Chapter 8

Parafoveal Preview and Lexical Access During Eye Fixations in Reading

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Lexical access is a topic of considerable interest to psycholinguists, and a great deal of research on auditory and visual word identification has been carried out over the past couple of decades. Much of the research on lexical access processes has focused on the identification of individual words that are isolated from the rest of the linguistic context in which they normally appear during listening and reading. Although the results of experiments dealing with lexical access processes for isolated words have yielded some important clues to the structure of the mental lexicon, contextual influences play an important role in how words are processed in listening and in reading. The processing of words during reading will be discussed in this chapter.

During reading, not only can prior context exert influences on how words are identified, but *parafoveal* processing of words can also influence how words are accessed in the lexicon. Whereas studies in which subjects must respond to a target word presented in isolation can effectively manipulate the preceding context (Morton 1964; Tulving and Gold 1963; Schuberth and Eimas 1977; Stanovich and West 1979), it is considerably more difficult to manipulate the amount of parafoveal information available for processing. Moreover, one can easily question the generalizability of studies in which words are responded to in isolation after either an appropriate, an inappropriate, or a neutral context has been presented, because the timing relationship between the processing of the context and the target word is often at variance with the timing relationships found in normal reading.

We will deal here with research concerning the relationship between lexical access processes and eye movements during reading. Our primary argument will be that lexical access processes (or word identification) typically serve to trigger eye movements in reading. In addition, we will argue that parafoveal processing on fixation n can influence this lexical-access process on fixation $n + 1$.

1 Defining Lexical Access

Our discussion of lexical access processes does not rely heavily on any particular model of lexical access. At one level, lexical access simply refers to the fact that the reader has made contact with lexical-level information. In this sense, lexical access is more a process than a completion of a stage. Consider, for example, the McClelland-Rumelhart (1981) model of word recognition. Within this model one might assume that the lexical access process begins when activation begins to accumulate at the lexical level. Clearly, there are many different levels in this access process, reflecting varying degrees of activation accumulation. Moreover, the levels tapped are defined in some sense by the tasks used to investigate them. For example, those who believe that lexical-decision performance is a good reflection of lexical access must rely on the notion that lexical access is the point at which the subject has obtained sufficient information to discriminate words from nonword letter strings. Likewise, those who use pronunciation tasks to measure lexical access apparently believe that lexical access is the point at which the subject has obtained sufficient information to determine a pronunciation code for the word.

When one considers normal reading, neither a discrimination between words and nonwords nor the assembly of a pronunciation code seems necessary. Then what do we mean by lexical access? We could begin by assuming that lexical access is the process whereby the reader accumulates sufficient information to make the decision to leave the currently fixated word. Like others investigating lexical access processes, we would then be defining lexical access by the task used to measure it. Obviously, such a definition is somewhat circular. The more important question is: What are the characteristics of the word that influence the decision concerning when to move the eyes from the currently fixated word? We will argue that the trigger that determines when to move the eyes is the speed with which a lexical-level representation reaches threshold (i.e., word identification). Within this vein, it is important to realize that we do not see word identification as the major holdup in normal skilled reading. Rather, factors associated with the programming of the eye movements represent the bottleneck in reading, since the motor aspects of programming a saccade take at least 150–175 msec (Rayner, Slowiazcek, Clifton, and Bertera 1983; Salthouse and Ellis 1980). Since the average fixation duration is around 225 msec, the programming of the saccade takes a considerable amount of time during a typical fixation. Once word identification has taken place, the programs still have to be set in motion to move the eyes to the next location in the text. We know that the visual information necessary for reading can be obtained within the first 50 msec or so of a fixation (Rayner, Inhoff, Morrison, Slowiaczek, and Bertera 1981), and reading is certainly possible under RSVP (Rapid Serial Visual Presentation) conditions wherein a new word is presented every 50 msec (Forster 1970; Potter, Kroll, and Harris 1980). Hence, we will argue that the process of lexical access takes place very quickly during an eye fixation and serves as the primary trigger to propel the eyes forward through text.

