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Eye movements in reading: Old questions and new directions

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Trends in the articles reported in this volume are identified: (1) landing position effects, (2) word skipping, (3) parafoveal-on-foveal effects, (4) eye movement control, and (5) eye movements and word identification. Each of these issues is discussed in the context of prior research on the issue. We also identify some issues that are not included in the present set of articles, as well as some research questions that need further attention.

Since the mid-1970s there has been an incredible amount of research conducted examining the characteristics of eye movements in reading. Since the publication in 1975 of two classic articles (McConkie & Rayner, 1975; Rayner, 1975) using eye-contingent display change techniques to examine the perceptual span, numerous other questions about reading have been addressed utilising eye movement measures (see Rayner, 1978, 1998; Starr & Rayner, 2001, for reviews). When Tinker (1958) published the last of his reviews of eye movement research on reading, he felt it was the case that all that could be learned about reading from examining eye movements had been learned. Yet, he was clearly wrong, and he was wrong for two reasons: He did not anticipate (1) the technological advances that yielded (a) better (and more accurate) equipment for monitoring eye movements and (b) high speed computers for stimulus presentation and data analysis; or (2) the theoretical advances in psychology and linguistics that would lead to far better understanding of language. Many laboratories throughout the world are now equipped with eye-tracking equipment and the amount of effort devoted to eye movement research on reading (and other cognitive processing activities) continues to increase.

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European researchers have been particularly interested in using eye movements to study reading. Furthermore, it is interesting to note that there is nothing in the US (or other parts of the world, for that matter) equivalent to the European Conference on Eye Movements (ECEM, which is held every other year). This particular volume is further evidence of the fact that eye movement research on reading is alive and well in Europe. It has been argued elsewhere (see Liversedge & Findlay, 2000; Rayner, 1995; Rayner & Liversedge, in press) that there are two extremes with respect to research on reading using eye movements: At one extreme are those researchers who are primarily interested in studying either eye movements *per se* or questions that are related to perceptual processing during reading, while at the other extreme are those researchers who are primarily interested in using eye movements as a tool to study some aspect of the reading process (such as syntactic parsing or comprehension). In mainland Europe, it has been the case that there has been more of the former type of research than the latter. In the United Kingdom, on the other hand, there is probably a more even split between the two types of research. No value judgement is being made with respect to which type of research is more valuable. Indeed, it is clearly the case that researchers from both extremes need to pay attention to the findings from each other (Rayner & Liversedge, in press).

The articles in the present volume therefore reflect the reality of current research activities in Europe which use eye movements to study reading. As such, there are no articles using eye movements to study higher level language processing, such as sentence parsing or discourse comprehension (which would be more likely to emerge from the UK than mainland Europe). Rather, all of the articles deal with aspects of visual and linguistic word processing, in many cases combined with issues concerning the control of eye movements in continuous reading. As such, they provide an accurate overview of current research activities in much of Europe. Indeed, it is also interesting to note that of the 30 comments on the Reichle, Rayner, and Pollatsek (in press) target article (which compared the E-Z Reader model to other models) in *Behavioral and Brain Sciences*, 21 were from Europe. In the remainder of this article, we will not comment extensively on individual articles. Rather, we will focus our comments more generally on trends evident in the articles. Then, we will discuss a bit about what is missing from the current set of articles and also discuss the issue of old questions and new directions.

The articles in the present volume can be divided into five general topic areas: (1) landing position effects (Radach, Inhoff, & Heller; White & Liversedge), (2) word skipping (Drieghe, Brysbaert, Desmet, & DeBaecke), (3) parafoveal-on-foveal effects (Hyönä & Bertram; Kennedy, Murray, & Boissiere; Pynte, Kennedy, & Ducrot; Starr & Inhoff; Vitu, Brysbaert, & Lancelin), (4) eye movement control (Yang & McConkie), (5) eye movements and word processing/identification (Andrews, Miller, & Rayner; Kliegl, Grabner, Rolfs, & Engbert; Williams & Morris). All of these topics have been the focus of a considerable amount of recent research.

Before we discuss each topic, we will make a few general points on which we think most researchers who study eye movements and reading would agree (see Rayner, 1998, for the empirical support for our claims). First, we think it is not at all controversial that there are parafoveal preview effects in reading: When a reader has a preview of the next word in the text, fixations are shorter on the previewed word than when preview is denied. Second, fixation time on a word varies as a function of its frequency and predictability: low frequency words are fixated longer than high frequency words and unpredictable words are fixated longer than predictable words. Third, words are skipped (i.e., not fixated) as a function of their length: Shorter words are skipped more frequently than longer words. These three points serve as points of reference for arguments that we will make. With this as a background, we now turn to each of the five topics that are central to the present volume.

