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Reichle et al.: The E-Z Reader model of Eye Movement Control in reading: Comparisons to other models

<CT>**Serial programming for saccades: Does it all add up?**

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<C-AB>**Abstract:** This commentary analyses the quantitative parameters of **Reichle et al.**'s model, using estimates when explicit information is not provided. The analysis highlights certain features that appear to be necessary to make the model work and ends by noting a possible problem concerning the variability associated with oculomotor programming.

<C-text begins>**Reichle et al.**'s target article presents a model of eye control during reading that is impressive in a number of ways. It is fully explicit, quantitative, and economical, and it brings in known features of the visual system (differential magnification) and oculomotor system. It provides a good account of a number of observed phenomena and a quantitative fit to data. Its appearance in *BBS* is particularly welcome because if it proves robust against criticism, this must be regarded as a triumph not only for the model itself but for the serial stage approach to modeling that underpins it.

The duration of fixations are modeled on the basis of a signal traveling through a number of stages that are strictly serial with the visual, lexical, and oculomotor processes taking place sequentially. These stages are shown in Figures 3 and 13 of the target article; and the latter figure in particular suggests that the time-consuming processes leading to saccades are conceived as the time for signals to traverse brain regions. This represents a different tradition and philosophy to the approach of Findlay and Walker (1999), where the emphasis was on specific time-consuming processes of competitive inhibition, particularly in the late oculomotor stages. Some common ground might be found in the separation of the programming of saccade amplitude from the remainder of the programming. This occurs through the direct (dashed line of Figure 3) pathway from the early stage of visual processing bypassing the word identification system. Section 3.1.3 indicates that this pathway provides the low spatial frequency information needed to program a saccade. However, it would appear that there needs also to be a modulatory influence from the word segmentation process on this pathway, since the whole basis of the model is that saccades are programmed to words.

The remainder of this commentary works through the model in detail, following the commentators' understanding and looking particularly at the time course of events.

The seriality has the consequence that the duration of a fixation can be expressed as a sum of contributions from the component stages

$$FXDUR=t(V)+L_I+M_I+M_2-(OV_V+OV_L+OV_M)(1)$$

where $t(V)$, L_I , M_I , and M_2 are defined as in the model. OV_V , OV_L , and OV_M are introduced to denote the modifications that occur when the model is working dynamically, since overlap (OV) processes can occur. OV_V and OV_L are savings in the visual and lexical stages, respectively, that can come from peripheral preview. OV_M reflects changes in oculomotor preparation time when saccadic programming stages overlap. All the components are described clearly in the target article and, although the detailed magnitudes can be made only with precise knowledge of the text being read, it is possible to make estimations of the distributions. The terms in Equation 1 (above) are all stochastic variables and therefore the grand mean of FXDUR must equate to the combination of the means of the various contributing components. How does this work out? Our analysis below ignores refixations but otherwise tries to follow **Reichle et al.**'s model through.

Section 3.1.1 discusses the variable $t(V)$, which takes values upwards from 90 ms. L_I is defined in Equation 2 of the target article as a product of two factors. The first ranges from 110 to 228 ms dependent on word frequency, and the multiplier ranges from 0.5 to 1.0 dependent on word predictability. A plausible overall mean value might be 130 ms. M_I and M_2 are clearly set out to have mean values of 187 ms and 53 ms respectively.

OV_V , OV_L , and OV_M are not defined explicitly and depend on what happens when the model runs. OV_V and OV_L represent savings on the visual and lexical stages through peripheral preview advantage. OV_M represents modifications when saccadic programming stages overlap. Fixation durations are *shortened* when the planning for a saccade is able to take advantage of preparation already made (as with the second fixations in 5D and 5E). Fixation durations may also be *lengthened* when saccade skipping necessitates a reprogramming of the location-distance stage, as in the first fixation of 5C.

The sum of the means of the first four terms of Equation 1 is 460 ms. Therefore, to obtain a plausible overall mean, it seems necessary for the OV components to be quite substantial. OV_M can, as far as we can see, only be positive when two conditions are satisfied. First, peripheral preview has allowed completion of the $t(V)$ and L_I stages of word_{n+1} . Second, the triggering signal falls in the 53 ms nonlabile stage of the previous saccade preparation or during the saccadic movement itself (25 ms). Therefore, OV_M cannot exceed 78 ms. Whenever this occurs, OV_L must equal the full value of L_I (50 ms–228 ms). This suggests that the OV_M component will usually be smaller than OV_L . Our estimates of plausible parameters are as follows: $t(V)$ 90 ms, L_I 130 ms, M_I 187 ms, M_2 53 ms, OV_V 90 ms, OV_L 60 ms, OV_M 30 ms, summing to a mean FXDUR of 280 ms. Of this figure, 70 ms is “visual-lexical” and 210 ms “oculomotor.” This reasoning assigns a very considerable role to peripheral preview, and two predictions seems to follow. If preview is prevented, fixations should be considerably lengthened; consequently, we find the 26 ms preview benefit figure given on page 29 surprisingly small. Second, the very first fixation on a text should be substantially longer than subsequent ones.

A similar exercise can be carried out with the variance of FXDUR, which again must be predictable from the variances of the component distributions, taking into account any nonindependence of the terms. How does the variance divide among the various components of the sum, and in particular between the visual-lexical and the oculomotor components? The calculations above suggest that the oculomotor components contribute about 75% to the mean. Unfortunately, the variance of the gamma-distributions from which M_I and M_2 are drawn are not given in the target article (we very much hope the authors will supply these in their response). However, our rough estimates suggest the oculomotor components must contribute a considerable amount.

If indeed this is the case, it must be reconciled with the fact that in studies of saccades in simple situations, distributions with s.d's in the 25–30 ms band are often found (Carpenter & Williams 1995; Walker et al. 1995; Wenban-Smith & Findlay 1991). It is, of course, possible that oculomotor variability depends on the circumstances in which the system is used and is higher in reading than in the cases cited. However, it could also be that the serial assumptions of the model are the source of the problem.<C-text ends>

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