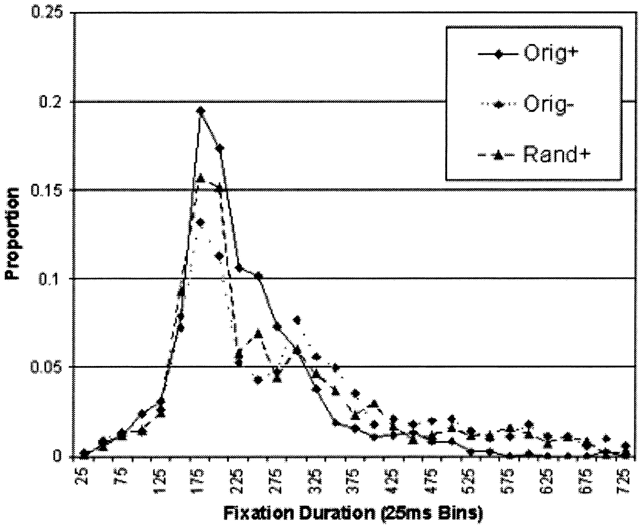

Figure 1 (McConkie & Yang). Fixation duration frequency distributions for people reading under three conditions defined by the nature of the text present during critical fixations: Orig+ (original text with spaces: control condition), Rand+ (letters replaced by random letters, but with spaces remaining in the text), and Orig− (original text but with spaces replaced by letters). Data from Yang & McConkie (in press).

tion, perhaps even a majority, of saccades occur at their normal time regardless of whether the text consists of words. Furthermore, as Figure 1 shows, a large proportion of saccades occur at their normal times even when there are no perceptual word units to which to shift attention or direct saccades. While E-Z Reader and other cognitive saccade triggering theories may expect a small set of preprogrammed early saccades, it is unclear how they can account for so many saccades occurring uninfluenced by such aberrant stimulus patterns. Triggering a saccade must not depend on word-based processes.

We have proposed an alternative explanation for saccade generation in reading, in which saccades are produced on a strategic basis, not directly determined by the language processes (see also Engbert & Kliegl 2001; Engbert et al. 2002). However, when processing difficulty occurs, the saccadic system is inhibited, reducing the likelihood of saccade generation. The nature of the processing difficulty determines the onset time and severity of the inhibition, with a given saccade being delayed only if it has not occurred by the time of the inhibition (a horserace model). Earlier and strong inhibition delays more saccades, resulting in a longer mean fixation duration. There is ample evidence that such autonomous saccades are generated in situations requiring repetitive or predictable eye movements (Basso & Wurtz 1997; 1998; Fischer & Ramsperber 1984; Vitu et al. 1995). Our proposal suggests that cognitive events inhibit saccades rather than triggering them during reading. We do not rule out the possibility that in reading, saccades can be triggered based on the guidance of cognitive information, but evidence suggests that these saccades will take much longer time to take place (Yang & McConkie, in press).

The primary strength of E-Z Reader is its ability to reproduce many previously observed phenomena. However, if further research confirms that its basic assumptions are incorrect, this may raise questions about the value of this type of evidence – and raise the interesting question of what the tests of E-Z Reader have actually been tests of. Much of the framework of the model could be preserved while changing these basic assumptions, but would it then be E-Z Reader? The future of this model will be interesting to watch.

The eye-movement engine

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Abstract: E-Z Reader fits key parameters from one corpus of eye movement data, but has not really been tested with new data sets. More critically, it is argued that the key mechanism driving eye movements – a serial process involving a proportion of word recognition time – is implausible on the basis of a broad range of experimental findings.

Reichle et al. provide an appealing, explicit, and, to a first approximation, accurate model of eye-movement control. One problem with being fully explicit is that it encourages nit-picking concerning details of the formulation. But Reichle et al. do a pretty good job of justifying the existence of, and appropriate values for, most of their mechanisms and free parameters. However, it seems a terrible pity that this model (and others) have been developed and "tested" using a single, rather limited, corpus of data. A real test involves setting parameters and then testing the model on another corpus.