LANDING POSITION EFFECTS

Dunn-Rankin (1978) and Rayner (1979) first demonstrated that where the eyes land in a word is rather systematic. Dunn-Rankin examined words in isolation and Rayner examined words in context. Rayner (1979) found that the eyes tend to land about halfway between the beginning and the middle of an English word (see Deutsch & Rayner, 1999, for similar evidence with Hebrew). Rayner referred to this as the preferred viewing location, and the finding has been replicated many times. Stimulated by research by O'Regan and colleagues (see O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984), many European researchers have been fascinated with these landing position effects. Initially, it was believed that landing position effects were due primarily to word length. More recently, Hyönä (1995) found that in comparison to an orthographically regular cluster at the beginning of a word, an orthographically irregular cluster causes the eyes to land further towards the beginning of the word (see also Beauvillain & Doré, 1998; Beauvillain, Doré, & Baudouin, 1996).

The articles by Radach et al. and by White and Liversedge serve to further confirm that orthographic information from the beginning of upcoming words influences where readers initially fixate in those words. Radach et al. also found that lexical and/or morphological processing does not have a modulating effect on where the eyes initially land (so the effect is a low-level one). They further demonstrated that orthographic landing site effects are graded since they used a three-level variation of orthographic regularity and found that the differences between low versus medium regularity words (at the beginning of the word) and between medium and high regularity words were of the same order of magnitude. White and Liversedge likewise show that orthographic familiarity, but not informativeness, of word initial letter sequences influence where words are first fixated.

It is interesting to note that the size of the landing position effect that Radach et al. and White and Liversedge report was quite small (on the order of one-third or one-quarter of a letter). Frankly, our observation is that many researchers outside of the area of eye movement research question how interesting effects this small might be. Our own view is that if the effect is reliable, it is of interest. When researchers first started reporting 25 ms effects on fixation time, such an effect seemed infinitesimally small. Yet, if you add up 25 ms across 100 fixations, the effect soon adds up to a larger effect. It is likewise the case with landing site effects.

WORD SKIPPING EFFECTS

It has long been known that readers do not fixate on each word in the text. Rather, about 30% of the words do not receive a direct fixation. There is good reason to believe that although these words are not fixated, they are still processed (Rayner, 1998). That is, skipping a word is not equivalent to not processing a word. What exactly is the reason that certain words are skipped? Obviously, word length is a factor in that short words are skipped more frequently than longer words (Rayner & McConkie, 1976). But, given that word length is controlled, why are some words skipped more frequently than others? Word predictability influences skipping rates and high frequency words tend to be skipped more than low frequency words particularly when the eyes are near the beginning of the upcoming word (Rayner, Sereno, & Raney, 1996). Brysbaert and Vitu (1998) argued quite strongly that word length was far more important than either predictability or frequency with respect to word skipping.

In their article, Drieghe et al. continue with this proposition and begin by arguing quite strongly that word length is the most important factor in skipping. No one can reasonably argue that word length is not important, but there is also clear evidence that predictability and frequency are both also important (Rayner, 1998). Actually, the experiment that they report in this volume leads them to ultimately conclude that while there is a strong word length effect on skipping behaviour, there is also an effect of contextual constraint. Again, there are simply too many extant studies in which, with word length controlled, an effect of contextual constraint emerges for a purely length account to hold up.

PARAFOVEAL-ON-FOVEAL EFFECTS

Perhaps the most contentious issue in recent research on eye movements in reading is that of parafoveal-on-foveal effects. As clearly explained in the five articles dealing with this issue, parafoveal-on-foveal effects refer to the possibility that characteristics of the word to the right of fixation impacts on the processing of the currently fixated word. Undoubtedly, the reason for why so much work has focused on this issue is because it has been assumed that the demonstration of such effects would be highly damaging to serial attention models of eye movement control such as the E-Z Reader model (Pollatsek, Reichle, & Rayner, 2003; Rayner, Reichle, & Pollatsek, 1998b; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle et al., in press).

