CHAPTER 8

Parafoveal Pragmatics

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Abstract

The influence of pragmatic plausibility on eye movement parameters was examined in a study in which participants were required to make same/different judgements concerning vertically aligned sentence pairs. The results reported here extend those in Murray and Rowan (1998), addressing only the reading of the initial member of each sentence pair and focusing on the questions of the immediacy of the effects of pragmatic plausibility on eye movement control and the evidence for effects of plausibility derived from 'parafoveal' words before they are directly fixated. It is argued that the effects of plausibility on first fixation duration pose a major problem for 'strong' oculomotor models of eye movement control, which deny or seek to minimise the effects of linguistic processing on eye movement control. Further, the 'parafoveal' effects provide a challenge for 'processing models', such as that proposed by Morrison (1984) and its later revisions. While these results show strong effects of pragmatic plausibility on the when decision of eye movement control, there are no clear effects on where the eyes land. There is, however, some evidence for a lack of independence between the when and where decisions.
Introduction

While we no longer see arguments suggesting that there is complete decoupling between eye movement parameters and on-going cognitive processing, this certainly does not suggest that there is unanimous agreement about the nature of the relationship. As the chapters in this volume attest, there is considerable debate surrounding the question of what various eye movement measures might reflect.

That last sentence is phrased very much from the perspective of a cognitive psychologist who wishes to use eye movement measures to provide a 'window' onto on-going processing, and that, for the most part, is the perspective I will adopt here. We can look at the question, however, from another viewpoint and ask the question "what factors influence the process which determines when a saccade will be launched and where it will be targeted?" Clearly, the two questions both relate to the same underlying mechanism, but it's tempting to speculate that such differences in perspective might underlie at least some of the controversies we see in the current literature relating, at least, to eye movements in reading. From the perspective of an 'eye movement researcher', it may seem pointless or misguided to search for 'high level' influences on fixation location or duration when 'low level' factors are capable of accounting for, say, 90% or more of the variance. From the perspective of, for example, a psycholinguist, however, it may be that this 90% is not particularly interesting. It represents the 'noise' that must be dealt with while searching for high level effects. Neither perspective is necessarily right or wrong, but it seems clear that they are likely to motivate quite different approaches to the question of what needs to be explained.

I will not dwell here on the details of any of the eye movement models, since these are more than adequately covered in Chapters 4, 7, 9 and 11. For present purposes, it is sufficient to point out that there appears to be a sort of continuum in what has been suggested. At the extreme 'low level' end there are the 'oculomotor' models of, for example, O'Regan and his colleagues (e.g. O'Regan, 1992). These suggest that in reading the targeting of eye movements is (largely) controlled by oculomotor factors related to word length and spacing. O'Regan's (1992) model denies any effect of higher level factors on either the targeting or the duration of the first fixation which lands on a word. In the 'centre ground' we find models by, for example, Morrison (1984), Henderson and Ferreira (1993) and Rayner et al. (Chapter 11). These all suggest that (at least some) high level information taken in during the

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1 This is a slight oversimplification of the model. Chapter 11 gives a more precise account. The reader should also bear in mind that later versions of this model (e.g. O'Regan et al., 1994) acknowledge some earlier lexical influences. However, the spirit of this model, and of even more moderate oculomotor positions, such as that of Radach and McConkie (Chapter 4), is to propose that it is principally oculomotor factors which drive eye movement decisions.
current fixation will influence its duration and that there may be consequences of this for the targeting of subsequent saccades. They deny, however, that either the duration of the current fixation or the targeting of a saccade out of a word will be influenced by other than low level information derived parafoveally from a subsequent word. Finally, on the ‘far right’ (in left-to-right scanning languages at least) there have been claims that ‘higher level’ characteristics of the parafoveal to-be-fixated word can influence either the targeting of the saccade launched into that word or the duration of the fixation before it is launched (for example and details, see Chapters 7 and 9).

It seems clear that, at least from the perspective of a psycholinguist, a ‘strong’ oculomotor model is patently false. While low level configural information related to word length undoubtedly plays a large, sometimes overwhelming, role in determining fixation location and whether or not a refixation will be launched (see, for example, the consequences of landing on the right hand end of a long word in Pynte, Kennedy and Murray, 1991), there is now a large body of evidence showing that the duration of the initial fixation falling on a word will normally be modulated by that word’s frequency of occurrence (for a summary, see Chapter 11). There is also substantial evidence that even higher level factors can influence initial fixation duration. A number of studies have demonstrated clear effects of syntactic structure on first fixation duration. Critically, some of these (e.g. Rayner, Carlson and Frazier, 1983; Liversedge, 1990; and Murray and Liversedge, 1994) have shown the effect on a fixation falling on exactly the same word in exactly the same local environment. Under such circumstances it is not possible to claim that there might have been some sort of ‘contamination’ of the effect related to differences in low-level configural information between the conditions. Further, as will become apparent later in this chapter, even higher level factors influence first fixation duration.

This leaves us with a situation where most researchers agree that information about these sorts of higher-level properties of the currently-fixated word can be extracted within around 100–150 ms (since average fixation duration is frequently around 250 ms and saccadic programming time is generally agreed to lie somewhere between 100 and 150 ms, e.g. McConkie et al., 1985) and this information used to modulate both the decision about when the eye should move and where the next fixation should be targeted (including at least decisions about whether or not to reinspect). The next controversy, however, centres around the question of the types of information which may be extracted from words which are not being directly fixated, and what role this information might play in the decisions about when and where to move the eyes. The question is usually phrased in terms of whether ‘parafoveal’ information can be used to direct eye movements. I will continue to use that terminology here, but it is worth pointing out that the terms ‘fovea’ and ‘parafovea’ carry very little weight in the context of reading. There is no clear anatomical dividing line between what is usually termed the fovea and the para-
fovea. More importantly, the acuity function shows a steep, but very smooth fall off throughout the entire range from close to the centre of the fovea out into the periphery. To complicate the matter further, there is a near-perfect trade-off between effective acuity and letter size, such that it is possible to identify about the same number of letters in one fixation regardless of their size and how many of them consequently fall within the ‘fovea’. The point is that there is nothing ‘special’ about letters which either do or do not fall within the fovea. It is possible to have a situation where some letters falling within the fovea are not identifiable, or where it is easy to identify letters which fall well outside. At normal reading distances, the letter which is most directly fixated will be the one most clearly registered. Every other letter will be less clear, and increasingly so the further into the periphery it falls. We are therefore talking about a perceptual continuum. Whether this maps onto a functional continuum, in the context of eye movements in reading, is an empirical question. It may be the case that once functional acuity drops below a certain level, a different process takes over, or it may be that the functional influences are graded along with the acuity. In either case, it is clear that what we should really be talking about is the question of what the functional consequences are of information which falls more than a certain number of letter spaces away from the point of fixation. We certainly shouldn’t assume that there is any magic dividing line between ‘foveal’ and ‘parafoveal’ information.

I will not review here the debate between Rayner and colleagues and Underwood and colleagues concerning the influence of ‘parafoveal information’. As I have said, the issues are more than adequately covered elsewhere in this volume and so far as I am concerned, it is an entirely empirical question. I can see no principled reason to argue either for or against ‘parafoveal effects’. Natural cynicism might have led me to doubt their existence, but cynicism can be overtaken by data. At this point, it is, however, worth pointing out that the view espoused by Rayner and colleagues appears to have, perhaps not logical inconsistencies, but at least what might be termed a lack of continuity.

The model, from its earliest incarnation (Morrison, 1984) right through to the latest version (Chapter 11), has consistently proposed that information in the ‘parafovea’ can be processed, at least to the level of word recognition. It has, however, consistently denied that the nature of this information can influence either the duration of the current fixation or the targeting of the subsequent saccade. It is only the case that if word recognition is completed that a targeting effect will occur,

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2 The most compelling demonstration of this simply involves taking a page of text, such as this, steadily fixating a particular letter while holding the page close and determining how much text is in clear vision. When the page is moved to twice the distance or more, you will find that approximately the same amount of text is still in clear vision, despite the fact that now twice as many letters fall on the fovea.
with the identified word being skipped (or briefly fixated). No information from the parafovea is allowed to influence current fixation duration and only word length information is allowed to influence targeting. This is despite the fact that even when the word is not fully identified, there is still seen to be some 'saving' resulting from the parafoveal 'pre-processing'. That is, information of various types is derived from words in the periphery and is used to initiate lexical identification processes. Information from this pre-processing is integrated with information derived when the word is directly fixated and the two together will determine when the current fixation will end (through lexical identification, or 'lexical familiarity' in the current model). We therefore have a situation where parafoveal information influences fixation duration, just so long as the fixation now happens to be targeted on that particular word. If the current point of regard does not correspond to the word from which information is being derived, then the only parts of that information which can influence an eye movement relate to its length or to the fact that it has been identified. This seems possible, if a little curious, but becomes an even more 'interesting' proposal in the light of various other claims originating from this group of researchers.

Not least of these is the claim by Balota (1990) that there is no such thing as the 'magic moment' of word identification. Balota views the process as the continual extraction and increasing availability of word-related information over time, and this notion is central to some of the discussions about how contextual and parafoveal orthographic information might be integrated (see, e.g., Balota, Pollatsek and Rayner, 1985). Without a 'magic moment' some other identification criterion must be determined. As mentioned above, the current model suggests that it is not lexical identification which plays a critical role in the triggering of eye movements, but a pre-lexical stage termed 'familiarity'. This is equated to something like 'candidate generation' (see, e.g., Becker, 1976; Norris, 1986; Paap et al., 1982), but could, of course, correspond to any point in the sort of continuum envisaged by Balota. It could correspond to some sort of 'process monitoring' status, an activation criterion or any of a range of possibilities. All of these, however, are pre-lexical (in the conventional sense) and will be based on the extraction of various sorts of information — orthographic, perhaps morphological, perhaps even phonological, as suggested by Pollatsek et al. (1992) — from the 'parafoveal' word. It would be possible to construct an eye movement system that ignored these sources of information and only reacted to whether a particular single criterion had been reached, but it seems difficult to conclude that this must be the case when we know that in long words, at least, the execution of eye movements is strongly conditioned by sub-lexical sources of 'information'. For example, Pynte et al. (1991) found immediate effects

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3 But see Rayner, Sereno and Raney (1996) for an apparent contradiction when they suggest that the identification of letters in the periphery might influence targeting (p. 1189).
of the ‘lexical informativeness’ of the beginnings and ends of 12 letter words on first fixation duration, probability of refixation and saccade length within the word.

Pragmatic plausibility and eye movements

It has been known for some considerable time that pragmatic plausibility influences the time taken to process a sentence (e.g. Forster and Ryder, 1971; Forster and Olbrei, 1973; Forster, 1974). But while its influence is clearly implicated in the resolution of prepositional phrase attachment ambiguities (e.g. “The cop shot the man with the gun” cf. “The cop shot the man with the hat”) and it has therefore been involved in eye movement studies related to this ambiguity, there has until recent times been little systematic study of the direct effects of plausibility on eye movements. Some exceptions are recent studies by Fodor et al. (1996), Traxler and Pickering (1996), Pickering and Traxler (in press) and Murray and Rowan (1998). All show ‘early’ effects of plausibility on eye movement parameters: the time spent inspecting words in a sentence relates directly to how plausibly they continue it. This occurs not only in situations, such as the prepositional phrase ambiguities above, where plausibility might provide a cue to the correct syntactic analysis, but also in circumstances where there is no alternative analysis (Fodor et al; Murray and Rowan).

In Murray and Rowan (1998) we argue that this reflects a word-by-word incremental sentence processing system where the derivation of sentential representations influenced by pragmatic plausibility is both early and mandatory. We suggest that the fact that there are highly localised pragmatic plausibility effects and that they appear to be both unrelated to the nature of the task and insensitive to repetition context, poses difficulties for certain types of both modularist and interactive sentence processing architectures. For present purposes, however, these results are interesting insofar as they comment on the question of the types of information which can influence eye movement parameters and how rapidly they do so. Before describing the nature of the results, however, it is important to explain the experimental paradigm from which they were derived. This is a procedure which should minimise any possible influence of subject strategic factors and tap early, arguably mandatory, reading processes.

Delayed same/different sentence matching

When a participant is given two sentences to read and asked to make a simple decision about whether these are physically identical or not, the time taken to make that decision is influenced by both the syntactic and the semantic form of the sentence (e.g. Forster, 1979; Murray, 1982; Forster and Stevenson, 1987). This
happens even though both items are simultaneously available for inspection while the judgement is made and although they are, as shown below, vertically aligned on successive lines. It even happens when the first member of the pair has been presented by itself for sufficient time to complete its processing and then response time is taken from the onset of the second, identical, item immediately below it. This appears to always be true for ‘same’ items, such as the first pair shown below, and under some circumstances, at least, for different items, such as the second.

The monkey with the red nose ate a banana.
The monkey with the red nose ate a banana.

The priest with the green teeth delivered the sermon.
The priest with the green teeth delivered one sermon.

I will not attempt to reproduce here the detailed arguments about why this occurs. For present purposes it is sufficient to note that it apparently just happens to be the case that it is faster to derive a higher level representations of the sentences and make fewer comparisons than to compare the items on word-by-word or letter-by-letter bases. Thus, for example, with a five word sentence, it would be possible to compare the items word-by-word with five individual comparisons. Alternatively, one could spend a little longer deriving higher level representations of the sentences and make fewer comparisons — perhaps only one. In practice, it appears that, at least for ‘same’ items, where the entire string needs to be compared, the time taken for the greater number of word-by-word comparisons outweighs the extra processing time required to derive sentence level representations for the two strings. Consequently, the sentence-based comparison process wins the ‘race’. Importantly, though, such a comparison process should be based on the earliest available sentential representations and participants should be inhibited from completing any ‘unnecessary’ processing of the sentences. The reason that higher level effects are found with this task is that these comparison processes happen to be fastest. The development of more complicated, optional, sentence representations would inevitably be slower and highly unlikely to result in a simpler comparison process. The decision participants are required to make is, after all, completely unrelated to the nature of the sentence, or even the fact that it is a sentence.

