
Rayner's 1979 paper

[Rayner K, 1979 "Eye guidance in reading: fixation locations within words" *Perception* 8 21–30. Original paper reproduced at the back.]

Comments

It is not surprising to me that Rayner's 1979 paper is amongst the most highly cited papers to have been published in the history of the journal *Perception*. This paper is a classic in that it can be characterised in ways that only the very best papers in the field can be. The paper reports data that were acquired through the use of experimental techniques that were considered very technologically advanced at the time. The data themselves are fairly simple to understand, and yet provided a very clear demonstration of the systematicity observable in eye-movement behaviour during reading. Furthermore, the paper raised a number of very important theoretical issues in relation to those data. These issues were certainly novel and topical at the time, and many of them remain so today. Also, the paper contextualised the data in terms of contrasting models of eye-movement behaviour during reading, evaluating the strengths and weaknesses of each in relation to the data. Finally, it has stimulated a substantial amount of further research. These, in my view, are the defining characteristics of a classic psychology article. Below I will briefly detail the main points that I found to be of particular significance when I read the paper.

One of the first points the article makes is that where readers fixate, and how long those fixations last, are independent and therefore likely to be controlled by different mechanisms. In relation to the question of where we fixate when we read, the data in the paper do a good job of showing that saccades are targeted to the preferred viewing location of a word, a point just to the left of the word's centre. It is also clear that saccadic landing positions are distributed (roughly normally) around this point. Rayner argues that the preferred viewing location is the point at which the reader can obtain maximal information about the word being read. Today, this idea is very widely accepted as a fundamental and basic aspect of eye-movement behaviour during reading. Turning next to the question of how long we fixate when we read, Rayner makes the important point that fixation durations during reading are closely related to underlying cognitive processes. This is a vital point, since what is implicitly being argued here is that accurate measurement of eye movements during reading allows experimental psychologists to make inferences regarding linguistic processing required for sentence comprehension. Furthermore, Rayner suggests that saccadic targeting is influenced mainly by the visual characteristics of the text (the length of words and the position of spaces), whereas fixation durations are likely to be influenced to a far greater degree by ongoing linguistic processing. Thus, the article makes some very important claims regarding the primary influences of where and when we move our eyes during reading. What's more, these points (arguably) stand up as well today as they did 29 years ago.

Another important issue that is raised towards the end of the paper concerns what we are processing at any particular moment during a fixation. Under consideration is not simply how acuity limits visual processing in reading, but instead the relationship between eye movements, attention, and the visual and linguistic processing that occurs on a moment-to-moment basis in order for sentence comprehension to be attained. Specifically, within the paper Rayner suggests that words cannot be fully identified in the parafovea, and questions how much time during a fixation is allocated to processing the fixated word, and how much to processing the upcoming words in

the parafovea. Clearly, the time course of processing is at the fore. To me, the article gives the impression that processing of words occurs serially and sequentially during reading, an assumption that is central to the E-Z Reader model of reading that has been so influential in recent years.

Given the important points this paper raises, the influential data it presents along with the theoretical questions against which the data are considered, it is probably clear why I am not surprised that Rayner's article is so widely cited.

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Preferred viewing locations: A validation and an extension

Rayner (1979) established the Preferred Viewing Location (PVL) for reading fixations: typically, readers fixate at a location slightly left of word centre. Despite its simple elegance, the design of figure 2 of this citation classic has not become a standard for illustrating this phenomenon. We like to pay tribute to this core result (and its visualisation) with a cross-language validation of the PVL. We also extend our analysis to include PVLs of forward and backward refixations and use the new results to qualify proposals of refixation preprogramming.

PVL validation

We analysed landing-position data from 226 German readers (age range: 16 to 84 years) of the Potsdam Sentence Corpus (Kliegl et al 2006). Our figure 1 shows median fixation points⁽¹⁾ for single fixations following forward movements (figure 1a), and single fixations following inter-word regressions (figure 1b). For forward single fixations, the German data are very similar to the original English data. Median fixation positions are close to word centre with a slight leftward shift increasing with word length.