At this point, it appears that orthographic properties of the word to the right of fixation can have an effect on the processing of the currently fixated word (and Starr & Inhoff provide further support for this assertion). However, the most recent version of the E-Z Reader model (Reichle et al., in press) can account for this effect. What is more contentious is the extent to which the meaning of the word to the right of fixation can influence the processing of the currently fixated word. Rayner, White, Kambe, Miller, and Liversedge (2003c) have reviewed this question in detail and argued that there is reason for scepticism on this issue. We will not repeat all of the arguments made by Rayner et al. in detail here. However, we will briefly note their main points. First, there is no evidence that preview effects are due to semantic processing. Although readers clearly process a word more efficiently when they have had a preview of that word before fixating it, the basis of the preview effect is not due to semantic priming. Second, when the meaning of the word to the right of fixation is obtained on the current fixation, the parafoveal word is typically skipped on the ensuing saccade. Third, there is evidence that the frequency of the word to the right of fixation does not influence the duration of the current fixation (Carpenter & Just, 1983; Henderson & Ferreira, 1993; Rayner, Fischer, & Pollatsek, 1998a; though see Kennedy, 1998, 2000, for evidence of frequency effects in a reading-like task). Fourth, most demonstrations of parafoveal-on-foveal effects come from experiments in which subjects are not reading, but rather engaged in tasks that may or may not approximate reading. The main concern here is that some of the tasks that have been used seem more like visual search or pattern matching tasks, and there is clear evidence that when subjects engage in such tasks well documented effects in reading (such as the word frequency effect wherein low frequency words are fixated longer than high frequency words) completely disappear (Rayner & Fischer, 1996; Rayner & Raney, 1996). Fifth, even if we grant that parafoveal-on-foveal effects have been demonstrated, they seem to be somewhat fragile and elusive. An important result reported by Murray and Rowan (1998) has proved difficult to replicate (even by the lab that originally demonstrated it, see Murray, in press) and sometimes the effect is one of facilitation and other times it is one of interference. These inconsistencies are good cause for scepticism (though see Kennedy, Pynte, & Ducrot, 2002 for an attempt to explain the inconsistencies). Furthermore, there are a number of clear failures to find parafoveal-on-foveal effects (see Rayner et al., 2003c).

The articles reported in the present volume, in our opinion, continue the trend for inconsistency with respect to the nature of the effect. Whereas Kennedy et al., Pynte et al., and Vitu et al. provide support for confirmation of parafoveal-on-foveal effects (and some in the context of reading, rather than reading-like-tasks), White and Liversedge find no evidence consistent with the notion. Perhaps the most telling paper is that of Hyönä and Bertram. Across five experiments, they found inconsistent effects. In one experiment (in which the frequency of the first constituent of a compound word was varied), they found that gaze durations were slightly longer when the first constituent of the word to the right of fixation was low frequency. Yet, in a second experiment with exactly the same manipulation, they found the opposite effect. There were also no effects on gaze duration in the experiments in which whole word frequency was manipulated, but they did find an effect on the final fixation before moving to the target word. Likewise, the other measures that were examined (skipping, probability of a refixation) yielded variable and inconsistent effects. As Rayner, Pollatsek, and Reichle (in press) noted, beauty is in the eye of the beholder; Hyönä and Bertram argue that parafoveal-on-foveal effects can occur under some circumstances. Yet, like Rayner et al. (in press) we also believe that a sceptic could argue that such effects are unreliable. In our view, further work is needed to determine more precisely the extent to which parafoveal-on-foveal lexical and semantic effects are reliable. Furthermore, we very much believe that attempts to demonstrate such effects need to be done in the context of reading.

EYE MOVEMENT CONTROL

Underwood and Radach (1998) recently argued that the E-Z Reader model (Rayner et al., 1998; Reichle et al., 1998, in press) is the standard against which alternative models will have to be evaluated. According to the E-Z Reader model, cognitive processes associated with processing a fixated word serve as the engine to drive eye movements through the text. Such a view, which is consistent with many other models of eye movement control (see Reichle et al., in press), contrasts with other theoretical views that attribute a much larger role to low-level visuomotor processes such as the Strategy-Tactics model of O'Regan (1990, 1992). According to this latter model, low-level oculomotor processes are more important than cognitive processes in influencing eye movements. Thus, for example, where readers fixate in a word was argued to be the primary determinant of how long readers look at words. This notion was based largely on research on words presented in isolation (O'Regan et al., 1984) demonstrating that there was a processing cost associated with being fixated in a noneffective location in a word (i.e., being fixated away from the centre of the word). Indeed, it was found that the processing cost amounted to 20 ms per letter that the eyes deviated from the optimal viewing location near the centre of the word.