Method

Materials

Twenty-four sets of experimental items were used. Within each set two factors were systematically manipulated. The first was the plausibility of the relationship between the initial noun phrase (NP) and the verb. The second, the plausibility of the combination of the verb with the subsequent NP. There were therefore, as shown
below, four versions of each experimental item, and these contained either a plausible (P) or an implausible (I) relationship between NPI and the verb and either a plausible or an implausible relationship between the verb and NP2. The verb remained the same in all four versions and the manipulations of plausibility involved the substitution of alternative nouns in the first and the second NPs. The alternative nouns in the different versions were of exactly the same length and were closely matched for Kucera and Francis (1967) word frequency.

PP: The hunters stacked the bricks.
PI: The hunters stacked the tulips.
IP: The bishops stacked the bricks.
II: The bishops stacked the tulips.

The term ‘plausibility’ here is used in a relative sense. It will be apparent from the examples above and the full set of items contained in the appendix that the manipulation does not rely on highly stereotyped or expected relations and that this is a relatively subtle manipulation of plausibility; far more subtle in fact than the type of manipulation used by Traxler, Pickering and other authors that have shown effects of plausibility on eye movement parameters. However, while more subtle, the manipulation nonetheless results in significant differences in rated plausibility. A group of 10 judges, who did not otherwise take part in the experiment, assessed the plausibility of the experimental items on a seven point rating scale. Mean plausibility ratings were, P/P: 5.3; P/I: 3.0; I/P: 3.0; I/I: 2.0. The differences in plausibility were consistent across items, with highly significant effects of both NPl-verb plausibility, $F_2(1,23) = 458.37$, $p < 0.001$, and verb-NP2 plausibility, $F_2(1,23) = 373.18$, $p < 0.001$.

Four counterbalanced item files were used. Each contained only one version of the members of an experimental set, together with 18 simple declarative filler sentences and 12 practice items. Half of the items in each file were matched with a second sentence which was exactly the same. The other half contained one changed word of exactly the same length as the word it replaced. The changed word occurred with roughly equal frequency in all serial positions.

Procedure

The 24 participants were informed that their task was simply to decide whether pairs of sentences were identical or not. They were asked to read the first sentence, press a button to initiate the display of the second, and then decide as rapidly and as accurately as possible whether the two were identical. If the sentences differed, they were told, this would always be because one word did not match. Sentences were presented in lower case (except for initial capitals) in a monopitch font on single lines of a high resolution VDU display. At the beginning of each trial, a fixation
point appeared momentarily to the left of the first word of the first sentence. This disappeared and the first sentence appeared on the screen. When this had been read, participants pressed a button. This triggered the display of the second (comparison) sentence, vertically aligned, on the line immediately below. Both sentences then remained on the screen until the participant signalled their decision by pressing either a “yes” or a “no” button.

Participants’ head movements were constrained by use of a dental composition bite bar and chin rest and their eye movements monitored throughout using a ‘Dr Bouis’ infrared pupil-centre computation device, sampled with a 12 bit A-D at 5 ms intervals. Calibration of the equipment was carried out at the beginning of the experiment and after every three sentence pairs. Data were stored for off-line analysis. The calibration and clustering algorithms employed statistical procedures to maximise resolution for each participant on each trial and provided a resolution of better than one character position (mean resolution was around 0.8 character spaces). The accuracy of calibration was also verified off-line before items were entered into the data analysis. If there was any question regarding the accuracy of the calibration, the item was deleted from the analysis. The final analysis included data from more than 95% of the trials.

Results and discussion

The overall results of the experiment are reported in Murray and Rowan (1998). In summary, they show localised effects of both NP1-verb and verb-NP2 plausibility on the reading of both the first and the second (comparison) sentence. Some aspects of the results, however, bear repetition here, since they directly relate to the controversies concerning the factors which control eye movements. Some analyses not reported in Murray and Rowan will also be presented.

All of the results reported here are derived from the reading of the initial sentence in each comparison pair. That is, they relate only to the reading of the first sentence, up to the point at which the participant presses the button to signal they have finished reading it and triggers the display of the second, comparison, item on the line below. These results therefore reflect only the participants’ initial encounter with each sentence and are unrelated to either the nature of the comparison process or to the decision (‘same’ or ‘different’) which will eventually be made. Participants made a correct judgement on 93.9% of experimental trials, but since the measures reported here relate only to the reading of the first sentence, no trials were excluded from the analysis on the basis of an inaccuracy of comparison or judgement which would follow after the presentation of the second member of the pair.

For analysis purposes, the sentences were considered to contain three regions: the initial NP, the verb and NP2. Fixations falling on the spaces between these regions were assigned to the region on the right.
‘Foveal’ effects

Initial fixation durations on the verb were significantly longer when the preceding NP was an implausible subject (271 ms) than when it was a plausible subject (254 ms), $F_1(1,20) = 13.18, p < 0.005$; $F_2(1,20) = 8.76, p < 0.01^5$. Thus, for example, the first fixation on the verb “stacked” was longer when it had been preceded by the NP “The bishops”, than when preceded by “The hunters”. At this point in the sentence there was no effect of NP2 plausibility or interaction between NP1 and NP2 plausibility (all $Fs < 1.32$). However, one word (and usually one fixation) later, the duration of the first fixation in NP2 was no longer influenced by NP1-verb plausibility, ($F_1$ and $F_2 < 1$), but did increase when the fixation fell on an NP that was an implausible object of the verb, such as “the tulips” (301 ms), than when it fell on a plausible object NP, such as “the bricks” (278 ms), $F_1(1,20) = 5.49, p < 0.05$; $F_2(1,20) = 10.00, p < 0.005$. There was no interaction between the effects of NP1 and NP2 plausibility.

These are clear effects on first fixation duration related not to word length, or even to a ‘high level’ factor, like frequency (since the verb was identical in the two conditions and the words in the second NP were matched for both length and frequency). Nor can they be related to the location of the first fixation falling within either of these regions, since this did not vary with the experimental conditions ($Fs < 1$). It seems clear that the duration of these fixations is modulated by on-going semantic processing related to the meaning of the sentence. It is somewhat surprising that sentence meaning can exert such a rapid effect on eye movement parameters, but it should be remembered that these were all very simple sentences and would have posed little load on syntactic parsing. Semantic effects might not always manifest themselves in the eye movement record quite so rapidly. However, the fact that they do here, and with such reliability, provides a major challenge to ‘oculomotor models’ — or at least the subset of these which seek to minimise the effects of on-going linguistic processing on eye movement control.

It is not possible to ‘escape’ from this challenge by suggesting that the effect might be in some way related to low-level configural information: Word length was identical across all conditions and at least one of these effects occurs on an absolutely identical word in the two conditions (the verb). The only way out would appear to be to suggest that these fixations were ‘abnormally’ long and that this

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4 In this and all subsequent analyses which rely on the presence of a fixation in one or more of these regions, cases where the region was not directly fixated were treated as missing data. It does not seem sensible to consider the duration of a fixation and to include zero as a value when it did not occur, or to talk about saccade size into a region if, in fact, the saccade went somewhere else. A zero gaze duration, on the other hand, is sensible. Fortunately, region skipping was a relatively infrequent event. The highest frequency (5.7%) occurred on the verb. Verb skipping did not vary systematically with experimental condition, $\chi^2(1) = 0.290$. 
allowed higher level factors to exert an effect. But while fixation durations on the second NP are perhaps a little longer than average, they are not markedly so, and those falling on the verb are well within the normal range. It seems far more parsimonious to suggest that these are normal fixations which have been lengthened in the context of more demanding higher level processing. The allowable duration for a 'normal' fixations is going to become remarkably short if these are to be excluded by the definition.

Clearly, 'oculomotor' theorists are right in asserting that word length and the location of a fixation within the word play a major role in determining fixation duration. However, it is apparent that a range of 'higher level' factors, such as word frequency, syntactic and semantic form, also exert potent effects.

A sceptic might wish to suggest that these effects are not in fact due to higher level factors such as pragmatic plausibility, but can instead be related to word or syntactic level factors. For instance, it might be argued that the effect of NP1-verb plausibility can be laid at the door of lexical semantics, since many of the 'implausible' NPs contained non-human agents. This, however, is to misunderstand the nature of the effects. There is nothing whatsoever about non-human nouns that restricts their taking an agent role. It is only when they are combined with particular verbs that the agentive role becomes less plausible. There is nothing to suggest that non-human nouns are in any way intrinsically less identifiable than frequency-matched human nouns, and certainly nothing to suggest that such an effect carries over to the following word. But, in any case, such an argument becomes considerably less plausible in the context of reliable effects of NP2 plausibility clearly unrelated to lexical-semantic properties of the nouns, and the observation that, despite the split of implausible agents into 13 human and 11 non-human, the effects on rated plausibility and on fixation duration clearly generalise well across the items tested.

I will return to this issue further, below, when discussing 'parafoveal' effects. For the moment, however, it is worth noting that the effects also cannot, of course, relate to syntactic processing differences other than those which arise as a consequence of the perceived plausibility of a particular syntactic analysis. The possible structural analyses are identical across the members of each matched pair.

'Parafoveal' effects

One intriguing result reported by Murray and Rowan is that not only did the plausibility of the combination of the first NP with the verb influence inspection time on the verb, it also influenced first pass reading time on the NP before the verb had been directly fixated. That is, readers were sensitive to how the currently fixated information would combine with that provided by a word which had not yet been inspected. In order to determine whether this was in fact a 'parafoveal' effect,
Table 1

Effects of boundary position on First Pass reading time and Last Fixation Duration in the initial noun phrase

<table>
<thead>
<tr>
<th>Boundary</th>
<th>0</th>
<th>-2</th>
<th>-3</th>
<th>-4</th>
<th>-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>First pass NP1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plausible</td>
<td>482</td>
<td>439</td>
<td>414</td>
<td>369</td>
<td>315</td>
</tr>
<tr>
<td>Implausible</td>
<td>512</td>
<td>457</td>
<td>423</td>
<td>364</td>
<td>316</td>
</tr>
<tr>
<td>Difference</td>
<td>30</td>
<td>18</td>
<td>11</td>
<td>-5</td>
<td>1</td>
</tr>
<tr>
<td>Last fixation NP1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plausible</td>
<td>248</td>
<td>247</td>
<td>243</td>
<td>238</td>
<td>228</td>
</tr>
<tr>
<td>Implausible</td>
<td>279</td>
<td>271</td>
<td>260</td>
<td>244</td>
<td>229</td>
</tr>
<tr>
<td>Difference</td>
<td>31</td>
<td>24</td>
<td>17</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Murray and Rowan set about localising it within the initial NP. Clearly, if the effect was distributed throughout the majority of fixations making up the first pass reading time in the zone, it is unlikely that it could be attributed to parafoveal preview of the verb. In the event, they discovered that it was attributable only to the duration of the last fixation falling in the initial NP. The duration of this fixation increased significantly from 248 to 279 ms as a consequence of the plausibility of the following verb, $F_1(1,20) = 35.73, p < 0.001$; $F_2(1,20) = 10.90, p < 0.005$. They further argued that this is clearly a parafoveal effect, since moving the analysis boundary between NP1 and the verb three character spaces to the left resulted in no remaining effect of NP1-verb plausibility on first pass times in NP1, $F_1 = 0.41; F_2 = 0.46$, but a continuing effect on first fixation durations to the right of the new boundary, $F_1(1,20) = 17.27, p < 0.001; F_2(1,20) = 8.88, p < 0.01$.

While the above results appear to present a pretty convincing case for a parafoveal effect related to pragmatic plausibility, we can consider the question in a more systematic way by examining the effects of moving the NP1-verb 'boundary' through a range of values. Table 1 shows the effect of moving this boundary on both the first pass reading time and the duration of the last fixation in the initial NP. A 'zero' boundary position falls immediately after the noun, with fixations on the subsequent space assigned to the following verb. Boundary positions with negative values are to the left of this: -2 is two characters further left, with the last two letters
Table 2

Effects of boundary position on First Fixation Duration in the second (verb) zone

<table>
<thead>
<tr>
<th>Boundary</th>
<th>0</th>
<th>-2</th>
<th>-3</th>
<th>-4</th>
<th>-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>First fixation duration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plausible</td>
<td>254</td>
<td>252</td>
<td>250</td>
<td>247</td>
<td>247</td>
</tr>
<tr>
<td>Implausible</td>
<td>271</td>
<td>268</td>
<td>271</td>
<td>271</td>
<td>272</td>
</tr>
<tr>
<td>Difference</td>
<td>17</td>
<td>16</td>
<td>21</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

of the noun now not counted as part of the initial zone; -3 is three characters to the left etc. It is clear from these results that the plausibility effects on both first pass reading time and last fixation duration systematically diminish as the boundary is moved further leftward. As mentioned above, the first pass effect is not significant with a boundary moved three characters to the left, but the last fixation duration effect does survive this move, $F_1(1,20) = 8.49, p < 0.01; F_2(1,20) = 5.08, p < 0.05$. However, when the boundary is moved one more character to the left, to -4, neither the first pass, nor the last fixation duration effect is sustained, $F_1 = 0.17; F_2 = 0.40$, and, $F_1 = 1.55; F_2 = 0.94$. And, clearly, with a boundary five characters to the left, there is no remaining trace of either effect.

It is also apparent from Table 1 that the magnitude of the first pass effect in the initial NP rests entirely on the duration of the last fixation in this zone. Both diminish equivalently as the boundary is moved leftwards. The same, however, is not true of the duration of the first fixation which falls to the right of the boundary, on, or slightly to the left of, the beginning of the verb. These first fixation durations are shown in Table 2. It is readily apparent that as the boundary moves up to five characters to the left, the plausibility effect on this fixation does not diminish. In fact, it is remarkably constant and does not vary significantly with boundary position, $F_1(4,80) = 1.14, p > 0.3; F_2(4,80) = 0.78$. It appears, therefore, that fixations falling more than four or five character spaces to the left of the verb are not influenced by its plausibility, but that fixations which fall either on the verb or on the last few characters of the preceding word are influenced to an equivalent extent by the plausibility of the verb. Clearly, this suggests that the verb is being identified and processed not only when it is directly fixated, but also when a fixation falls in the latter part of the preceding word.