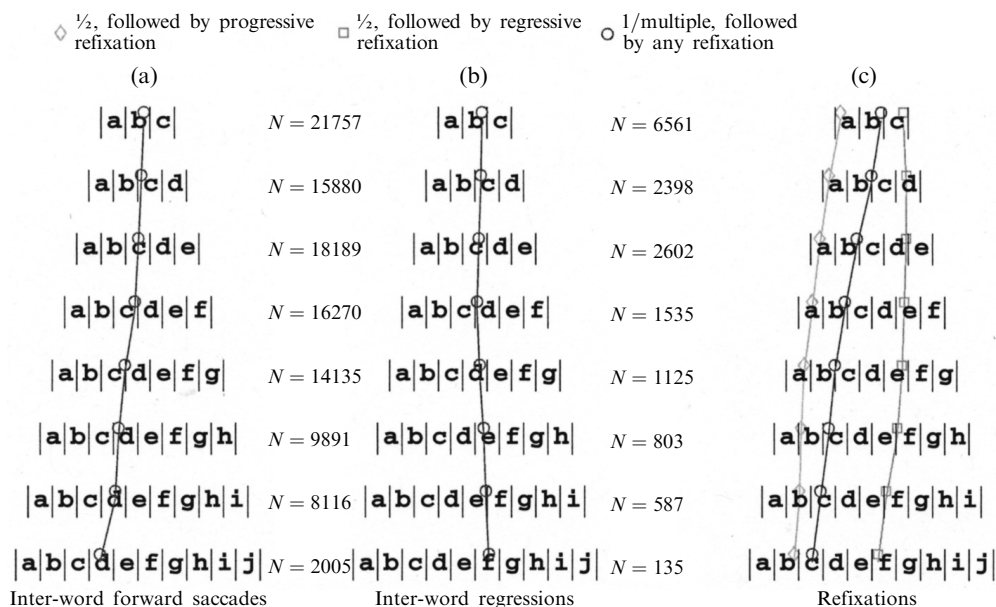


Figure 1. Median landing positions: (a) for single fixations following inter-word forward saccades; (b) for single fixations following inter-word regressive saccades; and (c) for different types of refixation cases.

⁽¹⁾ As in Rayner (1979), fixations on the space sign in front of the word were excluded from analyses.

Differences emerge, however, for regressive saccades. For most word lengths, median fixation position is close to word centre, with a slight shift towards the end of words for longer words (see also Radach and McConkie 1998). In contrast, the English data showed a stronger tendency for inter-word regressive saccades to land towards the end of the word (Rayner 1979).

PVL in refixations

Figure 1c additionally shows data for refixation saccades. When considering all initial fixations that are followed by a refixation, there is only a very small, though still systematic, influence of word length on median initial landing position which is around the second letter position (figure 1c, circles), replicating McDonald and Shillcock (2004). Interestingly, this initial landing position close to word beginning as opposed to a mean landing position close to word centre in single-fixation classes is interpreted as an argument in favour of the so-called preprogramming hypothesis of refixation saccades (McDonald and Shillcock 2004). However, the present analyses show that this constant landing position at the second letter disappears when progressive refixations (diamonds) and regressive refixations (squares) are considered separately (though restricted to 2-fixation-cases in the present analysis). Thus, constant landing positions for refixations are not a strong argument in favour of the refixation preprogramming hypothesis.

Other current applications

McConkie et al (1988) expanded upon PVL, arguing that the considerable variance in landing positions within words is due to systematic and random oculomotor error. These errors in saccade programming may lead to mislocated fixations, ie fixation on unintended words. With recent work, we provided an algorithm to estimate the proportion of mislocated fixations from empirical data (Nuthmann et al 2005). In addition, we identified mislocated fixations as a main factor contributing to the ‘inverted-optimal viewing position’ effect for fixation durations (Nuthmann et al 2005, 2007) and validated the underlying assumptions with the SWIFT model (Engbert et al 2005). In summary, PVL has enjoyed a venerable history; it is bound to stay around as a key result of reading fixations.

