serial fashion from word$_n$ to word$_{n+1}$, and (2) eye-movement programs are initiated by completion of the first of two stages of word identification. The SWIFT model does not make these assumptions; its three core assumptions are: (1) eye-movement programs are initiated by an autonomous timer, (2) words within the perceptual span are processed in parallel at rates that depend on the distance from the current fixation, and (3) lexical processing difficulty of the fixated word delays the initiation of a saccade program (Engbert et al. 2002). We comment on implications of E-Z Reader's core assumptions in the light of new experimental results and speculations.

Lexical cancellation of saccade programs. E-Z Reader is strongly committed to the assumption of serial word-to-word shifts of attention. Together with the assumption that saccade programs are triggered by completion of a first stage of lexical processing, this implies longer fixation durations prior to skipped than prior to nonskipped words. The reason is that word skipping requires that a saccade targeting the next word is canceled and reprogrammed to the following word; saccade cancellation necessarily increases the fixation duration. E-Z Reader and our own previous model generate a large effect of this kind (58 msec in E-Z Reader 7; 75 msec in Engbert & Kliegl 2001). The empirical evidence, however, is not consistent with this assumption, with effects ranging from 38 to −26 msec (see Kliegl & Engbert [2003a] and Radach & Heller [2000] for references to six studies/twelve estimates with a median close to zero). We checked this effect in a recent corpus based on 32 young and 33 older adult readers of German sentences (Kliegl et al., in press). In both samples the critical fixations were shorter (−9 to −4 msec) in various analyses (e.g., contrasting saccades from word$_n$ to word$_{n+2}$ with saccades from word$_n$ to word$_{n+1}$; matching words that preceded a skip with the same words [read by different participants] when they preceded a saccade to the next word).[1] Obviously, this experimental variance needs to be explained, but given that E-Z Reader 7 overestimates even the maximum reported increase in fixation duration by 53%, the assumption of lexical-processing triggered saccade-cancellation does not appear to be well supported. Guidance by attentional gradients does not predict a specific increase of fixation durations prior to skipped words.

Lexical initiation of saccade programs. The SWIFT assumption of autonomous saccade generation was motivated by the considerable explanatory power of models assuming primary oculomotor control and by research demonstrating a close link between attentional selection and saccade program initiation (see Deubel et al. [2000] for an excellent review). Recently, covert attention shifts were shown to modulate microsaccade rate and orientation in spatial cueing paradigms (Engbert & Kliegl 2003; see also Hafed & Clark 2002). If attention modulates microsaccade rate and orientation in reading fixations, we can test the E-Z Reader assumption that saccade programs are triggered exclusively by the completion of the first stage of word identification (*L1*), which is

130 to 150 msec after the beginning of a fixation. Alternatively, the completion of early visual processing or attentional selection in the visual system might trigger saccade programs. Indeed, preliminary analyses indicate a linear increase in microsaccade rate from 90 to 200 msec (Kliegl & Engbert 2003), which is after early visual processing but already before the completion of *L1*. We speculate that, aside from effects related to the spatial position, some of these microsaccades represent traces of inhibited saccade programs as postulated in SWIFT, but any reliable link between perceptual or lexical processing and microsaccade rate or orientation will provide important constraints for attentional and ocular control during reading.

Reading as a special case of dynamic attention allocation. Obviously, attention and ocular control did not evolve for reading, but reading is a special application of the attentional/ocular control system. Indeed, the highly constrained spatial nature of the reading process represents an ideal testbed for the further development of theories of attentional/ocular control models. We argue that SWIFT can be ported more readily to nonreading situations (such as visual search) than E-Z Reader, because it does not make any reading-specific assumptions with respect to target selection; indeed a variant of the model was applied to searching for a target in a display of Landoldt rings (Engbert & Trukenbrod 2003). Moreover, the combination of target selection via attentional gradient and parallel processing of words within the perceptual span allows us to generate all types of reading eye movements from the same underlying mechanism. In contrast, in E-Z Reader some reading eye movements require special assumptions (i.e., word skipping or refixations) and others are not even part of the present framework (i.e., interword regressive movements). SWIFT may actually be too flexible, given emerging empirical constraints. For example, it may be necessary to constrain parallel processing within the perceptual span to lexical preprocessing to reduce semantic parafovea-on-fovea effects. Such constraints, however, can be implemented and tested in nested models.