It is not, however, the case that these 'parafoveal' effects are critically related to a
was directly fixated on 94% of occasions, and an analysis of last fixation duration in NP1, limited to cases where the next fixation falls directly on the verb, continues to show a robust effect of NP1-verb plausibility with mean durations of 250 ms and 274 ms for plausible and implausible items respectively, $F_1(1,20) = 23.70, p < 0.001; F_2(1,20) = 8.02, p < 0.01$. Contrary to the claim by Henderson and Ferreira (1993), it appears that fixation measures can reflect the processing difficulty of a word in 'parafoveal vision'. It seems to have been over-simplistic to conclude that it is only the processing of a directly-fixated word which can influence the decision about when to move the eyes.

Finally, if we consider whether these 'parafoveal' effects can instead be attributed to some property of the initial noun, it is apparent that this is extremely unlikely. In general terms, it seems clear that any property of these nouns which had a direct effect on fixation duration would be expected to influence the word's inspection pretty well regardless of the exact location of the fixation. It certainly would not be anticipated that lexical properties would influence fixation duration only for those instances where the fixation fell on the last few characters of the word (recall that it is only these fixations which show any indication of a difference in duration).

However, despite the implausibility of the argument, we can nevertheless consider whether there is any lexical property differing in the plausible and implausible conditions which might have such an effect. Clearly, it cannot be length or frequency, since these were matched. There are no systematic morphological differences between the nouns. The only possibility would appear to be the aforementioned difference in the number of non-human entities occurring in the two conditions. Ignoring, for the moment, the fact that the participant’s task was completely unrelated to meaning, and therefore that strategies based on meaning are very unlikely and also the reliability of the effects shown across the entire set of items tested, we can investigate this possibility directly by completing an analysis involving only the 13 item pairs containing human agents in both conditions. This analysis in fact shows a significant and numerically larger effect of plausibility on last fixation duration: mean fixation duration for plausible nouns was 248 ms and for implausible, 290 ms, $F_2(1,12) = 10.44, p < 0.01$. The conclusion is obvious.

Nor, of course, can it be the case that the effect is related to low level orthographic factors such as trigram frequency at the beginning of the 'parafoveal' word (see, e.g., Chapter 7), since this word (the verb) was identical in the two conditions. There therefore appears to be no property of the words involved, other than their combinatorial plausibility, which could give rise to the effects on fixation duration.

If we turn now to the where decision, it is clear, as previously mentioned, that with this manipulation at least, there was no effect on landing position on the verb or in the final noun phrase. Pragmatic plausibility did not significantly influence where the eyes landed in either of these regions. There was, however, an intriguing trend in
the saccade length measure for the saccade which left the initial NP and landed on the verb. When the verb was plausible, the average length of this saccade was 8.37 characters; when the verb was implausible, the length of the saccade was 8.66 characters. This difference, however, failed to achieve statistical significance, $F_1(1,20) = 1.96, p = 0.17; F_2(1,20) = 1.84, p = 0.19$. It is interesting, nonetheless, that it is in the direction of larger saccades following longer final fixations in NP1. To determine whether there was in fact a relationship between the duration of this fixation (which it will be recalled was influenced by the plausibility of the following verb) and the saccade which was launched from it, a correlational analysis was performed. This involved correlating duration of the fixation and saccade size for the full participants by items data matrix. To avoid introducing inter-subject variability into the analysis, all fixation durations and saccade sizes were ‘normalised’ by subtracting that participant’s mean on each of the measures. The resulting analysis showed a moderate, but significant, positive correlation between duration and extent, $r = 0.112, F(1,460) = 5.80, p = 0.016$. While this correlation does not account for a large percentage of the variance, it seems that the *when* and *where* decisions of eye movement control are not completely independent. There appears to be some tendency to ‘trade-off’ current inspection time against saccade size. Clearly, this result too suggests that the uptake of ‘parafoveal’ information is being monitored by the system which is responsible for launching the next saccade.

**General discussion**

These data (in concert with the results from many other studies) do not support ‘strong’ oculomotor theories, which deny or minimise the direct effect of linguistic variables on the current fixation. Not only does it appear to be possible to extract information about word identity within the necessary 100–150 ms needed to influence fixation duration, but the consequences of this word identity for both syntactic and semantic processing can be evaluated and, at least under some circumstances, influence the duration of the fixation. The coupling between eye movements and on-going cognitive processes appears to be even tighter than many would have envisaged even a few years ago.

There has undoubtedly been a ‘softening’ in the views of both oculomotor and ‘processing model’ theorists in recent years, with a convergence towards a middle ground where it is acknowledged that while oculomotor factors exert a major influence, there are at least *some* early effects of linguistic factors on eye movement control (e.g. O’Regan et al., 1994). Nonetheless, the speed, magnitude and nature of the higher-level effects reported here seems likely to reach beyond the bounds of what many oculomotor theorists would have been prepared to predict. It appears, however, that these effects are not susceptible to counter-explanation in terms of lower level factors.
The findings from this study are especially significant since the task employed is one which would be expected to, and has been shown to (e.g. Crain and Fodor, 1987; Forster and Stevenson, 1987; Freedman and Forster, 1985), engage only the most basic and fundamental reading processes. It is not the case that participants in the study needed to understand what the sentence was about, or remember its content, in order to complete the task. The results reported here relate only to their initial scanning of the first sentence presented by itself on the screen, but immediately following this, both this sentence and the comparison item were freely available for inspection as participants made their decision. Under these circumstances there can be little argument that the results are somehow a consequence of ‘experiment-specific strategies’. Rather, it appears that even high level information about sentence meaning directly, and very rapidly, influences basic reading dynamics.

While these data clearly support what Rayner et al. refer to as ‘processing models’, there are aspects of the results which do not accord with some of the details proposed by Morrison (1984) and later variants of this model. Specifically, it appears to be over-simplistic to conclude that there is any necessary functional distinction between information picked up from a word when it falls directly under the point of fixation and when it does not. There was no evidence, in this study at least, of any fundamental distinction between information about a word picked up by direct inspection, as compared to when the point of regard fell up to five character spaces to the left. It would be unwise to assume that information related to word identity can always be ascertained from such a distance. It may be the case that the nature of the task imposed a relatively light ‘foveal’ processing load (Henderson and Ferreira, 1993) and that this enabled greater uptake of ‘parafoveal’ information. But, where this information can be obtained, it appears to have immediate consequences. The span of apprehension is clearly not limited by word boundaries, and it seems that any information fed into the system during a fixation is, in principle, capable of influencing eye movement decisions.

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References


Appendix: Experimental materials

The savages/uranium smacked the child/money
The carpenter/ambulance cleared his throat/finger
The fugitive/pedigree groomed the horses/forest
The constable/islanders answered the telephone/orchestra
The tutor/trout delivered his sermon/bubble
The robbers/newborn rehearsed the part/meal
The hostess/charity weighed the carcass/sleeves
The lecturer/princess delivered the packages/wardrobe
The burglars/doorbell amused the crowd/grass
The comedians/lyricists picked the lock/lift
The labourer/bacteria stalked the tiger/algae
The housewife/alligator loaded the rifle/chair
The scientist/guerrilla arrested the criminals/ambulance
The policeman/therapist tested the chemicals/saxophone
The tailor/Libyan took the tickets/scenery
The bishop/knight carried the luggage/buttons
The guard/saint cooked the meal/beer
The hunters/bishops stacked the bricks/tulips
The servant/lawyers locked the gates/drums
The porter/rebels heard the organ/dolls
The vicar/beast corrected his pupil/giant
The soldiers/treasury were tipped by the customers/musicians
The politician/expedition wore the costumes/cylinder
The butcher/witches welcomed the guests/horses
CHAPTER 9

Foveal Processing Load and Landing Position Effects in Reading

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Abstract

In this chapter we describe two eye tracking experiments which investigated whether orthographic information may be extracted from the parafovea and used to guide the eye towards infrequent letter strings at the beginning of seven-letter target words. We also investigated whether the ease with which the preceding word was processed influenced the degree to which the point of fixation was attracted to an infrequent letter string. In the first experiment we manipulated whether a category word prior to the target word referred to an antecedent noun phrase which was either a typical or an atypical instance of that category. In the second experiment we used a possessive pronoun to refer to an antecedent noun phrase with a stereotypical gender which was either congruous or incongruous with the gender of the pronoun. Reading times during the first pass were not influenced by the two manipulations of foveal load. Additionally, there was no effect of the frequency of the initial trigram on where within the target word a reader initially fixated. However, the foveal load manipulations did cause differences on other eye movement measures indicating the manipulations were not entirely ineffective. Exploratory analyses in Experiment Two suggested that if subjects experience light foveal processing load, orthographic information in the parafovea may influence their landing position on the following word.
Introduction

Much of our insight into the processes involved in reading has come from studies which have used eye movement recording techniques. Such techniques provide a relatively natural, non-intrusive, 'on-line' method for studying reading, and allow inferences to be made concerning the perceptual and cognitive processes involved in reading (Rayner and Pollatsek 1989; Rayner et al., 1989; see also Chapter 3). In recent years much progress has been made in understanding how the eyes are controlled as we read. We now know that there are a large number of characteristics of text, both linguistic and visual, that influence where and for how long a reader spends fixating a portion of text as they read. More importantly, a number of these factors have been incorporated into models of eye movement control (e.g. Morrison, 1984; and more recently Reichle, Pollatsek, Fisher and Rayner, 1998) and these provide quite a good account of eye movement behaviour during reading.

Importantly, however, these models remain underspecified in two areas. First, they make no predictions concerning regressive saccades required for re-reading text that has already been processed. Such re-reading often occurs due to a failure in higher order processing, for example, a syntactic misanalysis. Upon detection of such a misanalysis, ongoing eye movement control processes are interrupted in order that the sentence may be re-read to permit the reader to reanalyse it. However, to date, such reanalysis procedures are not sufficiently well understood for them to be incorporated into a model of eye movement control. The second area of under-specification concerns the exact location of a fixation within a word. The models provide no account of where a reader will fixate within a word. Again, this is probably because the factors which influence where a reader fixates within text are not yet sufficiently well understood for them to be incorporated into a model of eye movement control during reading. In this chapter we will describe two experiments we conducted to investigate the factors that influence where a reader’s point of fixation will land on a word.

Although this question is not yet fully understood, a substantial amount of research has been conducted within this area. Indeed, a considerable number of experiments have been conducted to investigate whether a reader will fixate a string of letters within a word possessing certain orthographic or morphemic properties (Everatt and Underwood, 1992; Hyönä, 1995; Hyönä, Niemi and Underwood, 1989; Hyönä and Pollatsek, 1997; Inhoff, Briihl and Schwartz, 1996; Rayner and Morris, 1992; Underwood, Clews and Everatt, 1990; Underwood, Hyönä and Niemi, 1987). These studies have produced a number of conflicting findings. Some researchers have obtained results indicating that the point of fixation is drawn towards strings of letters within a word, while others have not. However, there is now a growing body of evidence to suggest that under certain circumstances certain orthographic and morphemic characteristics of a word do influence where the point of fixation will
land on that word. The issue now seems to be one of identifying the exact orthographic and morphemic characteristics along with the precise conditions which cause such effects occur.

Basic findings and terminology

When discussing experiments investigating landing positions, it is important to distinguish between two qualitatively different types of processing: Foveal and parafoveal processing. The fovea is that part of the retina that extends approximately 2° across the fixation point. Beyond the fovea, the parafovea extends a further 8° and the area which is beyond this is termed the periphery of vision (cf. Balota and Rayner, 1991). The eye movements we make during reading allow text to be viewed with the area of the retina where visual acuity is sharpest. The terms foveal and parafoveal processing are often used in the context of landing position experiments and in such circumstances psychologists term the fixated word the foveal word and the words to the right of the fixated word the parafoveal words. In this chapter we will adhere to this use of the terminology.

The extraction of orthographic information from parafoveal words

A series of studies by Underwood, Hyönä and their colleagues (Everatt and Underwood, 1992; Hyönä, 1995; Hyönä, Niemi and Underwood, 1989; Underwood, Clews and Everatt, 1990; Underwood, Hyönä and Niemi, 1987) have investigated whether there is a sensitivity to the orthographic frequency of letter strings within parafoveal words (i.e., the number of words which appear in the norms which are of a particular length and have a particular initial trigram). They have also investigated whether such orthographic information affects where the eye fixates on those words. Underwood, Hyönä and Niemi (1987) found that readers were more likely to fixate an infrequently occurring letter string than a frequently occurring letter string at the beginning of a word. They termed this effect the landing position effect. More recently, Hyönä (1995) has suggested that these results may be explained in terms of an Attraction hypothesis. Hyönä suggests that unusual (i.e., infrequent) letter strings attract the point of fixation as people read because they represent a less familiar stimulus in the parafovea. Hyönä provided evidence in favour of this claim by showing that a highly infrequent letter cluster at the beginning of a ten or eleven character word caused people to land close to the beginning of the word.

However, Underwood, Bloomfield and Clews (1988) found that infrequent letter clusters did not attract the point of fixation. Furthermore, studies by Underwood and his colleagues which found a landing position effect have come under criticism from
Rayner and Morris (1992). Rayner and Morris argued that such higher level processing of parafoveal words would require complex processing and decision processes inconsistent with the time constraints typical in normal reading. They further argued that the eyetracking system used by Underwood and his colleagues was unreliable considering the small size of the effect obtained. They attempted to replicate the findings of Underwood, Clews and Everatt (1990) using the same stimuli, but found no difference in the landing position on the target word as a function of word type. Rayner and Morris concluded that “low level visual information (primarily word length) is the primary determinant of the initial landing position on a word in reading” (p. 170).