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Rayner (1979) demonstrated longer saccades into longer words, giving rise to the suggestion of a 'preferred viewing location' whereby readers seek to fixate a location in the word that will facilitate recognition and optimise the reading process. Furthermore, the length of the word currently being fixated also influences the landing position. The significance of the results was substantial at the time, in that it helped distinguish between two main hypotheses of eye-movement control. Our eyes do not move along a line of text with reasonably constant saccadic amplitude, varying only when comprehension becomes difficult, but are sensitive to moment-to-moment processing influences. Rayner's work established beyond doubt that this view was incorrect, and that eye movements vary according not only to what is being inspected at the start of the saccade but also what will be fixated at the end of the saccade. This is fine-grained control of saccadic programming, and the mechanism for the 'where to look' decision is now an established component in formal models of eye guidance in reading. These are the principal reasons for Rayner being well-cited, but if the experiment were to be re-run and the paper re-submitted, what developments should be taken into account?

The confound of word length and word frequency/AoA

It has been known for some time that, in general, short words have a higher frequency of usage than longer words. Zipf (1935, 1949) accounted for the relationship with a 'principle of least effort' whereby the words that people use most frequently are the shortest and simplest ones. The report that readers' eyes land further into longer words, therefore, is confounded with an effect of word frequency, and it may be that readers move their eyes further into low-frequency words in search of more detailed information. We know that, when reading natural text, readers are more likely to fixate more informative or contextually less probable words (Ehrlich and Rayner 1981), and they might similarly elect to vary their fixation location according to frequency (and, of course, age of acquisition, AoA, which also correlates with length). However unlikely this may be, word frequency/AoA should be eliminated as a confound, with a multivariate analysis that isolates these influences from that word length.

Orthographic influences on the landing position

The location of the first fixation varies as a function of word length, presumably because length (or the absence of a white space between letters) is identified with parafoveal vision. What else might be identified with parafoveal vision and used to guide the next fixation location? On the basis of tachistoscope experiments that established that the meanings of non-fixated words can be identified (eg Underwood 1976; Underwood et al 1983), we hypothesised that readers might be able to use the meanings of words ahead of fixation in deciding where to look next (Hyönä et al 1989; Underwood et al 1990). A series of eye-movement studies demonstrated that the landing position on a long word is influenced by the distribution of information, with a word-like *trajectory* (informative beginning) attracting a fixation nearer to the beginning than a word-like *supervisor* (informative ending). Although this supported the hypothesis that there was a morphemic or lexical influence, and therefore that this information was processed with parafoveal vision, it turns out that the influence is orthographic. An unusual sequence of letters at the beginning of a word will attract a fixation closer to the word's beginning (see also Beauvillain and Doré 1998; Inhoff et al 1996; Radach et al 2004; Vonk et al 2000; White and Liversedge 2006). Like the influence of word frequency on landing positions, this effect also needs to be taken into account, not only in the analysis of the data presented in experiments such as those carried out by Rayner (1979) but, more importantly, in the models of our descriptions of eye guidance. Reichle et al (2003) acknowledged the existence of this



orthographic influence, but relegated it to a footnote (page 475), and later argued that the effect is small and of minor interest (page 515). This comment comes as a surprise, particularly in view of the size of some of the effects reported elsewhere by Rayner and his colleagues, and the regular appearance of the orthographic effect requires that it should be explained by the models.

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Author's response

My response will be largely limited to Underwood's comments. Liversedge primarily reinforces points made in my comment on why the article is cited frequently, while Nuthmann and Kliegl provide a cross-language validation of the PVL. They note that for forward-going saccades their data replicate the original findings, but that there are some differences for regressive saccades. Underwood, however, seems to pick up the gauntlet and provide something in the way of a challenge. He first provides some comments regarding why the paper is cited frequently, but also raises three challenges in the context of what should be done differently if the paper were to appear in 2008 (rather than 1979).