I will, however, focus here on whether the conceptual properties of E-Z Reader 7 seem appropriate, given what we know. Let's look at the engine that drives fixation timing in the model: a process that serially identifies successive words in text. Or, more specifically, a serial mechanism sensitive to some proportion of that process. This is a constant (67%) for unpredictable words but increases with predictability. In no case, however, is it greater than the time required for word recognition. Nor does it ever encompass the recognition – or even part thereof – of more than one word. Partial or even complete recognition of a subsequent word can proceed after that engine is engaged and while the gears drive the saccade into motion, but these factors cannot influence engagement of the engine.

How plausible is this? It leads to conclusions that appear to be at variance with much of what we know about eye movements. First, obviously, is the question of whether processing is strictly serial. The authors concede that two "attention gradient" models (SWIFT and GLENMORE) do a similarly good job of accounting for critical phenomena. (To say that these models "fail" to account for some phenomena that they have never attempted to model is no damning criticism.) Others, I am sure, will point out the accumulating mass of evidence pointing to the *possibility* of parafoveal difficulty influencing fixation duration. Indeed, the authors point to some of it themselves – while suggesting that it occurs only if the task "isn't quite reading." I'll content myself with the observation that well-established, uncontroversial phenomena often come and go across experiments that clearly involve "reading" (see below). The same is true of parafoveal effects in "reading-like" tasks: Murray and Rowan (1998; see also Murray 1998) found effects of the pragmatic plausibility of a yet-to-be-fixated word. The effect was replicated by Kennedy et al. (in press), but not by Rayner et al. (2003), using a different procedure. The effect was also not replicated with the same procedure but differently structured items, by Murray and Clayes (1998). However, using the same task, and items of the same structure as Murray and Clayes, but differing semantics, Murray et al. (1999) found evidence for a parafoveal pragmatic effect. It appears not to be either the task or the items that drive it, but a complex interplay of these factors – and possibly others. The same, as we will see, is true of other, less controversial, effects. To dismiss effects as coming from "non-reading tasks," as the authors are inclined to do, appears to be missing the point: The mechanism "normally" used for reading (whatever that means) is just as likely to be applied to the processing of a piece of text forming a paragraph, a line, a single sentence, a phrase, or indeed any concatenation of words; and it is just as likely to be applied when the task involves "understanding" a piece of text, as when it is to decide if this text is the same as another. If this mechanism sometimes shows evidence of parafoveal-on-foveal effects, that constitutes a priori evidence that such a process is possible (but not always necessary) in normal reading, just as we assume that syntactic or pragmatic effects sometimes reflected in first fixation durations on a critical word reflect a part of the normal reading process, despite the fact that such early effects are not always found.

It is no exaggeration to say that the time course of syntactic and pragmatic effects can be frustratingly variable. Some investigators, in some experiments (e.g. Traxler & Pickering 1996), tend to find them only "downstream" – in later measures, such as gaze duration, regional reading time, or probability of regressions. Yet other experiments demonstrate very early effects of the self-same phenomena, sometimes on the duration of the first fixation falling on the critical word. Two points are worth making: As mentioned above, variability in the time-course of these phenomena (or the fact that they sometimes show up in longer inspection times and sometimes only as increased regressions) has never been used to call into question the possibility of their (early) existence in normal reading. The second and more critical point is that early effects of this sort should not exist, according to E-Z Reader. It should not be possible for syntactic or pragmatic factors to influence the duration of the first fixation falling on a word, but there is plenty of evidence that they can (see Murray & Liversedge [1994] and Murray & Rowan [1998] for examples, but also many other studies).

When the engine that drives the saccade is 67% of word recognition, how can the timing of that saccade be affected by the nature of the syntactic or semantic combination of the identified form of that word and other words in the text? Even adopting the generous assumption that combinations of this sort start to be computed before complete recognition of the critical word, is it plausible that the consequences of that combination could then be used, within the time frame envisaged, to drive the saccadic mechanism?

The authors state that they wish to begin to incorporate an ability to account for other established linguistic phenomena into E-Z Reader. It is very difficult to see how results such as these could be incorporated, and indeed they call into question basic assumptions regarding the engine. It seems that it is driven more variably across tasks or texts, and sometimes by the properties of more than one word.

