the AVM and the word identification component of E-Z Reader stops here. Worse, the precise structure of the AVM was generated to account for experiments showing no frequency effects on early orthographic processing in perceptual identification paradigms. E-Z Reader does just the opposite, by pronouncing frequency effects in the first stage of lexical access. The same is true for predictability. In the AVM, predictability as well as word frequency are thought to influence the second stage of processing exclusively. This is in contradiction to the implementation in E-Z Reader, where effects of predictability on stage L_1 are necessary to account for both word skipping and reduced fixation times for predictable words, since the completion of this early stage triggers eye-movement behavior. While it seems reasonable to assume that predictability may reflect top-down influences from higher-level sentential or text-level representations in the later phases of word identification, the authors need to provide independent evidence for such influences on early orthographic processing.

Furthermore, the option to put orthographic processing in one stage and phonological and semantic processing in the other stage appears to be totally arbitrary. Why not have three separate stages, or put orthography and phonology together (as representations of form), separate from semantics? Indeed, the authors' own presentation of parafoveal preview effects would motivate a regrouping of orthographic and phonological processing. The exclusion of phonology from early word processing is clearly not in harmony with the results obtained by the same group of authors using their fast priming paradigm (see Pollatsek et al. [2000] for a recent review of these issues).

In sum, it appears that there is a considerable gap between the verbal description of the model and its actual mathematical implementation – and no clear theoretical justification for the particular option adopted in either the verbal or the mathematical version of the model.

As mentioned by the authors in their detailed discussion of alternative models, a different approach to the integration of linguistic processing and eye-movement control has been taken by Reilly and Radach (2003). They used a letter- and word-processing module that implements a well established type of interactive activation model as developed in research on single word recognition (Grainger & Jacobs 1996; 1998). The results of word processing are continuously fed back to a spatial salience vector that serves as an arena to integrate visual and linguistic processing in the selection of words as saccade targets. The trigger for the execution of an eye movement comes from an independent fixate center that is codetermined by the level of activity in the word processing module (see Engbert et al. [2002] for a similar approach). In this architecture, there is no distinct processing event that triggers saccade programming, and no shifting of attention. Hence, there is also no need to divide word processing into stages, and some of the problems originating from this division can be avoided. However, although the Glenmore model appears to represent a promising theoretical alternative, it has still to be tested in simulations with a realistic corpus of reading data. It remains to be seen whether it can then match the impressive performance of E-Z Reader in accounting for a wide range of eye-movement phenomena in reading.

Future challenges to E-Z Reader: Effects of OVP and morphology on processing long and short compounds

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Abstract: We argue that although E-Z Reader does a good job in simulating many basic facts related to readers' eye movements, two phenomena appear to pose a challenge to the model. The first has to do with word length mediating the way compound words are identified; the second concerns the effects of initial fixation position in a word on eye behavior.

As Reichle et al.'s target article convincingly demonstrates, the research on eye guidance has reached a stage where the accumulation of empirical data has paved the way for attempts to model and simulate the basic findings related to eye movements in reading. Without any doubt, E-Z Reader has been the most influential model in this respect.

For the information-processing models, it is desirable that they (1) are transparent; (2) are psychologically and neurally plausible; (3) account for the basic empirical facts; and (4) make novel, testable predictions. On the one hand, we think E-Z Reader fares well with respect to the first three requirements (with some limitations, mentioned below). On the other hand, although E-Z Reader may also be capable of producing novel empirical predictions, we are not told what these might potentially be (with one exception concerning a previous version of the model). We are left wondering whether the model is indeed restricted to predicting only the effects that it is designed to simulate, or whether the authors have not yet fully exploited its capacity to generate novel predictions.

In what follows, we take up two empirical phenomena that pose a challenge to E-Z Reader, namely, the role of morphology in the processing of compound words and the effects of fixation location in a word on eye behavior.

Many languages (e.g., German, Dutch, and Finnish) depart significantly from English in having highly frequent compounding. For example, in Finnish, more than 50% of all existing words are compounds. If we are to understand the basic reading processes in these languages, we need to acquire a good insight into how compounds are processed. In a recent study, we (Bertram & Hyönä 2003) demonstrated that word length mediates this process: For relatively long compounds (12–14 characters) the recognition process starts with lexical access of the first constituent and not of the whole word (see also Hyönä & Pollatsek 1998; Pollatsek et al. 2000), whereas the opposite is true for the relatively short compounds (7–8 characters). The potential challenge these findings pose to E-Z Reader is that word length appears to determine whether word or constituent frequency affects the initial fixation on a word.

An initial attempt to model compound word processing with E-Z Reader demonstrates that the job is not trivial (Pollatsek et al. 2003). Pollatsek et al. showed that a version that fitted the data best on reading long compounds was the one in which word identification was assumed to appear serially via the constituents (i.e., accessing first the initial constituent, then the second one, then gluing the two together). However, such a model runs into problems in accommodating our finding (Bertram & Hyönä 2003) that short compounds are recognized via the whole word form and that the first constituent does not seem to get activated. What might be needed are letter-level representations feeding activation to word-level nodes, where letter-level activation varies as a function of eccentricity from the center of fixation point (cf. the Glenmore model of Reilly & Radach [2003]). In the case of short compounds this is not enough, but there should also be a mechanism that gives priority to word-level nodes over compound word constituents. Without such a mechanism, there would be faster and more pronounced activation of the first constituents, because they are typically of higher frequency than the whole words. In morphological processing models (e.g., Schreuder & Baayen 1995) it is assumed that a morphologically complex word is segmented into its component morphemes before they can be mapped onto their corresponding access representations. The priority of word-level nodes over constituent nodes might be accounted for by incorporating this additional segmentation time into the above-mentioned mechanism. We have unpublished data suggesting that segmentation might indeed not be a straightforward operation, especially when there is a lack of clear segmentation cues (Bertram et al. 2003). The apparent reason why the first constituent of long compounds is more strongly activated than the whole-word form (despite the potential segmentation problems) is due to low letter-level activation for the end letters (attributable to eccentricity).