Underwood, Clews and Everatt (1990), acknowledged that the landing position effect is small and has emerged only as a trend in some previous experiments (Underwood, Bloomfield and Clews, 1989; Hyönlä, Niemi and Underwood, 1989, Experiment 3). They suggested that it is possible that readers do not always make use of orthographic information from parafoveal vision in the guidance of their eyes and that the landing position may be determined by parafoveal processing in some cases, and rightwards movement insensitive to orthographic information in others. A factor that has been shown to influence the amount of preview benefit gained from a parafoveal word is foveal processing difficulty (Henderson and Ferreira, 1990).

Henderson and Ferreira presented subjects with sentences and independently manipulated both the difficulty of the foveal word and the availability of parafoveal information through the use of the boundary technique (Rayner, 1975). In studies employing the boundary technique, as the point of fixation passes an invisible boundary in the text, the linguistic information to the right of the boundary is changed in some way. In Henderson and Ferreira's study, the preview of the parafoveal word was either visually similar or dissimilar to the word that replaced it when the boundary was transgressed. Foveal difficulty was manipulated lexically as a function of the frequency of the foveal word. They found that when the foveal word had a high frequency, a parafoveal preview of the next word was more beneficial than when the foveal word had a low frequency. In a second experiment they manipulated the syntactic difficulty of the text prior to the parafoveal word and again demonstrated a reduced parafoveal preview benefit when foveal processing was high. They concluded that the perceptual span, that is, the area of effective vision during reading, is variable and attentionally constrained, being shorter when foveal processing load is high and longer when foveal processing load is low.

Henderson and Ferreira (1990, 1993; Rayner, 1986; and see also Reichle et al., 1997) proposed a model, the sequential attention model, explaining the relation between covert visuo-spatial attention and eye-movement control, based on Morris-on’s (1984) model. The model proposed that at the beginning of a fixation on a new word, attention is allocated to that word. When processing on that word is complete, attention is redirected to a new word allowing a higher level analysis of that word.
This relocation of attention is the signal to move the eyes, and an eye-movement is programmed, taking as its new location the word to which attention is directed. A saccade then brings the eyes to the attended word but this follows an eye-movement programming latency. Therefore, there is a preview benefit derived from the parafoveal word as a function of the latency between the shift of attention and the saccade to that word. To account for their finding that foveal processing difficulty decreased parafoveal preview benefit, Henderson and Ferreira added a programming deadline assumption to the model. If processing of the fixated word is difficult then a programming deadline may be reached before attention has shifted to the next word. In this case an eye-movement is programmed prior to the shift of attention. If processing on the fixated word is subsequently finished, attention shifts to the next word, but the latency between this shift and the next eye-movement will be reduced, thus reducing attentive parafoveal processing and so the preview benefit. This model suggests that if foveal processing load is high, then the ability to detect orthographically infrequent strings of letters in parafoveal words will be reduced. This in turn suggests that the landing position effect should be more apparent in situations where foveal processing load is low than when it is high.

In our studies we attempted to determine two things. First, whether the point of fixation was attracted to an infrequent letter string at the beginning of a word. We therefore used target words with either an initial trigram which occurred frequently for seven letter words, or an initial trigram which occurred relatively infrequently for such words. Secondly, whether sensitivity to orthographic information within the parafovea is modulated by foveal processing difficulty.

**Experiment One: Imposing a foveal load with category typicality**

In Experiment One we required a means of manipulating processing load on the word prior to a target word with a frequent/infrequent initial trigram. There are many factors which have been demonstrated to influence foveal processing difficulty, however, for this study the means of inducing such difficulty must possess two important characteristics. First, foveal processing difficulty must be induced by a small localised area of the sentence (preferably a word). Secondly, whilst the tool must induce sufficient processing difficulty to potentially influence parafoveal processing, it must not cause subjects to make a regressive saccade (otherwise it will be impossible to observe the influence of attentional demand on the position of the subsequent fixation on the word to the right). In addition, it is desirable to ensure that the sentence fragment immediately preceding the target word has similar content under each of the four conditions to ensure that the characteristics of the target word could be the only cause of any landing position effect which might occur.
One phenomenon which induces foveal processing difficulty and which has been shown to be localised to a word, is the process of anaphoric assignment (Garrod and Sanford, 1977; Duffy and Rayner, 1990). In a whole sentence self paced reading study Garrod and Sanford (1977) presented pairs of sentences to subjects. The first sentence contained an instance of a category (e.g., robin) and the second sentence contained the category noun (e.g., bird). Garrod and Sanford manipulated the typicality of the instance, on half the occasions the instance being typical (e.g., robin), and on half the occasions the instance being atypical (e.g., ostrich). They found that the category sentences took longer to read when the sentences contained an atypical instance than when they contained a typical instance.

While the study by Garrod and Sanford indicated processing difficulty for category words following atypical instances, their measure of reading time was not sufficiently fine-grained to allow us to be sure that processing difficulty occurred when subjects first read the category noun. However, more recently, Duffy and Rayner (1990) conducted an experiment using eye tracking methodology and sentences similar to those used by Garrod and Sanford (see also Rayner, Raney and Pollatsek, 1995). They found that gaze durations on the category noun and the portion of the sentence immediately after the category noun were longer when the instance in the preceding text was atypical than when it was typical. However, this difference only occurred when the antecedent was close to the anaphor in the text. We therefore constructed pairs of sentences like (1)-(4) below containing either a typical or an atypical instance of a category word which appeared in the second of the sentences. The category word immediately preceded a word which either contained an infrequent initial trigram (e.g., irksome) or a frequent initial trigram (e.g., trivial).

1. The man hated to watch cricket.
   He found the sport irksome and boring.
   (Typical Infrequent)

2. The man hated to watch hurling.
   He found the sport irksome and boring.
   (Atypical Infrequent)

3. The man hated to watch cricket.
   He found the sport trivial and boring.
   (Typical Frequent)

4. The man hated to watch hurling.
   He found the sport trivial and boring.
   (Atypical Frequent)

We predicted that subjects should spend longer reading the category noun after an atypical instance than after a typical instance. We also predicted that this effect
should interact with the landing position on the following word such that when foveal processing load was light, subjects should fixate closer to the beginning of a word with an infrequent initial trigram than to the beginning of a word with a frequent initial trigram. Conversely, when foveal processing load was high, we anticipated no difference in landing position on the target word.

**Method**

**Subjects**
Thirty-two subjects from the University of Nottingham participated in the experiment.

**Materials**
A prescreen experiment was conducted to obtain typicality ratings for the instances of each category used in the experiment. An analysis of variance (ANOVA) showed subjects gave higher typicality ratings to the typical instances than the atypical instances: $F_1(1,13) = 147.026, p = 0.0001, MS_e = 0.320$; $F_2(1,35) = 267.360, p = 0.0001, MS_e = 0.462$. Using these instances and categories, four files of thirty-six experimental sentence pairs, along with forty intermixed filler sentence pairs were constructed. Each file contained nine items from each condition, such that only one form of each material appeared in each list. The experimental sentence pairs contained an instance of a category in the first sentence. This was either a typical instance or an atypical instance. The category was given in the second sentence. A seven letter word (the target word) immediately followed the category in the second sentence and either contained an infrequently occurring initial trigram, or a frequently occurring initial trigram (i.e., a manipulation of Type Frequency, see Chapter 7). These words were matched for length and syntactic class. The words with an infrequently occurring initial trigram had a first bigram frequency, a second bigram frequency, and a first trigram frequency of less than or equal to 9 in a sample of 20,000 words. The words with a frequently occurring trigram had a first bigram frequency, a second bigram frequency, and a first trigram frequency of greater than or equal to 20 in a sample of 20,000 words (Mayzner and Tresselt, 1965; Mayzner, Tresselt and Wolin, 1965). The sentence pairs were presented one above the other on a computer screen with a blank line between them, thereby minimising the possibility that readers could detect the category word in the second sentence whilst still reading the first sentence.

**Apparatus**
Subjects' eye movements were monitored using a SRI Dual Purkinje Generation 5.5 eyetracker produced by Fourward Technologies. The eyetracker has angular resolution of 10° arc. Subjects used both eyes to read, but the tracker monitored only the right eye. Materials were presented on a VDU at a distance of 70 cm from
subjects' eyes. The VDU displayed four characters per degree of visual angle (cf. Rayner and Morris, 1992). The tracker monitored subjects' gaze location every millisecond and the software sampled the tracker's output to establish the sequence of eye fixations and their start and finish times.

Procedure
A bite bar and a head restraint were used in order to minimise head movements during the experiment. The eye-tracking system was then calibrated. When the subject was calibrated, the sentence pairs were presented one at a time on the screen. Four practice sentence pairs were displayed first, followed by a mixture of experimental and filler sentence pairs. The subject pressed a key to indicate that they had read the sentence and on a proportion of trials received a question to ensure comprehension. The experiment lasted approximately 45 minutes.

Results
For the analysis of the results, the experimental sentences were divided into four regions, indicated by the slashes as follows:

The man hated to watch cricket.
He found the sport irksome and boring.

We computed first pass reading times for Regions One and Two. We defined first pass reading time as the sum of all fixations from the first fixation in a region until the point of fixation exited the region to either the left or the right. For Region Two, in which we anticipated differences in reading time due to anaphoric processing, we also considered the first fixation duration and also the duration of the last fixation in Region Two prior to direct fixation of Region Three. In addition to the reading time measures, we considered the landing position in Region Three. Trials where tracker loss occurred, and trials on which Region One, Regions Two and Three, and Region Four had zero first pass reading times were excluded from the reading time analyses. This procedure removed 6% of the data.

A $2 \times 2$ ANOVA was carried out for these measures across both subjects ($F_1$) and items ($F_2$). The mean reading times for Regions One and Two and the landing positions and saccade lengths in Region Three are shown in Table 1.

For the first pass reading times in Region One, a main effect of Typicality was observed: $F_1(1,31) = 12.657, p = 0.0012$, $MS_e = 9.299; F_2(1,35) = 16.062, p = 0.0003$, $MS_e = 9.751$. As expected in this region, there was no main effect of Initial Trigram ($F_1$, $F_2 < 1$) and no interaction between Initial Trigram and Typicality ($F_1$, $F_2 < 1$). Subjects' first pass reading times in Region One were longer when the region contained an atypical rather than a typical instance, even though at this point in the sentence the category word had not yet been read.
Table 1
Mean first pass, and first fixation times for Regions One and Two, and landing positions for Region Three under the four conditions of Experiment One

<table>
<thead>
<tr>
<th>Measure</th>
<th>Typical Infrequent</th>
<th>Typical Frequent</th>
<th>Atypical Infrequent</th>
<th>Atypical Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean first pass reading time for Region One (ms/C)</td>
<td>37.3</td>
<td>37.1</td>
<td>39.2</td>
<td>39.0</td>
</tr>
<tr>
<td>Mean first fixation duration in Region Two (ms)</td>
<td>240.9</td>
<td>227.5</td>
<td>230.1</td>
<td>232.9</td>
</tr>
<tr>
<td>Mean first pass reading time for Region Two (ms/C)</td>
<td>26.9</td>
<td>27.9</td>
<td>27.2</td>
<td>27.2</td>
</tr>
<tr>
<td>Mean last fixation duration in Region Two (ms)</td>
<td>228.5</td>
<td>228.3</td>
<td>224.9</td>
<td>224.2</td>
</tr>
<tr>
<td>Mean landing position in Region Three (Chars)</td>
<td>4.99</td>
<td>4.91</td>
<td>4.70</td>
<td>4.67</td>
</tr>
</tbody>
</table>

There was no main effect of Typicality or of Initial Trigram on the duration of the first fixation in Region Two ($F_1, F_2 < 1$). There was also no interaction between the two ($F_1(1,31) = 1.566, p = 0.2202, MS_e = 1348.470; F_2(1,35) = 1.102, p = 0.3011, MS_e = 2294.340$). Similarly, for first pass reading time in Region Two, there was no main effect of Typicality, or of Initial Trigram and no interaction between the two (all $F < 1$). Finally, an analysis of the duration of the fixation prior to direct fixation of Region Three showed no main effect of Typicality, no main effect of Initial Trigram and no interaction (all $F < 1$). Clearly, effects of typicality were observed in Region One, but no such effects were apparent for the reading time analyses of Region Two.

For the landing position analyses, additional trials were removed from the data set. Those trials where subjects did not fixate Region Three during first pass reading and those trials where subjects skipped the category noun were excluded from the analysis. This procedure removed a total of 20.1% of the data. We counted the space before the word as landing position 1.

Analyses of variance showed no main effect of Initial Trigram ($F_1, F_2 < 1$). However, a main effect of Typicality was almost significant by subjects and items: $F_1(1,31) = 3.787, p = 0.0608, MS_e = 0.589; F_2(1,35) = 3.545, p = 0.068, MS_e = 0.424$. No interaction was found ($F_1, F_2 < 1$). These results suggest that while the reading times in Region Two were insensitive to Typicality effects, there was at least the suggestion that landing position on the following word was affected. The nature of the target word's initial trigram did not modulate this effect.
Discussion

In this experiment, the influence of foveal processing difficulty on the occurrence of the landing position effect in reading was examined. It was predicted that a category name would take longer to process when its antecedent was an atypical, rather than a typical, exemplar of that category. It was also predicted that when the category word was easy to process, the point of fixation would land closer to the beginning of a target word with an infrequently occurring initial trigram compared to a target word with a frequently occurring initial trigram. Following Henderson and Ferreira’s (1990, 1993) sequential attention model, and Hyönä’s (1995) attraction hypothesis, it was anticipated that increased foveal load would reduce the amount of information extracted from the parafovea and so reduce the extent to which a fixation was attracted by an infrequent letter string at the beginning of a word.