We are by no means arguing that higher-level comprehension processes never play a role in the decision to leave the currently fixated word. The notion is that breakdowns in the comprehension process signal the eye-movement system to abort the decision to move the eyes. For example, such situations might occur when the reader is garden-pathed (and misparses to string of words), or cannot find a referent of a currently fixated pronoun, or is having difficulty integrating the currently fixated word with the rest of the text representation. The point that we will be making is that in normal skilled reading the signal to move the eyes is determined *primarily* by word-identification processes. In addition, we will argue that this process can be influenced by the use of parafoveal information.

There is an alternative account of the decision concerning when to move the eyes: Since higher-order processes can influence how long the reader fixates a word, it may be that these comprehension processes *always* play a role in the decision to move from the currently fixated word. That is, the decision concerning when to move the eyes could be based on the combined effects of a number of levels of the language-processing system (including lexical-level analyses, syntactic analyses, and text-integration analyses). Unfortunately, the research to date has not discriminated clearly between this alternative and the previous alternative. In the present discussion we will attempt to force the more simplistic earlier account while also mentioning evidence that could be seen as consistent with the alternative account.

The primary evidence we will discuss consists of eye-movement data collected as subjects read text. In order to provide a framework for this discussion, we will provide in section 2 a brief overview of eye movements and the size of the perceptual span (or area of effective or useful vision) in reading. The major point that will be made in that section is that readers utilize varying levels of parafoveal information to the right of fixation. In addition, section 2 addresses the basic eye-movement characteristics typically found in reading. This will be critical in our discussion of parafoveal effects on lexical access. In section 3 we will discuss the cognitive processes in reading that may be reflected in fixation times on words. There we will argue that there is a rather tight link between the eye and the mind, so that how long a reader looks at a word reveals information about the ease or difficulty associated with the processing of that word. The research described in section 3 clearly indicates that the decision concerning when to leave a word can be influenced by higher-order comprehension processes.

In section 4 we will discuss the parafoveal-preview effect: If a reader has a preview of a word before looking directly at it, the processing time associated with that word is facilitated. Elsewhere (Balota and Rayner 1989) we have discussed the range of lexical-processing effects for foveal and parafoveal vision, emphasizing both the similarities and the dissimilarities. In sections 4 and 5 we will sketch the findings concerning the parafoveal-preview effect. These sections are important because we are going to end up arguing that lexical-access processes on fixation n can be modified by parafoveal information acquired on fixation $n - 1$.

2 Eye Movements and the Perceptual Span During Reading

Specifying the Eye-Movement Parameters

When we read, our eyes do not move smoothly across the page, as it seems phenomenologically. Rather, we make a series of left-to-right eye movements called *saccades*, separated by fixational pauses that last about 200–250 msec each. About 15–20 percent of the saccades in reading are *regressions* in which the reader makes a right-to-left saccade back to material that has already been traversed by the eyes. It is important to distinguish regressions from return sweeps, which are also right-to-left saccades but which place the eyes at the beginning of the next line rather than back to material already traversed. It is commonly believed that the two most common reasons for regressions are (1) that the reader failed to understand some part of the text and (2) that a saccade was a bit longer than intended and the reader had to make a corrective movement.

New information is extracted from text only during the fixational pauses. Saccades take 20–40 msec, and no information is obtained from the text as the eyes are moving. This was clearly demonstrated in an experiment by Wolverton and Zola (1983), who replaced text with different words, random letters, or strings of *X*s for a 20-msec period either during the saccade or at some point during a fixation. Although such changes interfered with reading when presented during the fixation period (including the first 20 msec), they were not noticed and did not interfere with reading if presented during the saccade.

The average saccade length in reading is 7–9 character spaces, or a bit over one word. Number of character spaces is clearly the appropriate metric to use in assessing how far the eyes move, since the number of character spaces traversed by a saccade is relatively invariant when the same text is read at different distances even though the character spaces subtend markedly different visual angles (Morrison and Rayner 1981; O'Regan 1983).