Conclusion. Although E-Z Reader 7 and SWIFT differ in core assumptions, it does not seem insurmountable to introduce flexibility of saccade triggering in E-Z Reader and to constrain parallel processing and possibly autonomous timing in SWIFT. Therefore, E-Z Reader may need to abandon the assumption that all saccades are canceled or triggered by the completion of lexical processing stages; SWIFT may need to restrict parallel processing to visual/lexical preprocessing. Such adjustments, if necessary, will be forced by experimental results. The purpose of a computational model is to provide a coherent perspective on a complex set of empirical results and generate new hypotheses. Computational models of attentional and ocular control of reading already live up to this expectation.

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NOTE

1. We replicated longer fixation durations following a skipped word. Also, skipping saccades started closer to the end of word$_n$ and landed closer to the beginning of word$_{n+2}$ compared with matched movements from word$_n$ to word$_{n+1}$, as expected from oculomotor control theories.

Psycholinguistic processes affect fixation durations and orthographic information affects fixation locations: Can E-Z Reader cope?

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Abstract: This commentary focuses on two aspects of eye movement behaviour that E-Z Reader 7 currently makes no attempt to explain: the influence of higher order psycholinguistic processes on fixation durations, and orthographic influences on initial and refixation locations on words. From our understanding of the current version of the model, it is not clear how it may be readily modified to account for existing empirical data.

E-Z Reader 7 provides an impressive account of the processes that determine when and where fixations are made during reading. The eye movement patterns that the model predicts are remarkably similar to the observed data. Furthermore, the model is based on quite simple, fundamental principles. In this commentary, we would like to consider two central aspects of the model that we believe may require reconsideration if future versions of the model are to explain data that currently exist in the literature. First, there is evidence to show that processing beyond the level of orthographic identification can influence the duration of fixations. The second issue is that there is growing evidence to suggest that the orthographic characteristics of words can influence where they are first fixated and refixated. It is possible that future versions of the model could account for these additional phenomena and, therefore, our criticisms are intended to be constructive in nature.

Our first point is that Reichle et al. limit their model to explaining lexical and visual influences on fixation duration. In the E-Z Reader model, L_1 is a stage of orthographic identification that is influenced by word frequency and predictability. Completion of this stage of processing is the primary determinant of fixation duration. However, studies have shown that processing beyond orthographic identification does influence initial fixation durations on words (e.g., Murray & Liversedge 1994; Rayner et al. 1983a). To account for these higher-level influences on the duration of fixations whilst retaining the underlying mechanisms of the model, such processes must, it seems to us, modulate the time required to complete L_1. That is, L_1 must be redefined as being processing which includes full lexical access, syntactic processing, and perhaps even thematic and semantic processing.

However, it is not clear whether such depth of processing may be realistically achievable within existing L_1 time constraints. If not, then it may be necessary to extend the L_1 stage of processing, thereby providing sufficient time for higher order processing to occur during this period. Such a modification would result in more plausible timings for the occurrence and influence of higher order cognitive processes on fixation durations. Note, however, that since eye-movement programming can begin only after completion of L_1, this will necessarily reduce the time allocated to program a saccade (M_1 and M_2). As the authors note in section 3.1.4, given existing data (e.g., Rayner et al. 1983b), the mean eye-movement programming time cannot be much shorter than is currently specified in the model. Consequently, such a modification may not be viable. Note also that if this modification were made, it is then unclear what type of processing would occur during L_2 (the stage in which readers currently perform full lexical access and which triggers the attention shift). L_2 is central to the mechanism for decoupling of eye movements and attention, and abandoning this stage would constitute a major change to the model.

An alternative possible modification is to substantially alter the fundamental mechanism for the initiation of eye-movement programming. That is, completion of L_1 would not serve to trigger the

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