While we observed no effect of typicality for the category noun, typicality did influence first pass reading times for Region One and also the landing position in Region Three. Clearly, the typicality of the instance did affect how easily subjects found sentences to process. However, the lack of an effect of typicality on reading times for Region Two was somewhat surprising as such a result is in disagreement with the findings of Duffy and Rayner (1990).

The effect of typicality found in Region One may be explained in three ways. First, perhaps subjects started reading the first sentence and somehow, either with or without direct fixation, detected the category word in the second sentence at this point. We feel that this possibility is extremely unlikely because the sentences were spaced a blank line apart thereby reducing the possibility that subjects could have detected the category word without direct fixation. Furthermore, the first pass reading times for Region One were quite long (mean = 38.2 ms/C). However, this would not have been the case if subjects had directly fixated Region Two because such a saccade would have transgressed a Region One boundary thereby cutting short first pass reading times for that region.

A second possibility is that when the instance word in the first sentence is encountered, information concerning its category becomes available automatically from its lexical representation. For example, the representation of the word cricket may contain information concerning membership of the category sport and hence such information may become available automatically. If this is the case, then the atypicality of an instance could cause the increased reading times without subjects necessarily reading the category noun. Hence, the longer reading times may have been due to the category of the instance becoming available when the instance itself was lexically accessed. Alternatively, because typicality and frequency are highly correlated, the differences in reading time observed over Region One may arise due to the lower frequency of the atypical instances compared to the typical instances. However, frequency effects are usually short lived and it would be a little surprising
to see frequency effects spill over several words downstream. Whatever the reason for the difference, it is clear that reading times for Region One were affected by the typicality of the instance prior to subjects encountering the category noun.

Whilst typicality did not influence reading times for Region Two, there was an unpredicted marginal effect on the landing position on the target word following the category noun. The initial fixation on the target word was closer to the beginning when the instance was atypical than when it was typical. This finding may offer support to Henderson and Ferreira's view that when readers experience a light foveal processing load they are able to extract more information from the parafovea than when foveal processing load is heavy. If processing of the fixated word is difficult, then parafoveal preview benefit will be reduced. When a reader makes an eye movement they may fixate a position in a word that coincides with the point at which they need to obtain further information about that word. When foveal processing load is light, readers may process the first few letters of the subsequent word and therefore when they fixate that word they may fixate farther into it, to a point where they can gain new information. In contrast, when foveal processing is heavy the reader may fixate closer to the beginning of the following word because less information would have been extracted from the subsequent word.

The lack of an effect of typicality on reading times of the category words in the present study is unlikely to be due to the typical and atypical instances used not being perceived as typical and atypical by the subjects. Pre-screening, together with the typicality effect on first pass reading times for Region One and on the landing position on Region Three argue against this explanation. However, in our materials the category word was not always part of a simple definite noun phrase whereas in the Duffy and Rayner study it was. Some of our items contained demonstrative noun phrases and some were adjectival definite noun phrases. Hence, it is possible that the referential effects we observed were slightly delayed until the eye left the category noun to the right at which point referential processing affected fixation locations on the target word.

The landing position in Region Three was uninfluenced by the nature of the initial trigram of the target word with no observable landing position effect. This result suggests that under these experimental conditions, the point of fixation was not attracted towards the infrequent letter strings. The results of this experiment were not entirely as anticipated. The manipulation of foveal load was not localised to Region Two as we expected and although we found some evidence suggesting a landing position effect, it was due to the manipulation of typicality rather than to the nature of the initial trigram of the target word. We therefore ran a second experiment to see if we observed similar effects when we kept the characteristics of the target words the same, but changed the manipulation of foveal processing load.
Experiment Two: Imposing a foveal load with gender role typicality

In Experiment Two, we required an alternative means of manipulating foveal processing load prior to the reader directly fixating the target word. Once more we require that this manipulation is localised to a short region of a sentence but does not cause the reader so much disruption that they have to make a regressive saccade in order to re-read the sentence. We also require that content differences in the sentence fragment up to the target word are minimised. Kerr and Underwood (1984) reported an experiment in which they manipulated gender of a pronoun so that it was either congruous or incongruous with the stereotypical gender of an antecedent noun phrase in the preceding sentence (see also Carreiras, Garnham, Oakhill and Cain, 1996). Kerr and Underwood constructed passages with three sentences, the first of which contained a noun phrase such as the surgeon, which has a strong stereotypical gender associated with it. The third sentence contained a pronoun which referred to the antecedent noun phrase and either matched or mismatched its stereotypical gender. Kerr and Underwood found that subjects spent less time initially fixating the pronoun when it matched the stereotypical gender of the antecedent noun phrase than when it did not. Such a manipulation would appear to be ideal for Experiment Two. This would be particularly so if a possessive pronoun was used, as her and his have the same number of letters, thereby minimising differences in the region before the target word. We therefore incorporated this manipulation in Experiment Two. As before, we attempted to determine whether a reader's point of fixation landed closer to the beginning of a word when it had an infrequent initial trigram compared to a frequent initial trigram. We also tested whether such a landing position effect was modulated by the ease with which the preceding word was processed.

Sentences like (5)-(8) below were constructed. The sentences contained a possessive pronoun which was either congruous or incongruous with the stereotypical gender of an antecedent noun phrase in the preceding sentence. The pronoun immediately preceded a word which either contained an infrequent initial trigram (e.g. abysmal) or a frequent initial trigram (e.g. bermuda).

5. The football coach frequently wore outrageous clothing.  
   Due to their bright colours his abysmal shorts looked ridiculous.  
   (Congruous Infrequent)

6. The football coach frequently wore outrageous clothing.  
   Due to their bright colours her abysmal shorts looked ridiculous.  
   (Incongruous Infrequent)

7. The football coach frequently wore outrageous clothing.  
   Due to their bright colours his bermuda shorts looked ridiculous.  
   (Congruous Frequent)
8. The football coach frequently wore outrageous clothing.  
Due to their bright colours her bermuda shorts looked ridiculous.  
   (Incongruous Frequent)

The predictions in Experiment Two were the same as those for Experiment One. We anticipated an interaction between the congruity of the gender match and the nature of the target word. More specifically, when the stereotypical gender of the antecedent noun phrase matched that of the pronoun we predicted a landing position effect on the target word with initial fixations landing closer to the beginning of target words with an infrequent initial trigram compared to target words with a frequent initial trigram. However, when the stereotypical gender of the antecedent noun phrase did not match that of the pronoun we expected no difference in landing positions on the target word.

**Method**

**Subjects**
Thirty-six subjects from the University of Nottingham participated in the experiment.

**Materials**
Four files of twenty-four experimental sentence pairs, along with forty intermixed filler sentence pairs were constructed. Each file contained six items from each condition, such that only one form of each material appeared in each list. The experimental sentence pairs contained an antecedent noun phrase in the first sentence with a strong stereotypical gender cue associated with it. In the second sentence a possessive pronoun which either matched or mismatched the stereotypical gender of its antecedent immediately preceded the target word. The target words had the same characteristics as those used in Experiment One.

**Apparatus and procedure**
The apparatus and procedure were identical to that of Experiment One.

**Results**
The experimental sentences were divided into four regions, indicated by the slashes as follows:

"The football coach frequently wore outrageous clothing.  
Due to their bright colours/ his/ abysmal/ shorts looked ridiculous."

We computed first pass reading times for Regions One and Two and the landing position in Region Three. The reading time definitions remained the same as for
Experiment One. A 2(Gender Congruity) x 2(Initial Trigram) ANOVA was carried out across subjects ($F_1$) and items ($F_2$). The mean reading times for Regions One and Two and the landing positions in Region Three are shown in Table 2.

For the first pass reading times in Region One, there was no effect of Gender Congruity ($F_1, F_2 < 1$). There was also no effect of Initial Trigram ($F_1 < 1; F_2(1,23) = 1.358, p > 0.05, MS_e = 68764.7$) and no interaction between Initial Trigram and Gender Congruity ($F_1, F_2 < 1$). Somewhat surprisingly, there was also no effect of Gender Congruity or of Initial Trigram on the duration of the first fixation on the pronoun. There was also no interaction between the two (All $F < 1.1$). Similarly, for first pass reading time in Region Two, there was no main effect of Initial Trigram ($F_1(1,35) = 1.295, p > 0.05, MS_e = 2469.6; F_2(1,23) = 1.058, p > 0.05, Mse = 2913.4$), no main effect of Gender Congruity ($F_1, F_2 < 1$) and no interaction between the two ($F_1, F_2 < 1$). Clearly, we did not obtain the effects of Gender Congruity on the pronoun as anticipated. However, the mean first fixation durations and first pass reading times for Region Two were quite short. This was due to subjects skipping the pronoun on a large proportion (59.3%) of trials. We therefore repeated the ANOVAs on the data, replacing the zero first fixation and first pass reading times with the global mean, but obtained very similar patterns of effects to those obtained with the zeros included. Consequently, we recomputed the first fixation and first pass reading times for a redefined Region Two which included the word preceding the pronoun. Our rationale for the redefinition of Region Two was that if subjects were skipping the pronoun, then they were probably processing it when they were fixating the word to its left. Therefore, on those occasions when subjects skipped the
Table 3
Mean first pass, and first fixation times for the two-word Region Two in the four conditions of Experiment Two

<table>
<thead>
<tr>
<th>Measure</th>
<th>Congruous</th>
<th></th>
<th>Incongruous</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrequent</td>
<td>Frequent</td>
<td>Infrequent</td>
<td>Frequent</td>
</tr>
<tr>
<td>Mean first fixation duration in</td>
<td>194.9</td>
<td>203.2</td>
<td>187.6</td>
<td>202.8</td>
</tr>
<tr>
<td>the Extended Region Two (ms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean first pass reading time for the</td>
<td>259.1</td>
<td>271.2</td>
<td>268.1</td>
<td>275.6</td>
</tr>
<tr>
<td>Extended Region Two (ms/C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pronoun, the fixation(s) which could possibly show an effect of Gender Congruity were not being included in our first set of analyses for the one word Region Two and we may therefore have missed an effect. The mean first fixation durations and first pass reading times for the redefined Region Two are given in Table 3.

Despite the fact that redefining Region Two reduced the number of skipped trials (to 11.6%), the results were very similar to those obtained when only the pronoun was included. There was no effect of Gender Congruity or of Initial Trigram on the duration of the first fixation on the region. There was also no interaction between the two (all $F < 1.1$). Similarly, for first pass reading time in Region Two, there was no main effect of Initial Trigram, no main effect of Gender Congruity and no interaction between the two (all $F < 1$).

For the landing position analyses, we removed those trials where subjects did not fixate Region Three during first pass reading and those trials where subjects skipped the enlarged two word Region Two were excluded from the analysis. As before, the space before the word was landing position 1. Analyses of variance showed no main effect of Initial Trigram ($F_1, F_2 < 1$), no main effect of Gender Congruity ($F_1, F_2 < 1$)

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1 Although the sentences were necessarily different in the target region and were therefore not controlled for sense-semantic plausibility, we did compute total reading times to check whether there was an effect of gender congruity at all. Interestingly, these analyses showed highly significant effect of gender congruity on Regions Two ($F_1(1,36) = 10.8, p < 0.01, MS_e = 7213.0; F_2(1,24) = 10.3, p < 0.01, MS_e = 4219.4$), a marginal effect on Region Three ($F_1(1,36) = 2.8, p < 0.11, MS_e = 23865; F_2(1,24) = 5.2, p < 0.05, MS_e = 9033.0$), and a significant effect on Region Four ($F_1(1,36) = 6.58, p < 0.05, MS_e = 98827.9; F_2(1,24) = 5.84, p < 0.05, MS_e = 66424.9$). While we interpret these findings with caution, the implication is that in this experiment, stereotypical gender information associated with an antecedent noun phrase had an effect on possessive pronoun resolution, but this occurred relatively late during sentence comprehension.
and no significant interaction between the two ($F_1(1, 35) = 1.910, p > 0.05, MS_e = 0.851; F_2(1, 23) = 1.077, p > 0.05, MS_e = 0.343$). As with the findings of Experiment One, these results suggest that the frequency of a word’s initial trigram did not influence the location of a reader’s initial fixation on the word.

We also conducted some exploratory analyses, in response to our failed attempt to cause a variation in foveal load. To reiterate, following the appearance of a gender-associated noun phrase (e.g., football coach) a subsequent congruous stereotypical possessive pronoun (his) was intended to induce a low foveal load, thereby allowing greater parafoveal processing compared with when a non-stereotypical pronoun (her) appeared. As we have seen, this manipulation had minimal effects on our measures of early processing difficulty. Gender Congruity had no effect upon the duration of the first fixation on the pronoun, or upon the first pass reading time, for analyses in which the region on and around the pronoun was defined in different ways.

We therefore conducted an analysis of the data in which we considered a sub-sample of the data obtained in the experiment. Within each of the four conditions of the experiment (congruency of pronoun vs. frequency of the initial trigram of the critical word) we selected the single sentence in which the reader gave the least visual attention to the redefined Region Two (i.e. the shortest gaze duration), and the single sentence receiving the greatest amount of attention in Region Two (i.e. the longest gaze duration). Selecting a subset of the data in this manner prevented us from computing item analyses, and therefore, only subjects effects are reported below. The landing position on the critical word was obtained for these four conditions for each subject. The mean landing positions are given in Table 4 and are shown in Fig. 1.

An ANOVA applied to these landing positions revealed no main effect of Gender Congruity ($F < 1$) and no main effect of Initial Trigram ($F < 1$), in line with results from the original analyses of the complete data matrix. There was a main effect of gaze duration on Region Two ($F(1, 35) = 9.412, p < 0.01, MS_e = 25.087$), with the first fixation on the critical word being further into that word (4.66 characters) when Region Two received more attention than when it received less attention (4.07 characters). Importantly, Initial Trigram interacted with Visual Attention ($F(1, 35) = 7.158, p < 0.05, MS_e = 23.920$; see Fig. 1). Pairwise comparisons showed that when foveal attentional demand was low in Region Two, there was a difference between the landing position on critical words containing frequent and infrequent trigrams ($p < 0.05$). Subjects fixated farther into words containing frequent trigrams than words containing infrequent trigrams. However, when foveal attentional demand was high, the reader fixated approximately the same position in the word regardless of whether the initial trigram of the word was frequent or infrequent ($p > 0.05$).