The second empirical phenomenon that appears to pose a challenge to E-Z Reader is, on the one hand, the relationship between within-word fixation location and refixation probability, and, on the other hand, the relationship between fixation locations and fixation durations. Regarding the former relationship, it has been shown that the location of initial fixation has a marked influence on the probability of refixating a word (and subsequently on gaze duration; e.g., Rayner et al. 1996). The farther away the initial fixation lands from the optimal viewing position (OVP), the more probable it is that a refixation occurs. In E-Z Reader, refixation probability varies only as a function of word length (see Equation 7 in the target article). Therefore, we suggest that the posited mechanism for refixations is modified by also including fixation position in the equation.

As regards the second OVP phenomenon, Vitu et al. (2001) found that the closer the fixation is to OVP, the longer its duration. We have unpublished data (Bertram & Hyönä 2002) that replicate the results of Vitu et al.: First fixation is clearly shorter when it lands on the beginning letters in comparison to OVP. We observed this for both short and long compound words; thus, the relationship appears replicable across languages and for different word lengths (however, see Rayner et al. 1996). Although the authors do not acknowledge it, their Equation 1, which quantifies early prelexical visual processing, may be able to simulate the above-mentioned effect. According to our calculations, the time for early visual processing is shortened the further away a fixation is from OVP – a pattern in line with the inverted OVP effect observed in first fixation duration. Therefore, the authors' claim that the equation is "consistent with evidence that word identification is most rapid if the word is fixated near its center" (sect. 3.1.1, para. 3) appears to be at odds with the data and our interpretation of the equation.

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Selection for fixation and selection for orthographic processing need not coincide

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Abstract: The E-Z Reader model assumes that the parafoveal selection for fixation and the subsequent selection for attention allocation encompass the same spatially distinct letter cluster. Recent data suggest, however, that an individual letter sequence is selected for fixation and that more than one letter sequence can be selected for attention allocation (processing).

Reading requires that word recognition and sentence comprehension be coordinated with the programming of saccades, as the eyes need to be near the to-be-identified words. Although an abundance of evidence shows that eye movements are influenced by spatial and linguistic properties of a word at or near fixation, these data often reveal a complex relationship between word recognition and saccade programming. The main goal of the E-Z Reader model, and of other models of oculomotor control during reading, is to explain how local demands of text processing can yield a relatively heterogeneous – but carefully calibrated and well adapted – pattern of eye movements.

The central assumption of the model is that the individual word is the exclusive unit of orthographic and semantic processing at each point in time. Each and every word of text is the target of a programmed (but not necessarily executed) saccade and of a corresponding shift of attention that controls a word's orthographic and semantic processing. The pattern of executed saccades can differ from the strictly sequential pattern of attention shifts, because saccade programming and the shifting of attention are controlled by functionally distinct word recognition processes, and because the programming of an overt saccade is more intricate than the covert shifting of attention.

Earlier data (Inhoff et al. 2000; Starr & Inhoff, in press) challenged a core assumption of the E-Z Reader model, that the programming of a saccade to the next word in the text begins before the word is attended. The current commentary examines another assumption of the E-Z Reader, that the initial selection of a parafoveal word for saccade targeting is followed by its selection for processing so that their spatial areas coincide.

The current version of the E-Z Reader model (i.e., the target article) includes a pre-attentive stage of early (low-spatial frequency) visual processing. It segments visible text into spatially cohesive objects that are separated by interword spaces. A parafoveally visible object that occupies the space of the next word in the text becomes the target of a saccade after the orthographic form of the attended word is specified, and it becomes the subsequent target of a corresponding shift of attention after the meaning of the attended word is accessed. Pre-attentive processing thus discerns a parafoveally visible spatial object, the next word in the text, so that it can become the target of a saccade and of an attention shift.

The results of a recent study (Inhoff et al. 2003), in which we manipulated the spatial segmentation of a parafoveally visible word, are not in harmony with this concept. We created four parafoveal viewing conditions, two with matching and two with mismatching parafoveal word length previews. Mismatches were created by replacing a center or near-center letter of a parafoveally visible five- to eight-letter target word with a blank space that separated it into two spatially separate sequences of letters. For instance, the mismatching preview of the target word *student* consisted of *stu ent.* Matching previews were created by replacing the corresponding center letter with a dissimilar letter, for example, *stusent.*[1] Orthogonal to the manipulation of parafoveal word length, we also manipulated the linguistic informativeness of the preview by creating two conditions, one in which useful orthographic information was available, as shown in the examples, and one in which it was denied (e.g., *vip asp* and *vipsasp*). The intact target (*student*) was visible when the eyes moved to the right of the blank space preceding it, and target viewing durations were measured to determine effects of spatial segmentation and of useful orthographic information. If pre-attentive segmentation was used for the targeting of saccades, then saccades should have been longer in the matched condition than the mismatched condition, as the full target preview could be reached with a larger saccade. Furthermore, if pre-attentive segmentation directed attention, then more useful orthographic information should be obtainable from the matched parafoveal preview, as it reveals more useful orthographic information than the first segment of a mismatched preview.

As can be seen in Table 1, saccades to the target were longer in the matched condition, as readers appeared to direct the eyes to an individual parafoveally visible letter string, the first segment in the mismatched condition and the full letter string in the matched