The primary function of a saccade is to bring a new region of text into foveal vision for detailed analysis; reading on the basis of only parafoveal and peripheral information is difficult or impossible (Rayner and Bertera 1979; Rayner et al. 1981). Foveal vision represents the 2° of visual angle in the center of vision (about 6–8 letter spaces for normal-size text) and acuity is markedly better than in parafoveal vision, which in turn is better than peripheral vision. Since for English orthography the perceptual span is asymmetric to the right of fixation (McConkie and Rayner 1976; Rayner, Well, and Pollatsek 1980), our discussion of parafoveal and peripheral vision will deal with information to the right of fixation; parafoveal vision extends 5° to the right of fixation (or out to about 15 letter spaces from fixation), and peripheral vision includes the rest of the line.

Although a majority of the words in a text are fixated during reading, many words are skipped, so foveal processing of each word is not necessary. Roughly 80 percent of the content words in text and 40 percent of the function words are fixated. Of course, function words tend to be shorter on average than content words, and it is clearly the case that word length dramatically influences the probability that a word will be fixated (Rayner and McConkie 1976). Between 5 and 20 percent of the content words in a text receive more than one fixation. The values that have been cited are all influenced by text difficulty; thus, as the test becomes more difficult, the average fixation tends to get longer, the average saccade gets shorter, and the frequency of regressions increases. Therefore, the probability that a word will be fixated also increases, and fewer words are skipped, as the text gets more difficult.

The most striking aspect of both fixation duration and saccade length is the variability. Fixations can range from under 100 msec to over 500 msec within a given reader, although typically only a small percentage of fixations are under 100 msec and most fixation durations are between 150 and 350 msec. Even this restricted range indicates a considerable amount of variability. Saccades range from one character space to over 15. In fact, when a left-to-right saccade follows a regression or a series of regressions, saccades may exceed 15 character spaces, as the eyes typically do not fixate again on material read before the regression.

Lately, a number of researchers have begun to exploit the variability that exists in eye-movement records to study cognitive processes in reading. The basic idea is that eye-movement measures can be used to study moment-to-moment cognitive processes during reading. This is not to say that there is not a purely motoric component to the variability. For example, even when spatial and temporal uncertainty about when and where to move are eliminated, there is still variability in the latency of eye movements (Rayner et al. 1983). Similarly, there is variability in where the eye lands, even when a fixed target location is given (Coeffe and O'Regan 1987). Though this *noise* of motoric variability makes it difficult to interpret the cognitive *signal* in the eye-movement record, it is now clear that the signal is there, and great strides have been made in understanding reading via examination of eye-movement records.

The Perceptual Span in Reading

As was mentioned above, it is during the eye fixations that new information is obtained from text. Research on the size of the perceptual span during an eye fixation in reading has clearly demonstrated that the span is relatively small (for reviews, see Rayner 1978a and Rayner and Pollatsek 1987). This evidence has accumulated from experiments using the *moving-window* paradigm (McConkie and Rayner 1975; Rayner 1986; Rayner and Bertera 1979) or a variation of it called the *boundary* paradigm (Rayner 1975; Pollatsek, Rayner, and Balota 1986). As we shall see, both of these paradigms provide important information concerning the impact of parafoveal information on lexical access processes. Thus, we shall provide a brief description of each of them.