While the analyses described above provide an interesting pattern of data, they must be interpreted with care. In order for us to make the comparison of landing positions for sentences in which foveal processing demand was high or low, it was
Table 4
Mean saccade lengths into Region Three in the four conditions of Experiment Two

<table>
<thead>
<tr>
<th>Measure</th>
<th>Congruous</th>
<th></th>
<th>Incongruous</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Infrequent</td>
<td>Frequent</td>
<td>Infrequent</td>
<td>Frequent</td>
</tr>
<tr>
<td>Least attention to Region Two.</td>
<td>10.53</td>
<td>10.17</td>
<td>10.53</td>
<td>9.00</td>
</tr>
<tr>
<td>Mean saccade length from Region Two (character spaces)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greatest attention to Region Two.</td>
<td>9.69</td>
<td>9.69</td>
<td>9.56</td>
<td>10.11</td>
</tr>
<tr>
<td>Mean saccade length from Region Two (character spaces)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Mean landing positions in Region Three for the selected trials for the four conditions of Experiment Two.
necessary to discard a large proportion of the trials contributing to the two conditions. It is quite possible that some of the sentences might have been particularly easy to understand, and others particularly difficult in the high and low foveal load conditions. It seems most unlikely that the sentences that we constructed were equally difficult to read. If it is the case that some sentences caused long reading times because they were intrinsically difficult, and others cause short reading times because they were intrinsically easy, then the sentences will not be evenly represented in the analysis reported above. In such a situation the landing position effect could have been caused by specific sentences contributing to the cells containing the trials in which subjects experienced least difficulty, and other sentences contributing to the trials in which subjects experienced most difficulty. In other words, we would not be able to say that the effect generalised across the target words used in the study to any extent.

To check whether this was a problem we compared the number of times that individual sentences appeared in these two cells. If region two of certain sentences always receives short fixations, and region two of other sentences always received longer fixations, then we should expect a negative correlation between the frequencies with which individual sentences appear in the two cells. The correlation emerging from this comparison was not reliable \( r(24) = +0.134, p > 0.1 \), suggesting that there was no systematic bias in the sentences entered into the comparison of least and greatest attention in Region Two.

A second possible problem with the analysis of landing positions in Region Three is that the differences were a product not of selected landing positions, but of differences in the location of the previous fixation. If saccadic movements were of a constant amplitude, then the landing position effect would be attributable to the position from which the eye movement was launched. Accordingly, we conducted an analysis of the length of a saccade into the region, using the same factors as were used in the analysis of landing positions. The mean saccade lengths are presented in Table 4, and are represented as character spaces from the landing position in Region Three. An analysis of variance found no main effects of the amount of attention given to Region Two, of Gender Congruity, or of the Initial Trigram of the critical word in Region Three. There were no interactions. These results suggest that the difference in landing position could be due to differences in launch position.

Discussion

The results of Experiment Two are quite interesting. The failure to find effects of Gender Congruity on first pass reading time measures may be explained in two ways. Either readers do not make an anaphoric assignment immediately upon encountering a possessive pronoun. If this was the case, then we would not anticipate that they would detect any gender incongruity until later in the sentence.
Alternatively, it is possible that readers make an anaphoric assignment, but stereotypical gender information associated with the antecedent noun phrase is not made available until the point of fixation has left the pronoun. If either of these interpretations are correct, then they are at odds with the findings of Kerr and Underwood (1984). Given the failure to find effects of gender congruity, we are again unable to make assertions regarding whether sensitivity to orthographic information in the parafovea was modulated by foveal processing demand. Consistent with Experiment One, we found no main effect of initial trigram frequency. Again, the basic analyses showed that readers landed on about the same position in target words with both frequent and infrequent initial trigrams. The exploratory analyses produced a rather more interesting pattern of effects, however. Although we must interpret the data with care, it does appear that when we consider only those trials in which there was a low foveal processing load, we do obtain a pattern of landing position effects suggesting that a reader’s point of fixation may be attracted to an infrequent initial trigram. Since the same effects did not occur when foveal processing load was high, the exploratory analyses suggest that sensitivity to orthographic information in the parafovea may be modulated by foveal processing load. Such data provide support for Henderson and Ferreira (1990).

Conclusion

To conclude, we conducted two studies to determine whether the point of fixation was attracted to an infrequent letter string at the beginning of a word when it was first fixated. We also investigated whether the degree to which orthographic information was extracted from the parafovea is modulated by foveal processing demands. In both experiments the manipulation of foveal processing load did not influence first pass reading time measures. We were therefore unable to provide a rigorous test of whether foveal load modulates the extraction of orthographic information from the parafovea. The data of both experiments provide further evidence to suggest that landing position effects are not robust. However, the exploratory analyses of Experiment Two do at least suggest that under a light foveal processing load the reader’s point of fixation may be attracted to orthographically infrequent strings of letters at the beginnings of words in the parafovea.

Acknowledgements

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References


CHAPTER 10

Individual Differences in Reading and Eye Movement Control

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Abstract

As with other chapters in this book, this chapter emphasizes factors influencing eye movement control. It also discusses such control from the viewpoint of the process of reading and hypothesized linguistic influences on saccadic movements and fixations. However, it differs from other chapters by considering the effects of reading ability upon eye movement control. In terms of linguistic influences, the chapter presents evidence for initial fixations within words being affected by the informativeness/distinctiveness of sections within those words, evidence which also indicates that this effect is not influenced by semantic aspects of the text. In terms of reading ability, the chapter considers evidence for a relationship between the initial fixation location effect and reading ability in able readers. It further investigates such relationships by comparing eye movement control within reading disabled and matched control subjects. These data suggest that a number of individuals diagnosed as dyslexic show less influence of informativeness/distinctiveness ahead of fixation, and this is related to lower levels of reading ability within these subjects. The chapter concludes with a discussion of potential explanations for this relationship between reading deficits and the initial fixation location effect. The evidence presented indicates that the initial fixation location effect can be found within a wide range of different situations and, to some extent, is affected by variables commonly found to influence reading performance. In terms of the two factors which the referenced series of studies investigated, the initial fixation location effect seems to be more affected by the skill of the reader (at least within those with reading problems) than the semantic context within which informative beginning/ending words appear.
General introduction to the initial fixation location effect

A large proportion of this book has concerned the processes that guide saccadic movements through a text — the processes guiding the eyes from one fixation to the next. This chapter concentrates on one potential influence upon this process, that of within-word letter sequences, or within-word informativeness. There is now substantial evidence indicating that the informativeness or distinctiveness of sequences of letters within words can influence the movements of the eyes within that word. For example, O'Regan et al. (1984) presented French subjects with words with unequal distributions of information. Informative parts of words were identified as the first or last six letters of the word, with these sequences of letters uniquely identifying those words within the reader’s lexicon. Analogous words can be found in the English language. For example, in the word ‘moralistic’ the initial five letters are highly distinctive (there are very few other words that begin with this sequence of letters), but the final five letters are less rare. In contrast, a word such as ‘supervisor’ contains a common initial sequence of letters, but a distinctive final sequence.

O'Regan et al. (1984) presented such words to subjects with the initial fixation imposed on certain letters within the word. If the initial fixation was positioned at the beginning of a word, words with informative beginnings were characterized by a long fixation in their first half, while words with informative endings showed a shorter fixation at the beginning, a saccade towards the end of the word, and a longer fixation at this informative ending. Subsequent studies by O'Regan and Levy-Schoen (1987) provided evidence that the ‘convenient viewing position’ was shifted slightly to the right in words with informative endings. The convenient viewing position was a term used by O'Regan (1981) to refer to the position within a word that, if fixated, produced shorter overall gaze durations. This was assumed to be because less processing was required at this position. Within words with informative beginnings, gaze durations were shortest around the letter just to the left of centre, while for words with informative endings the gaze durations were shortest at a position further to the right. Similarly, O'Regan and Jacobs (1992) argued that there is an ‘optimum viewing location’ within a word and presented evidence that word recognition processes are more efficient if the eyes are located on this point. Such findings suggest that there is a location which can be identified within a word which will lead to the optimal processing of that word and that this position is influenced by the distinctiveness of letter sequences within the word. This view also presents the possibility that if this position is not fixated then reading will not be optimum, and may therefore lead to less efficient reading processes — i.e., the process of locating this optimum viewing location may be related to variations in reading ability. However, both of these terms may be distinguished from the ‘preferred viewing location’ (the point where the eyes actually land in a word; see
Rayner, 1979), suggesting that factors related to the optimal processing of a word are not the only influence on eye movements through a text.

The evidence presented so far suggests that within-word fixation locations can be influenced by within-word informativeness; however, research by Underwood and colleagues suggests that within-word informativeness can influence saccadic movements from beyond a word boundary. In the initial studies of this effect, Underwood, Hyönä and Niemi (1987) presented Finnish readers with words containing unequal distributions of information (distinctive beginnings or endings) within short passages which the subjects read for comprehension. As in the studies of O’Regan and colleagues, the locations of fixations within these words were influenced by these regions of informativeness. However, the critical finding within the Underwood et al. (1987) study was that the initial fixation within a word was influenced by the region of informativeness; it being, on average, 2.33 character places to the left of centre for words with informative beginnings, compared to 1.68 character places for words with informative endings. Similar initial fixation location effects were also reported by Hyönä, Niemi and Underwood (1989) and Hyönä (1995) with Finnish readers, indicating that letter sequences within unfixated words can influence the position of subsequent fixations within those words. The controversy surrounding this effect is discussed elsewhere in this book. Rather than repeating this discussion, the present chapter considers evidence concerning one possible explanation for this effect, that related to the semantic pre-processing of unfixated words, and then goes on to contrast this with an alternative explanation in terms of orthographic structure.

**Semantic influences of the fixation location effect**

One of the explanations by Underwood et al. (1987) for the initial fixation location effect suggested that the morphemic composition of an unfixated word was identified by parafoveal processes and used in the guidance of a subsequent saccade. This has been understood to suggest that a saccadic movement into a target word is influenced by the semantic pre-processing of that target word; although this viewpoint has been challenged (see Rayner and Morris, 1992). The experiments discussed in the first half of this chapter (two of which have been published elsewhere: Underwood, Clews and Everatt, 1990; Everatt and Underwood, 1992), therefore, investigated semantic influences on the initial fixation location effect. The rationale is that if we can show influences of semantic features on the initial fixation location effect then this would provide supporting evidence for the underlying cause of this effect being some form of semantic pre-processing.

The following studies incorporated two sets of multi-syllabic words (nine or more letters). The first set comprised words with distinctive or informative beginnings, while the second set possessed distinctive/informative endings. Such words
were obtained via pilot studies in which groups of subjects, different from those involved in the reported studies, but taken from the same college populations, were required to guess a word when only the first or last five letters were provided. The percentage of correct guesses varied due to the distribution of discriminating information (or redundancy) within the words (see Underwood et al., 1987, and Everatt and Underwood, 1992, for a description of the type of pilot study used to obtain these words). Words with distinctive beginnings were those where the subjects were correct more than 89% of the time when given the first five letters of the word, but less than 11% of the time when given the last five letters of the word. Words with distinctive endings were those where the subjects were correct less than 11% of the time when given the first five letters of the word, but more than 89% of the time when given the last five letters of the word. (The procedures for selecting words means that the findings presented here could equally be considered in terms of redundancy of initial or final sequences of letters.) These words were then checked using forward and backward crossword dictionaries to ensure that they contained distinctive beginnings and endings (i.e., that there were no, or very few, other words with the same beginning/ending designated as distinctive).

Each of the studies reported used a computer to present the informative beginning/ending words within short passages which the subject was requested to read. Informative beginning/ending words were positioned such that they did not appear at the beginning or end of a line (to avoid influences of regressions to the next line of text), or at the beginning or end of a sentence (to avoid influences of wrap-up processes); there were also no punctuation marks around these words (since punctuation may affect the pattern of fixations on these words). Subjects were informed that they would be asked questions regarding the passages they were reading at various points during the study. Any subject who could not answer these questions was deemed as having not read the passages, and their data were dropped from subsequent analyses. Separate sets of passages and related questions were also incorporated into the study to allow subjects to practice the procedures and to ensure accurate eye movement monitoring.