First, he suggests that the well-known confound of word length with word frequency was overlooked. Specifically, longer words tend to be less frequent, and he questions whether or not readers might elect to vary their fixation location according to frequency (and AoA). This is a reasonable question, but relevant data are available. Specifically, Rayner et al (1996) examined landing positions in words as a function of word length and found little difference between high and low frequency words in terms of where the eyes landed. Interestingly, there are also data (Rayner et al 2001; Vainio et al 2009) showing that contextual constraint does not influence landing positions in words. Thus, frequency influences how long readers look at a word, as does predictability, and they both influence word skipping, but neither of them influence where in the word the eyes land.

Second, Underwood suggests that readers may obtain the meanings of words not yet fixated and this will influence where they land. This is a controversial issue, and, in my view, the majority of the extant data suggest that readers typically don't get the meanings of words to the right of fixation (except in cases where they skip those words). Underwood cites studies that he and his colleagues reported where they sometimes found that readers were more likely to fixate nearer to the beginning of a word with an informative beginning than one with an uninformative or redundant beginning or one with an informative ending. However, Rayner and Morris (1992) reviewed this evidence and concluded that it was fairly mixed. Nor did we find evidence that word informativeness at the beginning or end of a word influenced landing positions (see also Hyönä 1995). Certainly, words can sometimes be identified before they are fixated, but in general such words are skipped. Skipped words tend to be either very short or highly predictable. As noted above, while predictability influences skipping, it does not influence where the eyes land in the word. This finding reinforces the argument that the 'where' and 'when' decisions in eye-movement control may be unrelated.

Finally, Underwood mentions that orthographic irregularity at the beginning of a word influences where the eyes land: an unusual sequence of letters at the beginning of a word will yield a fixation close to the word beginning. I do not doubt this finding, but he takes us to task a bit for relegating this finding to a footnote in a paper dealing with computational models of reading, and indicates that we suggested that the effect was small and of minor interest. Actually, while we did say that the effect was small, we did not say it was not of interest (quite the contrary, we specifically noted that if such effects were reliable they are important). And, it is also the case that the effect can be accommodated within the context of the E-Z Reader model.

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Author's update

Eye movements and landing positions in reading: A retrospective

It is interesting that my article (Rayner 1979) on eye movements and landing positions in words during reading is in the group of most frequently cited papers in *Perception*. Other than a fairly recent article on eye movements and visual search (Greene and Rayner 2001), the paper on the landing position effect is the only other article that I have published in the journal. The article is also atypical in comparison with most of the other most frequently cited articles in that it doesn't deal with hardcore perception issues, but rather with reading. A few other articles of mine (McConkie and Rayner 1975; Rayner 1975, 1978; Rayner and Bertera 1979; Rayner and McConkie 1976) that appeared roughly in the same time period are likewise cited quite frequently. In all cases, I suspect that it is because the work that George McConkie and I did back in the mid-seventies influenced two important trends with respect to research on reading. First, we developed the innovative gaze-contingent display change paradigm in which aspects of the text were changed contingent on where the reader was looking. This paradigm is now widely used, not only in reading, but in the context of visual search and scene perception, to study interesting questions related to perceptual processing. Second, we demonstrated that eye-movement data could be used to infer interesting things about the mental processes involved in reading. The 1979 article in *Perception* falls into this latter category.