However, two types of data proved problematic for this view. First, Vitu, O'Regan, and Mittau (1990) found that the processing cost disappeared (or was greatly attenuated) during reading. Second, Rayner et al. (1996) found that independent of where readers fixated in a word, single fixation durations on the word (where readers made only one fixation on the target word) yielded a frequency effect (wherein low frequency words were fixated longer than high frequency words; see also Vitu, McConkie, Kerr, & O'Regan, 2001, for the same finding[1]). Our view is that there is simply too much data indicating that cognitive processes strongly influence the processing of a fixated word (see Rayner, Liversedge, White, & Vergilino-Perez, 2003b, for one recent example) to sustain the position that low level oculomotor activities are more important than cognitive processes in determining when the eyes move.

The claims made in the article by Yang and McConkie, however, are quite reminiscent of arguments made by O'Regan and colleagues (though their second claim goes beyond what O'Regan and colleagues would claim). First, Yang and McConkie argue that cognitive processes serve primarily to inhibit a saccade from being made (as opposed to the view inherent in the E-Z Reader model, and many other models, that cognitive processes serve to trigger an eye movement) and that cognitive processes only affect rather long fixations (this latter point is very similar to claims made by O'Regan and colleagues). Second, they also claim, based on the data obtained from their text-replacement paradigm, that words do not play a critical role in generating saccades (as opposed to the view inherent in E-Z Reader, and many other models, that words are involved in selecting a saccade target). We will not go into great detail with respect to our objections to the claims made by Yang and McConkie. A detailed critique of their paradigm is provided by Rayner, Pollatsek, and Reichle (in press). All we will say here is that we strongly suspect that their results are influenced by unusual strategic processes. Furthermore, while we think that their claims regarding (1) cognitive processes and inhibition of saccades and (2) eye movement control not being word-based are interesting (and deserve further scrutiny), we also think that they are at variance with a great deal of other data.

EYE MOVEMENTS AND WORD PROCESSING/IDENTIFICATION

For some time now, it has been apparent that eye movements and word identification are intimately related in reading. In the E-Z Reader model, word frequency and word predictability are used as an index of how easy or difficult a word is to process and the ease of processing influences when the eyes move. The articles by Andrews et al., Kliegl et al., and Williams and Morris further continue research aimed at better explicating the relationship between eye movements and word identification.

[1] Vitu et al. would perhaps object to our characterising their results as being consistent with Rayner et al. (1996). To be sure, they did find a frequency effect that was independent of landing position (like Rayner et al.). However, they also found that fixations tended to be longer when the reader fixated at the middle of the word than when the reader fixated on the ends of the words. That is, they reported an inverted V-shaped function. This contrasts to the relatively flat function that Rayner et al. reported (actually, Vitu et al., 1990, also found a relatively flat function).

Kliegl et al. provide further evidence (see also Calvo & Meseguer, 2002) that word length, word frequency, and word predictability all influence fixation times on words. As they point out, the data can be used to serve as a further benchmark for computational models of eye movement control in reading (as the data of Schilling, Rayner, & Chumbley, 1998, have been used). Andrews et al. provide data regarding fixation times on compound words. By varying the frequency of the first and second morphemes, they were able to extend work by Hyönä and Pollatsek (1998; Pollatsek, Hyönä, & Bertram, 2000) on Finnish to English. Hyönä and Pollatsek found that the frequency of both the first and second morpheme in bimorphemic Finnish compound words affected fixation times on compound words. Like Hyönä and Pollatsek, Andrews et al. found effects due to the frequency of both morphemes, and some indication of earlier effects due to first morpheme frequency. This result can be compared and contrasted with results reported by Juhasz, Starr, Inhoff, and Placke (2003), who found stronger effects of second morpheme frequency with English compound words. Clearly, further research is needed on this issue. Finally, Williams and Morris follow up on interesting earlier work by Chaffin, Morris, and Seely (2001) on the processing of unusual and novel words. Like Chaffin et al., Williams and Morris examined how contextual information aids the reader to process novel words. However, they also report the very interesting finding that, with frequency held constant, subjective familiarity of a word led to differences in fixation time on a target word. We find this quite interesting since in a study using regression analysis techniques, we (Juhasz & Rayner, in press) also found that subjective familiarity ratings influence fixation time. Indeed, we also found that age-of-acquisition (see also Juhasz & Rayner, 2001) and concreteness exerted effects (in addition to frequency). We suspect that an important goal for future research should be to further determine to what extent different lexical word properties influence fixation time on a word during reading.