Underwood et al. (1990) presented English subjects with sentences to read for comprehension, within which were positioned words with unequal distributions of information. The important manipulation for present discussion was that the prior context of sentences within which informative beginning and informative ending words were placed was held constant. Even with this manipulation, words with informative beginnings showed initial fixations closer to their beginning than words with informative endings, indicating that the initial fixation location effect is not due to the prior context of the sentence within which the word is embedded. There was also no effect of word type on the length of the saccade into the target word, suggesting that saccade length did not produce the fixation location effect; although further studies of this potential influence would be appropriate (see, e.g., Kennison
Table 1

Examples of the preceding sentences and informative beginning/ending words, and the location of the first fixation within the informative beginning/ending words: locations are given in number of character spaces from the word centre, negative values indicate spaces to the left of centre. Data is based on that given in Underwood et al. (1990)

<table>
<thead>
<tr>
<th>Preceding sentence</th>
<th>Informative beginning</th>
<th>Informative ending</th>
</tr>
</thead>
<tbody>
<tr>
<td>He miscalculated the trajectory multiplier</td>
<td>meddlesome discomfort</td>
<td></td>
</tr>
<tr>
<td>The students knew their</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

First fixation location -1.73 -0.35

Table 2

Examples of the contexts used to prime informative beginning and informative ending words; the words in bold are the target words

<table>
<thead>
<tr>
<th>Sentence prime:</th>
<th>It was a very strict school. Even though the schoolboy was only a few minutes late, he knew he would be sent to see the headmaster straight away.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentence neutral:</td>
<td>As the headmaster was leaving the school ...</td>
</tr>
<tr>
<td>Related word:</td>
<td>We would have to sneak past the teachers and headmaster to buy ...</td>
</tr>
<tr>
<td>Neutral word:</td>
<td>We would have to sneak past the secretary and headmaster to buy ...</td>
</tr>
</tbody>
</table>

and Clifton, 1995; and Chapter 4 by Radach and McConkie). Table 1 presents examples of the stimuli used in Underwood et al. (1990)

Although these findings suggest that the initial fixation location effect can occur independent of prior sentence context, they are uninformative about the influence of semantics on this effect. Therefore, in two subsequent studies (one published: Everatt and Underwood, 1992) we manipulated the context within which informative beginning and ending target words were embedded. This was achieved in two ways (see Table 2). In the first (involving 18 subjects), the general context of the sentence leading to the informative beginning/ending words either primed these target words or was neutral. In the second (36 subjects), the informative beginning/ending words were preceded by a word with which they were either semantically related or unrelated; the remainder of the sentence context being held constant. (Words were counterbalanced across context and subjects to avoid repeated viewings of the same target words.) In both studies a statistically reliable initial fixation
Table 3

The average location (and standard deviations in brackets) of the first fixation within the informative beginning/ending words for the different types of preceding context. Fixation locations are given in number of character spaces from the word centre, negative values indicate spaces to the left of centre. (The top two rows of data are based on those presented in Everatt and Underwood, 1992)

<table>
<thead>
<tr>
<th>Preceding context</th>
<th>Informative beginning</th>
<th>Informative ending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentence prime</td>
<td>-0.81 (1.25)</td>
<td>-0.11 (1.42)</td>
</tr>
<tr>
<td>Sentence neutral</td>
<td>-0.39 (1.08)</td>
<td>0.28 (1.33)</td>
</tr>
<tr>
<td>Related word</td>
<td>-1.07 (1.35)</td>
<td>-0.07 (1.17)</td>
</tr>
<tr>
<td>Neutral word</td>
<td>-1.10 (1.15)</td>
<td>0.17 (1.43)</td>
</tr>
</tbody>
</table>

location effect was found (main effects of word type being significant in the first: $F(1,17) = 10.68, p = 0.005, MS_E = 0.8$; and the second: $F(1,35) = 28.22, p = 0.001, MS_E = 1.63$); however, in neither case was this affected by prior semantic context (interactions being non-significant, $F < 1$ for both studies); the initial fixation location effect was comparable with priming and unpriming prior context (see Table 3).

The data presented suggest two conclusions: first, that the initial fixation location effect is robust to different manipulations of context prior to the target word, but that there is little evidence for it being influenced by the prior context. Given the rationale that the semantic content of sentences prior to a target word would influence the semantic pre-processing of that target word, such findings seem inconsistent with the view that the initial fixation location effect is produced by semantic pre-processing.

Additionally, although these data cannot be taken as conclusive evidence against the possibility that the morphemic composition of a word is identified prior to its fixation and that this is the cause of the initial fixation location effect, a final study in this series suggests that this account is less likely than an alternative account proposed by Underwood et al. (1987). This alternative viewpoint suggests that rather than morphemic components within words influencing eye guidance, the letter sequences themselves lead to the initial fixation location effect, whether or not those letter sequences form a morphemic component. The two views differ therefore in terms of the level of the parafoveal influence of eye guidance through a text, the morphemic account suggesting that aspects of the meaning of a word will play an important role in eye guidance, whereas the alternative graphemic explanation suggests that distinctive letter sequences, independent of morphology, will guide saccades.
Individual differences in reading

Table 4

The average location (and standard deviations in brackets) of the first fixation within the informative beginning/ending words and for words with initial grapheme distinctiveness and final root morpheme. Fixation locations are given in number of character spaces from the word centre, negative values indicate spaces to the left of centre.

<table>
<thead>
<tr>
<th>Informative beginning</th>
<th>Informative ending</th>
<th>Grapheme/morpheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.47 (1.28)</td>
<td>-0.11 (1.07)</td>
<td>-1.15 (1.41)</td>
</tr>
</tbody>
</table>

We therefore conducted a fourth study involving two sets of long, multisyllabic words which contained informative beginnings or endings, similar to those reported in the studies above. However, we included a third set of words which varied in terms of the type of informativeness present in their initial and final sequences of letters. Words such as 'strawberry', 'drawbridge', 'alarmclock', etc., contain an initial letter sequence which is distinctive in terms of its graphemes, whereas the second half of the word is more informative in terms of its root meaning: e.g., berry being more informative as to the meaning of the word strawberry than straw. As in previous studies, all three sets of words were placed in passages which the subjects were required to read for comprehension; questions being asked of the 16 subjects to ensure reading. Similarly, target words were positioned as close to the centre of the screen as possible, and avoided punctuation marks.

An initial fixation location effect was found within the data ($F(2,30) = 4.57, p = 0.02, MS_c = 1.76$). Within the third category of words used, this was influenced by the distinctiveness of its graphemes, rather than its root morphemic composition (see Table 4). Both informative beginning words and words with distinctive initial graphemes and final root morphemes differed from informative ending words ($p < 0.05$ in both cases, based on Fisher post-hoc comparisons) but these did not statistically differ from each other. These findings, and those reported above, suggest that the initial fixation location effect is produced by distinctive letter strings within an unfixed word, independent on whether or not these letter strings form a morpheme (see Hyönä, 1995, for similar findings).

Individual differences in the fixation location effect

A second feature of the initial fixation location effect considered in this chapter is its relationship with reading ability. O'Regan and Jacobs (1992) proposed that fixating a certain location within a word produces optimal processing of that word. If this position is not fixated, reading will not be optimum. Although O'Regan and Jacobs
discussed this from the viewpoint of factors which influence lexical access, it is also possible that less-than-optimum reading caused by failing to fixate the optimal viewing location may be related to reading ability. We might therefore predict that individuals with superior reading ability should show more evidence of the initial fixation location effect.

The degree to which each subject evidenced an initial fixation location effect was assessed via tasks identical to those described in the previous section of this chapter (see Everatt and Underwood, 1994). Subjects (36 in total) were required to read short passages within which informative beginning/ending words were positioned. Again, care was taken to avoid punctuation marks and the beginning/ending of lines. The location of initial fixations within these words will be reported. Passage reading was also assessed following the same method of requiring the subjects to answer questions about the passages, and the total time taken to read the passages was used as an indicator of overall reading speed, one of the measures of reading ability used within the study.

Measures of text comprehension and single-word processing were also used to indicate individual differences in reading ability. Comprehension was measured via a variation of Form Y of the GAPADOL reading comprehension test (McLeod and Anderson, 1973) comprising the last two stories ("Brains as Machines" and "Is there Life on Mars?") and requiring the subjects to provide single words which could be used to fill the gaps within the passages from which single words had been removed. Correct completion of the passages necessitates the comprehension of the text around the gaps, and provides a measure of comprehension (see Everatt and Underwood, 1994, for a discussion of the use of this measure).

Single-word processing was assessed via a lexical decision task. One hundred and eighty words were selected from the Shapiro and Palermo (1968) norms. Each word contained three to six letters, and half were converted to pronounceable nonwords (e.g., the word "large" was changed to "larpe", and the word "web" was changed to "wab"). Nonwords contained, on average, the same number of letters and syllables as words. The words used to obtain the nonwords also had, on average, word frequencies similar to those of the word stimuli. Words/nonwords were presented by computer, subjects being required manually to indicate whether the letter string formed a word or nonword. The times taken to make correct word responses were recorded by computer and used as an indication of single word processing; nonword data are not reported here (see Everatt and Underwood, 1994), and the small number of incorrect responses negated their use.

Correlations indicate little relationship between the initial fixation location effect and reading ability (see Table 5); correlations with comprehension, reading speed and single word processing being around 0.2 to 0.3 for informative beginning words, but around 0.1 to 0.2 with informative ending words. However, the larger correlations with informative beginning words suggest a relationship in the opposite
Table 5

Correlations between initial fixation position within words with informative beginnings or endings, and reading speed (passage reading time), single word processing (LDT: words) and reading comprehension. (Data based on that reported in Everatt and Underwood, 1994)

<table>
<thead>
<tr>
<th></th>
<th>Informative beginnings</th>
<th>Informative endings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passage reading time</td>
<td>-0.28</td>
<td>-0.18</td>
</tr>
<tr>
<td>LDT: words</td>
<td>-0.19</td>
<td>-0.09</td>
</tr>
<tr>
<td>Comprehension</td>
<td>0.29</td>
<td>0.09</td>
</tr>
</tbody>
</table>

direction to that expected; i.e., more negative scores (indicating fixations closer to the more informative beginning of the word) are related to slower reading speeds and lower gap comprehension scores.

Our own view of the initial fixation location effect is that it is an aid to lexical access (see also O'Regan and Jacobs, 1992). If the most informative parts of a word can be located by an eye movement, then lexical access should be easier. Therefore, we expected those who show more information seeking behaviour to be more able readers due to their improved lexical access procedures. Finding little or no relationship between the initial fixation location effect and measures of text comprehension, single word decision times and text processing speeds does not support this view and suggest that the process of locating informative parts of yet to be fixated words is not related to reading ability within this population.

Similarly, although there is evidence that the ability to process information beyond the level of the fixated word varies with developing reading skill in children (e.g., Rayner, 1986), there is scant evidence that the ability to extract information further into peripheral vision is related to increased reading ability in normal adult readers. Jackson and McClelland (1975, 1979) presented adult subjects with the task of identifying letters at varying degrees of separation within central and peripheral vision. Performance in this task was unrelated to comprehension ability and reading speed. The size of the field within which a reader can extract information (often termed the perceptual span) does not appear to predict reading ability in normal adult readers. There is also little evidence to suggest differences in the size of the perceptual span between good and poor reading children (Underwood and Zola, 1986; but see Levinson, 1989). Poor reading ability does not appear to be related to under-developed, small perceptual spans.

Additionally, Kennison and Clifton (1995) presented data suggesting that poorer readers benefit as much from parafoveal inspection of a word as more able readers. Here reading ability was determined by reading span, a measure which was related to differences in sentence reading times (those with lower spans were slower
readers), and has been shown to be related to reading comprehension ability (Daneman and Carpenter, 1980). Although Kennison and Clifton's study did not directly assess reading ability, their findings are consistent with the data reported by Everatt and Underwood (1994) if one considers that preview benefits are measuring similar variables to the initial fixation location effect.

Based upon the above findings, it seems reasonable to conclude that processing non-fixated information (i.e., factors beyond the boundaries of the fixated word) will tell us little about variations in reading ability within a normally achieving population of readers. However, there is some evidence that a potentially different population of readers (those diagnosed as dyslexic) may show a different pattern of results.

A number of researchers have presented evidence that dyslexics show evidence of abnormal processing of information outside of foveal vision. For example, Geiger and Lettvin (1987) found that dyslexics were more successful, compared to control subjects, at identifying letters presented in the periphery of vision; a finding which has subsequently been replicated (Geiger, Lettvin and Zegarra-Moran, 1992; Perry et al., 1989), and extended to include increased peripheral identification of colour (Dautrich, 1993; Grosser and Spafford, 1989). These findings suggest that the dyslexic's processing of parafoveal or peripheral information is abnormal, and that they may show greater preview benefits than non-dyslexic readers; however, such effects may be restricted to certain dyslexic individuals (see Rayner et al., 1989).

Other findings, however, are less consistent with the enhanced peripheral processing interpretation. For example, Bouma and Legein (1977), and Klein et al. (1990) found little evidence for increased peripheral processing of information within dyslexics, whereas Gooolkasian and King (1990) and Slaghuis and Pinkus (1993) found enhanced performance within dyslexics compared with controls only in those conditions which used embedded letters or briefly presented masked items respectively. Hence, preview effects may be determined by presentation conditions. Additionally, Solman and May (1990) found that dyslexics were poor indicators of the position of an item presented to peripheral vision, and Raymond (1995) has indicated that dyslexics performed less well than controls in tasks related to peripheral motion perception. These findings suggest poorer peripheral processing by dyslexics.

Further research is obviously necessary to clarify these differences, but the findings suggest that conclusions regarding the processing of information beyond the centre of fixation may not apply to readers diagnosed as dyslexic, and differences related to the optimal viewing position have been found between normally reading children and those undergoing treatment for reading problems (Brysbaert and Meyers, 1993). The following study therefore compared the initial fixation location effect of dyslexics and non-dyslexics.
Developmental dyslexia

The term developmental dyslexia (we will use the term dyslexia) describes individuals defined primarily as those experiencing difficulties in acquiring literacy skills. Such difficulties with learning to read and poor spelling/writing ability are the main symptoms associated with dyslexia; however, dyslexics also experience problems with certain aspects of mathematics (Miles and Miles, 1992), and present abnormalities within certain perceptual and cognitive tasks (Miles, 1993; Thomson, 1990; Willows, Kruk and Corcos, 1993). Dyslexia is mainly considered as a childhood problem (e.g., see Fawcett and Nicolson, 1994); however, dyslexia-related problems often extend into adulthood (Bruck, 1993; Everatt, 1997; McLaughlin, Fitzgibbon and Young, 1994; Miles, 1993). Despite adult dyslexics often improving in reading ability to near normal adult levels, they often show continued poor spelling/writing performance and many of the perceptual and/or cognitive deficits found in childhood. The relevance for present purposes is that adult compensated dyslexics can be tested on their reading performance with the same passages as adult non-dyslexics without large numbers being rejected because they failed to reach the criteria for ensuring that they have read the passages. We therefore compared a group of adult dyslexics with a group of adult non-dyslexics on a passage reading task similar to those used in the previous studies outlined in this chapter. In total, 25 dyslexic and 23 non-dyslexic subjects were tested, but three of the dyslexic subjects and one non-dyslexic were excluded from the final analyses. The three dyslexic subjects were rejected due to their habit of fixating the end of a line of text and producing a series of leftward saccades to the beginning of the line, from which they then produced a series of rightward saccades. This reverse pattern meant that in many cases the initial fixation on a target word followed a leftward saccade. The single non-dyslexic subject was rejected due to poor scores on the comprehension and spelling measures used within the study (see below).