In the moving-window paradigm, readers move their eyes as they normally do in reading, but the amount of information available for processing on each fixation is controlled by the experimenter. Thus, within an experimenter-defined window, the normal text is available for the reader to process. However, the text outside the window is mutilated in some fashion. For example, all original letters (and sometimes the spaces between words) might be replaced by *X*s or other letters. The size of the window is sometimes equal to a certain number of character spaces to the right (and left) of fixation and sometimes coincides with word boundaries. Figure 1 shows examples of each. Figure 1 also shows an example of the boundary

The fluent processing of words during silent reading	Normal Text
XXXXXXXXXXXprocessing ofXXXXXXXXXXXXXXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXXssing of wordXXXXXXXXXXXXXXXXXXXXXXX	13- character window (spaces filled)
XXX XXXXXX processing of XXXXX XXXXXX XXXXXX XXXXXXX XXX XXXXXX XXXXXssing of wordX XXXXXX XXXXXX XXXXXXX	13-character window (spaces preserved)
XXX XXXXXX processing of XXXXX XXXXXX XXXXXX XXXXXXX XXX XXXXXX XXXXXXXXXX of words XXXXXX XXXXXX XXXXXXX	2-word window
The fluent processing of green during silent reading The fluent processing of words during silent reading	Boundary technique

Figure 1

Examples of the moving-window and boundary paradigms. The top line represents a line of normal text. Examples of 13 character windows and a two-word window are shown on two consecutive fixations. Fixation location is marked by the dot in each example. The bottom rows show an example of the boundary paradigm. In the example, the word *green* is initially presented, but when the reader's saccade crosses over the boundary location (the letter *o* in *of*) it is replaced by *words*.

paradigm in which a word (or a nonword) initially presented in text is replaced by another word when the reader's eye crosses a boundary location. By examining how long the reader fixates on the target word as a function of the relationship between the initially displayed word and the target word, one can make inferences about the type of information acquired at various distances from fixation.

Research using these eye-movement-controlled display-change paradigms suggests that the perceptual span extends from the beginning of the currently fixated word, or about 3–4 character spaces to the left of fixation, to about 15 character spaces to the right of fixation. However, within the perceptual-span region, different types of information appear to be obtained at different distances from the fixation point. Figure 2 shows a line of text on three consecutive fixations to illustrate the different types of information acquired on each fixation. From the area closest to fixation (extending to about 4–8 character spaces to the right of fixation), informa-

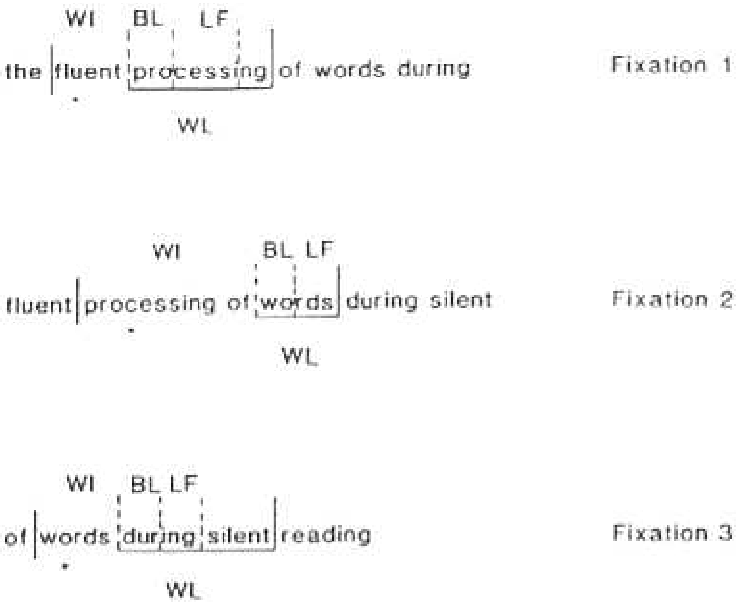

Figure 2
An example of the different types of information obtained within the perceptual span on three successive fixations. The dot marks the location of fixation. WI: word identification; BL: beginning letters; LF: letter features; WL: word length.

tion used to identify the word on the current fixation is obtained. The region within which words are identified is variable because, depending on word length, on some fixations one word can be identified whereas on others two words can be identified (or possibly three when a number of short words occur together in text). Further to the right of fixation than the region of word identification, beginning-letter information and letter-feature information is obtained. Word-length information appears to be acquired over the largest range. Note that the total perceptual span region is about twice as large as the distance that readers typically move their eyes on each saccade. In essence, readers move their eyes to the next unidentified word. In addition, word-length information acquired on fixation n is used not only to program the next saccade but also to program the length of the saccade from fixation $n + 1$. That is, Rayner and Pollatsek (1981) showed that information acquired on fixation n was the primary determinant of how far the next saccade moved, but that length information acquired on fixation $n - 1$ also influenced the distance of that saccade.