On the perceptual and neural correlates of reading models

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Abstract: The current model appears comprehensive but is probably not applicable to a writing system like Japanese, which has unspaced text, because the model is mainly based on English. The span size difference (smaller for Japanese than for English) may be a result of high-level working memory-based attentional processing and not of low-level processing. Further, neural correlates of the model are discussed in terms of central executive function.

In introducing the E-Z Reader model of reading, Reichle et al. reviewed the models that explain "the interface between vision and low-level aspects of language processing" (target article, sect. 1) in terms of eye-movement control and visuospatial attention. My first argument is based on the perceptual span and the second one is based on neural correlates of the model. The current model appears comprehensive but is probably not applicable to a writing system like Japanese, because the model is mainly based on English and other Roman alphabet-based script. Regarding perceptual span, for example, measured using the moving-window technique, the size of the span appears smaller for Japanese (about 3–4 character spaces to the right of fixation: Osaka 1992; Osaka & Oda 1994) than for English (about 14–15 character spaces to the right of fixation: McConkie & Rayner 1975). Does this difference in writing systems come from low-level eye-movement control or high-level processing involving attentional dynamics? Moreover, the model expects that the boundary of each word can be easily separated by blank spaces, as in English; that is why Reichle et al. hypothesize that the reader moves her/his eyes guided by the spaces under oculomotor control, as shown in Figures 3 and 5. However, writing systems like Japanese, Chinese, and other oriental languages lack the blank spaces between words in the text (causing a lower spatial frequency region, whereas languages like English involve high spatial frequency); this might introduce difficulty in interpreting eye-movement control tactics in Japanese in the same way as is done with English.

During eye-movement control while reading unspaced text, it was found that the eyes land on the Kanji characters (logographic symbols) more frequently than on Hiragana characters (phonetics symbols) (cf. Kajii et al. 2001) for extraction of meaning during reading. Furthermore, the systematic errors (SRE) estimated in Equation 4 of the target article were derived from English readers whose oculomotor systems "prefer" to make saccades that are seven character spaces in length, according to Reichle et al. However, this value would be influenced by differences in writing style, and most likely be different for different scripts, as described above. An alternative possible tactic under cognitive control is that the phonological loop in working memory determines when to move the eyes in the text. The identification of the currently fixated word may initiate the attentional spotlight (driven by phonological loop) to move to the next word, which in turn initiates the oculomotor system to begin programming a saccade to the next word (Morrison 1984). Further, a longer word takes a longer time to identify than a short word because the phonological loop takes longer for the former during reading, which is explicitly shown as parameter N in Equation 1. Therefore, the validity of a model applicable to a writing system *without* blank spaces might be expected to contribute toward a unified model of reading.

The second argument is based on the neural basis of visuospatial attention. Reichle et al. speak of a "low-level of language processing," not "high-level," when they refer to attention. However, visuospatial attention is not likely to be "low-level." Rather, it might involve more "high-level" processing based on the executive function of the prefrontal brain. Regarding the neural correlates of the model, the E-Z Reader model suggests an attentional neural network in the region around the intraparietal sulci and angular gyrus in the parietal brain; primary and extrastriate visual cortex in the occipital brain, inferior temporal gyrus in the temporal brain, and eye movement-related motor area (BA6 /8) in the frontal brain, are just described in Figure 14. However, the cognitive component of attentional control – that is, executive function, in the prefrontal region (i.e., BA 46/44/9 in the left brain), other than the motor component – seems more closely related to dynamic properties of visuospatial attention during reading. For example, the length of the span that is influenced by the dynamics of allocation of visuospatial attention appears to be increased for subjects with high working memory, with efficient attentional control, compared to that of subjects with low working memory (Osaka & Osaka 2002). This suggests that eye-movement control could also be influenced by attentional control by high-span subjects; in other words, working memory plays an important role in eye-movement control during reading.

Osaka et al. (2003) showed a strong functional connectivity between ACC (anterior-cingulate cortex) and left DLPFC (dorsolateral prefrontal cortex) for attention control during sentence reading: They reported that subjects with high working memory capacity (high reading span score) showed higher efficiency in controlling attention than did low capacity subjects. This was confirmed by a "focus word" experiment performed subsequently