The article starts out by listing three possible models for how eye movements are controlled in reading: (1) constant-pattern models, (2) stimulus-control models, and (3) process-monitoring models. My rendition of those three models in 1979 is interesting in the context of current models of eye-movement control. Let me first describe how I characterised the class of possible models of eye-movement control in 1979. According to constant-pattern models, there is no cognitive or stimulus content over eye movements in reading. Thus, readers move their eyes a set distance on each saccade and then process the relevant information. Another way of thinking about this model is in terms of an 'ice-cream scoop' model [see Bouma and DeVogd (1974) for a variation of this type of model], in which the eyes move forward a set amount and then scoop up what is available, with the characteristics of the text and mental processes associated with reading being somewhat independent from the eye movements. Of course, this type of model has long since been abandoned as there is too much variability in how far the eyes move for it to have such credibility. Furthermore, there is also now far too much evidence that eye movements are not independent of cognitive processing in reading (Rayner 1998).

In contrast to constant-pattern models, the other two models posited that stimulus properties of the text or cognitive-processing activity of the reader influenced where the eyes moved next. According to stimulus-control models, visual information (such as word length or the spaces between words) from parafoveal vision is used to determine where to look next. According to the process-monitoring models, the cognitive-processing state of the reader influences where the eyes move. For example, readers might identify words as far to the right of fixation as possible (given the limits of visual acuity/lateral masking) and, when word identification is no longer possible, move their eyes to the right in a saccade.

These models, of course, now seem rather simplistic in comparison to the highly complex models of eye-movement control in reading that have been developed like the E-Z Reader model (Pollatsek et al 2006; Reichle et al 1998, 2003), SWIFT (Engbert et al 2002, 2005), and GLENMORE (Reilly and Radach 2003, 2006) to name a few.⁽²⁾

⁽²⁾The first issue of the 2006 volume of *Cognitive Systems Research* includes overviews of a number of recent models of eye-movement control in reading.

These newer models are highly specified and use simulations to accurately mimic critical aspects of eye movements in reading. Furthermore, as suggested earlier by Rayner and McConkie (1976), it soon became clear by the early 1980s that decisions about where to move the eyes (saccade length) and when to move the eyes (fixation times) might well be mainly influenced by different mechanisms. Indeed, most researchers in the field would agree that, for alphabetic writing systems, the decision about where to move next is very much influenced by low-level visual factors (again, word length and spacing between words), while the decision about when to move is largely influenced by the ease or difficulty associated with processing the fixated word.

While there soon developed general agreement concerning the importance of low-level factors in determining where to move, there was for some time considerable debate concerning what the primary influence of when to move the eyes was. Here, the contenders were the strategy-tactics model of O'Regan (1992; O'Regan and Lévy-Schoen 1987), in which low-level oculomotor factors were the primary determinants of when the eyes move, versus views such as that of Morrison (1984) or Rayner and Pollatsek (1987, 1989) in which cognitive/linguistic processing was the engine driving the eyes through the text. It is instructive that, by-and-large, the implemented models of eye-movement control all have a central role for cognitive/linguistic processing influencing the decision of when to move the eyes.

But, back in the late 1970s, there really wasn't a lot of relevant data to use to choose between different models. At some point during that time period I met Peter Dunn-Rankin who told me about a method he used, which was also used a century earlier by Helmholtz and by Dodge (1907), in which people gazed into a light source for a short time and then their afterimage was used to determine gaze location. After fixating the light source, participants closed their eyes and a grey afterimage appeared which shifted whenever the gaze shifted. Dunn-Rankin claimed that the grey afterimage lasted for about 30 s and was followed by a red circular afterimage that persisted for as long as 3 min after the participants opened their eyes. Using this afterimage, he had participants mark their fixation points in words of various lengths presented in isolation or in short phrases, and found that where participants marked their gaze location was rather systematic. After I talked with him, I decided to examine a large corpus of eye-movement data to determine if such an effect was apparent during continuous reading. An article by Dunn-Rankin (1978) appeared around that time, and so I was able to compare the data that I reported with his report (see figure 2 of my original report); the data were strikingly similar.