OLD QUESTIONS AND NEW DIRECTIONS

The articles presented in this volume provide a representative overview of current research activities related to eye movements in reading. As such, they provide further data on interesting questions that reading researchers have been asking for the past few years. What is missing from the volume, however, in terms of current research interests, are studies dealing with parsing and discourse processing. Although there are now many studies, dating back to Frazier and Rayner (1982), examining syntactic ambiguity and parsing strategies that utilise eye movement data, there have been far fewer studies examining discourse representation and processing using eye movements (see Rayner, 1998, for a review of prior research on this issue). We think that one promising line of future research would be to more effectively utilise eye movement data to examine discourse processing.

Related to the issue of parsing and discourse processing, we think that another agenda (for researchers utilising eye movements to study these processes) should be to work out the timing constraints between higher order processing activities and eye movements. Thus, many such studies involve manipulations involving variables such as plausibility or reference relations. Exactly at what point do such variables have an effect? For example, some studies dealing with ambiguity have found immediate effects when a point of disambiguation is reached in a sentence (Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983), whereas in other studies (Pickering & Frisson, 2001) the effect is delayed until the eyes have moved past the word that provides disambiguating information. Likewise, some studies dealing with issues related to discourse processing and plausibility effects find immediate effects (O'Brien, Shank, Myers, & Rayner, 1988) and others find delayed effects (Garrod & Terras, 2000). Generally, researchers doing this type of research (in which eye movements are used as a tool to study language processing) are content enough to simply find effects. However, we would suggest that the time is ripe to determine more precisely what type of higher order effects are immediate and what types yield delayed effects.

At the other end of the spectrum, it is the case that more research is needed to determine exactly how low level effects influence eye movements in reading. Radach and Kennedy (in this issue) suggest that research on eye movements in reading should be tied to more basic research on oculomotor research. On the one hand, we can see the virtue of such an endeavour. Indeed, we (Rayner, Juhasz, Ashby, & Clifton, 2003a) have recently examined inhibition of return effects in reading, and, much to our surprise, found evidence that such an effect occurs in reading: That is, fixations preceding a saccade to a word that was fixated on the immediately preceding fixation are longer than those that cover about the same distance but that are to a word that was not just fixated. On the other hand, Rayner and Liversedge (in press) have documented a number of examples where research on basic oculomotor processes did not generalise to reading (as well as a number that did). Radach and Kennedy also suggest that research on eye movements should be tied more directly to work on basic word recognition processes. Again, we see the virtue of doing so though one can legitimately question the extent to which work on word recognition generalises to reading; one problem with most research on basic word recognition activities is that it assumes that processing of a word begins with the initial fixation on the word, but as a considerable amount of research has demonstrated, readers begin processing a word prior to fixating on it (i.e., there is clear benefit from having a preview of a word prior to fixating it).

Another issue that we suspect needs much more attention is that of regressions. As is well known, readers typically move their eyes backwards in the text on about 10–20% of their saccades, depending on task demands and materials. Although there are lots of assumptions about the nature of regressions, there is in reality very little in the way of hard data (see Kennedy, Brooks, Flynn, & Prophet, 2003; Meseguer, Carreiras, & Clifton, 2002; Vitu & McConkie, 2000, for some notable exceptions). The reason for this is obvious: experimenters can't easily find manipulations that will systematically lead readers to regress. Nevertheless, we do suspect that research activities geared to a better understanding of regressions would be quite useful.

Finally, we would like to point out that the vast majority of research on eye movements and reading has been done in the context of skilled reading. Thus, there are very few studies examining the eye movements of children (see Rayner, 1986, for an exception) and older readers (see the paper by Kliegl et al. in the present issue for an exception). Likewise, there really isn't a great deal of research on differences due to reading skill (see Jared, Levy, & Rayner, 1999). Research on some of the basic findings that have been obtained with skilled readers needs to be carried out with young children and older adults, as well as with readers who are less skilled. Furthermore, there are very little data examining the relationship between oral reading and eye movements. Given that beginning readers spend a lot of time reading aloud, it is the case that more data are needed on this issue (and the recent technological advances that have resulted in fairly accurate eye-tracking devices that do not require a fixed head should make such research more feasible).

In closing, we would like to emphasise again that the articles in this volume represent important contributions to our understanding of eye movements and information processing in reading. Such research is clearly alive and well in Europe. We suspect that it will be very interesting to see what the next 10 years of research on the topic reveals about reading.

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