The study requested subjects to read six passages and answer questions following each passage reading. Half of these passages contained words with unequal distributions of information, and the position of the initial fixation with these words was assessed. Questions relating to these passages (three questions per passage) were at a level to ensure reading of the passages, as in the previous studies outlined above. Any subject failing to answer more than one of these questions was rejected from the subsequent analyses. The other three passages were followed by a larger number (ten per passage) of more detailed questions and were selected to provide a distribution of scores indicative of comprehension ability (the use of these passages being based on a series of pilot studies on similar adult dyslexic and non-dyslexic subjects). Subjects were informed that different numbers of questions would be asked about the passages, and were given a practice passage and set of questions.
In addition to the above eye movement monitored task, subjects were assessed on (i) gap reading comprehension (the same variation on the GAPADOL test described above), (ii) single word and non-word naming (measures being the time to name 24 words or non-words), (iii) spelling ability (number of spelling errors from 85 words), and (iv) Raven's progressive matrices (number correct out of 36 items).

Comparisons between the two groups on each of the measures can be found in Table 6. These indicated differences in spelling ($F(1,42) = 62.52, p = 0.0001, MS_e = 158.82$), non-word naming ability ($F(1,42) = 13.9, p = 0.0005, MS_e = 30.75$), and both measures of reading comprehension (passage comprehension: $F(1,42) = 5.48, p = 0.02, MS_e = 35.86$; gap comprehension: $F(1,42) = 19.16, p = 0.0001, MS_e = 12.83$), but no difference between the groups in terms of single word naming ($F < 1$) and progressive matrices ($F(1,42) = 2.4, p = 0.13, MS_e = 29.5$). Differences were also apparent in the initial fixation location effect; although there was little evidence of a difference between the groups in terms of the initial fixation within informative beginning or ending words ($F < 1$ in both cases), there was some evidence of a difference between the groups in terms of the degree of the fixation location effect ($F(1,42) = 3.9, p = 0.05, MS_e = 2.9$) (see Table 6). As a group, the dyslexics seem to show little effect of informative regions within a to-be-fixated word, however, they present a larger degree of variability in this measure, indicative of some showing an initial fixation location effect and others not. Correlations between the initial fixation location effect and the two reading comprehension measures indicate little relationship between these variables for normal readers (−0.01 for the passages reading measure and 0.13 for gap comprehension), but suggest that those dyslexics with higher reading comprehension scores show larger effects of unequal distributions of information in words ahead of fixation (−0.43 and −0.36 for passage reading and gap comprehension measures, respectively).

There are a number of possible explanations for these differences between dyslexics and non-dyslexics. Evidence indicating differences between dyslexics and non-dyslexics in terms of the processing of information outside of the centre of fixation (e.g., Geiger and Lettvin, 1987) suggests the possibility that dyslexics may not be processing the to-be-fixated word to the same extent as the normal reader. This is consistent with explanations of the initial fixation location effect expressed in Chapter 9, if one assumes that foveal word processing is more resource demanding for the dyslexic than the non-dyslexic, leaving the dyslexic reader with fewer resources available for parafoveal word processing; a finding analogous to that for less experienced readers and the size of the perceptual span (see above: Rayner, 1986). The view that word reading is more resource demanding within the dyslexic is also consistent with recent evidence comparing single versus dual task performance in dyslexics and non-dyslexics (Nicolson and Fawcett, 1990). Such evidence has being used to argue that the dyslexic individual has fewer resources available to perform many common, everyday tasks, including word reading, possibly due to an
Individual differences in reading

Table 6

Mean scores (with standard deviations in brackets) for dyslexic and non-dyslexics subjects for the different measures: (i) for the position of the initial fixation within informative beginning and ending words, and the initial fixation location effect, which was calculated by subtracting the position of the first fixation within informative ending words from the position of the first fixation for informative beginning words — a more negative score indicating a larger effect of an information area within the word; (ii) passage reading comprehension, total score out of 30; (iii) gap comprehension; (iv) single word and non-word naming (both in seconds); (v) spelling ability (number of errors); and (vi) Raven's progressive matrices

<table>
<thead>
<tr>
<th>Measures</th>
<th>Dyslexic</th>
<th>Non-dyslexic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informative beginning words</td>
<td>-0.90 (1.44)</td>
<td>-1.20 (1.22)</td>
</tr>
<tr>
<td>Informative ending words</td>
<td>-0.39 (1.53)</td>
<td>-0.10 (1.08)</td>
</tr>
<tr>
<td>Initial fixation location effect</td>
<td>-0.08 (2.23)</td>
<td>-1.09 (0.96)</td>
</tr>
<tr>
<td>Passage reading comprehension</td>
<td>12.5 (6.2)</td>
<td>16.7 (5.8)</td>
</tr>
<tr>
<td>Gap comprehension</td>
<td>22.4 (3.9)</td>
<td>27.1 (3.2)</td>
</tr>
<tr>
<td>Word naming</td>
<td>24.6 (5.8)</td>
<td>23.9 (4.3)</td>
</tr>
<tr>
<td>Non-word naming</td>
<td>33.8 (6.7)</td>
<td>27.5 (4.1)</td>
</tr>
<tr>
<td>Spelling</td>
<td>47.3 (15.4)</td>
<td>17.2 (8.9)</td>
</tr>
<tr>
<td>Raven's matrices</td>
<td>23.4 (6.1)</td>
<td>25.9 (4.7)</td>
</tr>
</tbody>
</table>

automaticity deficit. A lack of automaticity within reading is resonant of findings of a reverse Stroop effect within the same population of adult dyslexics tested in the present chapter (see Everatt, 1997), with such abnormal interference effects possibly indicating a reduction of automatic word reading compared to colour naming or poorer control of the resources involved in word reading versus colour naming (see Everatt, Warner, Miles and Thomson, 1997). We are in the process of performing a series of further studies of the performance of dyslexics and non-dyslexics in these tasks to investigate the relationship between measures of automatic processing and the initial fixation location effect.

An alternative explanation is that the dyslexic may be processing words to the right of fixation as much as non-dyslexics, but that saccades into that word are not as accurate as non-dyslexics. For example, the research of Stein and colleagues has suggested that dyslexics show abnormalities consistent with problems in precise eye movement control (see Stein, 1993, 1996; Stein and Walsh, 1997). This viewpoint has subsequently been linked to the proposal that dyslexia is caused by a visual deficit, a view which may link the eye movement control explanation of the
differences between dyslexics and non-dyslexics in the initial fixation location effect with an explanation in terms of parafoveal/peripheral processing deficits within dyslexics. As a syndrome, dyslexia is often viewed from the perspective of a language disability, and hence as a function of the perception, storage, and/or production of sound (e.g., Liberman et al., 1974; Snowling, 1995; Stanovich, 1988; Velluntino, 1979). However, visual perceptual abnormalities are also associated with dyslexia, many of which are considered to be related to deficits within the transient (magnocellular) visual pathway.

The basis of the transient (magnocellular) deficit viewpoint is that the visual system comprises two interactive pathways: the transient or magnocellular (M) pathway, and the sustained or parvocellular (P) pathway. Although the transient/sustained distinction derives from relatively older neuroanatomical studies of the visual system of the cat, and the magnocellular/parvocellular distinction derives from more recent studies of primates, a commonly held view is that the functions of the these systems are analogous, and comparable with the human visual system (e.g., see Breitmeyer, 1993). Consistent with this proposal, we will therefore treat as synonymous the transient and magnocellular (M) systems, and the sustained and parvocellular (P) systems.

Anatomically, the two systems are most clearly distinguished in the lateral geniculate nucleus (the LGN), though M and P cells are also viewed as distinct at the level of the retina (e.g., Bassi and Lehmkuhle, 1990): P cells comprising the larger number of ganglion cells (approximately 80%), particularly within the central/foveal region of the eye, with M ganglion cells being more evenly distributed across the retina. From the retina, both pathways lead to the LGN, which is situated between the retina and cortex, and comprises six layers of cells, two forming the M pathway, four the P pathway. Both pathways project to the primary visual cortex, from where they separate, the P pathway moving on to temporal cortex regions, the M pathway to the parietal cortex. These neuro-anatomical differences also lead to the pathways been termed temporal (P) and parietal (M) systems.

The M and P systems are also considered distinct in terms of the processing they are designed for. The P pathway seems to respond to slowly changing (low temporal frequency) information, to more detailed stimuli (ie, higher spatial frequencies), and to colour (it seems to distinguish patches of different hue which have the same luminance). On the other hand, the M system seems to be more efficient with information of lower spatial but higher temporal frequencies; it seems to be more sensitive to gross detail, moving stimuli, and seems to be relatively insensitive to colour.

Psychophysical and neurological evidence has been presented for the view that reading disabled individuals have an abnormally functioning transient system. The psychophysical data indicates that, compared to matched controls, reading disabled individuals show:
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(i) poor contrast sensitivity for low spatial frequency stimuli (Martin and Lovegrove, 1984; Evans, Drasdo and Richards, 1994), which is consistent with deficiencies in the pathway responsible for processing low spatial frequency information;

(ii) poor flicker sensitivity at high temporal frequencies (Martin and Lovegrove, 1987); consistent with the view that the M pathway is more responsive to high temporal frequencies;

(iii) greater visual persistence for higher spatial frequency information (Badcock and Lovegrove, 1981; Slaghuis and Lovegrove, 1984); which is consistent with one view of an M on P inhibitory influence (e.g., Breitmeyer, 1993) suggesting that the M pathway is not inhibiting the responses of the high spatial frequency P pathway; and

(iv) poorer motion perception (Cornelissen et al., 1995; Eden et al., 1996); again consistent with the hypothesized view of the functions of the M pathway.

Neurological data which favour an M pathway viewpoint suggest cellular migration abnormalities within the M pathway of the dyslexic (Livingstone et al., 1991), and less activity within area V5 of dyslexic individuals during a motion detection task (Eden et al., 1996). Area V5 has been proposed as playing an important role in motion perception, and forms part of the parietal pathway of the M system.

Evidence for the M pathway deficit viewpoint is therefore quite compelling; however, a major problem prevents it from becoming a more widely accepted causal factor in dyslexia theorizing. Despite the evidence for differences between reading disabled and reading able subjects in terms of the functions, and even the anatomy, of the M pathway, it is hard to see why deficits within a pathway which is responsible for processing high temporal, low spatial frequency images should lead to poor reading ability. Written words are often thought of as highly detailed visual stimuli, and certainly do not move; why should an M pathway deficit lead to poor reading ability? Two main theories have been proposed which argue that deficits within the M pathway leads to problems in precise eye movement control, or that the M pathway is responsible for specific encoding operations vital for efficient word encoding.

For example, Breitmeyer (1980, 1993) has proposed that the two visual pathways mutually inhibit each other, with the normally functioning visual system involving a transient (M) system which inhibits the sustained (P) system at the initiation of a saccadic movement. Information recently processed by the P system is therefore removed, leaving the visual system free to process the next stimuli. A deficit within the M pathway would mean that the previously fixated word may still be within the P pathway, leading to interference with the newly fixated word and thereby poorer text reading ability; a proposal consistent with the data for increased visual persistence of higher spatial frequency information (see above). Also consistent with this
viewpoint, Slaghuis and Lovegrove (1984) found that if a high frequency flicker mask (which may reduce M pathway sensitivity) was used in conjunction with a visual persistence procedure, then control (non-dyslexic) subjects also showed increased persistence at low spatial frequencies.

A potential problem with this viewpoint is that Burr, Morrone and Ross (1994) have presented evidence suggesting that within the normally functioning visual system, the M pathway is less efficient during saccadic movements, whereas the operations of the P pathway seem to be relatively unaffected by the movements of the eyes, and may even be enhanced. Such evidence contradicts the views of Breitmeyer (1980, 1993) that the M pathway inhibits the functions of the P pathway during an eye movement.

An alternative viewpoint has therefore been proposed for the effects of a deficient M pathway on reading ability. There are a number of interrelated variants on this view (see Chase, 1996; Williams, Brannan and Lartigue, 1987; Williams and LeCluyse, 1990), but all assume that the M pathway provides some form of initial analysis of information which is then built upon by the P pathway. Hence, in word reading, the M pathway may provide basic, more global information about a word which is then supplemented by the operations of the P pathway; though further research is needed to identify the exact nature of this basic/global information (see Chase, 1996). Williams and LeCluyse (1990) go on to argue that the former operations of the M pathway may be performed preattentively and used to ‘direct the sustained subsystem to particularly salient areas’ (p. 112). Such viewpoints are consistent with findings such as the initial fixation location effect, though further research is required to substantiate this connection.

Finally, an association has also been made between measures of M pathway processes and precise control of the eyes. Evans, Drasdo and Richards (1996) found that dyslexic subjects showed deficits in tasks involving operations of the M pathway, such as flicker threshold, and binocular stability, and that these measures were related. This, and the hypothesized dominance of M projections to the posterior parietal cortex which is involved in the normal eye movement control, have led some researchers to argue that the deficits proposed within the M pathway of the dyslexic lead to visual processing deficits and poor eye movement control (see Stein and Walsh, 1997). This leads to the possibility that the abnormalities in the initial fixation location effect found within our adult dyslexics may be due to a combination of processing deficits outside the centre of fixation and poor control of the movements of the eyes to those locations. We are therefore conducting a second series of experiments comparing the precise eye movement control of adult dyslexics in reading (involving the initial fixation location effect) and non-reading tasks with measures of motion perception.
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