The basic finding that was reported in Rayner (1979) was that readers' saccades tended to systematically land between the beginning and the middle of a word for forward-going saccades. This landing-position effect has turned out to be very robust and numerous subsequent examinations of saccade landing positions in reading have confirmed the finding (see, for example, McConkie et al 1988; Rayner et al 1996). I also reported that, for regressive (right-to-left) saccades, the eyes tended to land half-way between the end and the middle of the word (though a bit closer to the end). Subsequently, we also found that readers of Hebrew, who move their eyes from right-to-left in forward-going saccades also tend to land between the beginning and the middle of the word (Deutsch and Rayner 1999). These findings have generally been interpreted as indicating that readers aim for the middle of a word, but owing to oculomotor error the saccade often falls short (and hence lands between the middle and the nearest edge of the word).

While the landing-position effect (referred to in the original article as the *preferred viewing location*, and subsequently often referred to as the PVL) is interesting in its own right and is one main reason why the article is cited frequently, I'm also quite certain that another reason that the article is cited so frequently is because of work by



Kevin O'Regan (1981) on what he initially referred to as the *convenient viewing position*, but subsequently and more frequently as the *optimal viewing position* (OVP). The OVP is the location in a word at which recognition time is minimised. The OVP, typically determined by examining word identification times (often using naming or lexical decision) when the initial fixation location in a word in isolation was varied, is a bit to the right of the PVL, closer to the centre of a word. Extensive research efforts by O'Regan and colleagues examining the characteristics of the OVP naturally led to much discussion of the relationship of the OVP to the PVL (particularly in Europe).

There was actually also a second important finding reported in the article, though it probably hasn't received as much attention over the years as the PVL effect has. That is, it was also demonstrated that the length of the currently fixated word and of the word to the right of fixation very much influenced how far the next saccade went. If the next word was quite long, the eyes moved further than if the next word was medium length. Also, if the next word was very short, the eyes tended to move further (because the short word was skipped). This finding that saccade length is influenced by both the length of the currently fixated word and the word to the right of fixation was also reported by O'Regan (1975) in his doctoral dissertation and other subsequent papers (O'Regan 1979, 1980). A third point that was emphasised in the original report was that the conditional probabilities of fixating two successive words varied systematically as a function of word length.

In the discussion section of the article, I concluded that the data were problematic for a constant-pattern type of model. I concluded that either of the other two types of models could account for the data. According to the stimulus-control model, word-length patterns in parafoveal vision would be particularly important in directing eye movements. According to the process-monitoring model, readers would process the content of the fixated word and try to identify words as far to the right of fixation. But, acuity limitations would make it difficult to identify words in parafoveal vision and the reader would then make an eye movement directing the saccade to the PVL in the upcoming word. However, in the end I suggested that both activities were probably relevant. Thus, I suggested that some internal processing state of the reader might be determining when to make an eye movement, and that word length would be a primary cue to use in deciding where to go. It is interesting that I noted that, although the reader might programme an eye movement to the PVL, there may be some noise in the oculomotor system such that, although the readers intended to fixate on the second letter of a five-letter word, but actually landed on the third or first letter, there would be no need for a corrective movement because they would be close enough to where they wanted to be. Others (McConkie et al 1988) have suggested that in fact readers programme their eyes to move to the OVP, but noise in the saccadic system results in them more frequently landing on the PVL.

Finally, it is interesting that I concluded the article by pointing out that timing factors related to the control of eye movements weren't seriously considered in the article, but that, for a valid model of eye guidance in reading, a specification of such factors was essential. This now seems a bit prophetic in light of the development of the more sophisticated recent models of eye-movement control. Fortunately, in the 29 years since the article was originally published, numerous experimental studies (see Rayner 1998 for a review) and much theoretical work has moved us much closer to a fuller appreciation of the intricacies involved in moving the eyes from one place to another in text.

Acknowledgments. Preparation of this article was supported by Grant HD26765 from the National Institutes of Health. I thank Jane Ashby, Charles Clifton, and Barbara Juhasz for their helpful comments.

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