When readers move their eyes, where they land on words is not haphazard (Rayner 1979; O'Regan 1981; McConkie and Zola 1984). A reader tends to fixate on the *preferred viewing location* (Rayner 1979), which is about halfway between the beginning and the middle of a word (although there is some variability in where the eye lands). This makes sense, since it is well known that the beginnings of words are more informative than the ends of words. That readers typically fixate between the beginning and the middle of the word is probably also related to the amount of partial information they obtained parafoveally on the prior fixation.

In essence, work on the perceptual span suggests that varying levels of information are obtained during a fixation depending upon the distance of that information from the fovea. By our present definition, lexical access clearly would occur for the fixated word. That is, readers obviously leave the currently fixated word. Also, because words are sometimes skipped, it appears that lexical access can occur for parafoveal words. Thus, we already have a modification of our definition of lexical access. That is, not only does lexical access influence the reader's decision when to move the eyes, but it can also influence the decision to skip words in the parafovea. Before we turn to a more detailed discussion of the impact of parafoveal information on lexical access processes, it is necessary to briefly discuss research that indicates that higher-level comprehension processes can also influence the decision to leave the currently fixated word. This research is particularly important because it suggests that word identification is not always the only determinant of the reader's decision to move the eyes.

3 What Processes Do Eye Fixation Times Reflect?

There is now abundant evidence that the amount of time a reader fixates on a word reflects something about the ease or difficulty of processing that word. However, before turning to this research it is important to note that there is an active debate concerning the most appropriate measure of processing time on a word (Rayner and Pollatsek 1987). The two primary measures that have been used are *first fixation duration* and *gaze duration*. Gaze duration represents the sum of all fixations on a word prior to a saccade out of that word to a new word. First fixation duration represents the duration of only the first fixation on a word. When a reader makes only one fixation on a word, then gaze duration and first fixation are the same. The fact that readers sometimes fixate more than once on a word has led to the debate concerning these two measures. Some researchers appear to use the first fixation duration on a word as a measre of lexical access (Inhoff 1984; McConkie, Zola, Blanchard, and Wolverton 1982). The reasons are not always explicit, but the assumption appears to be that what goes on beyond the first fixation reflects higher-order processing (Inhoff 1984) or is noise. However, the opposite assumption appears to have been made by

O'Regan, Levy-Schoen, Pynte, and Brugaillera (1984), who believe that refixations are often caused by landing in a "bad" place on a word and moving to more informative spot. Thus, according to O'Regan and colleagues, the second fixation on a word may be more informative than the first. (In their study, words were presented in isolation; it remains to be seen to what extent the mechanism they propose accounts for many of the refixations on words in text.)

The argument about which measure is best depends partly on what processes one is interested in measuring. For example, Inhoff (1984) argued that the duration of the first fixation on a word and the gaze duration reflect different processes. In his data, both first fixation duration and gaze duration were affected by word frequency, but only gaze duration was affected by the predictability of the word in the context. He thus posited that first fixation duration was the measure of lexical access, whereas gaze duration reflected text-integration processes as well. However, this distinction apparently does not hold up well when examined in light of a number of studies (see Rayner and Pollatsek 1987). As Rayner and Pollatsek (1987) have suggested, it is quite plausible that there is only a quantitative difference between the two measures, namely that the decision to refixate on a word can be made later in a fixation than the decision when to move the eyes. Thus, if a cognitive operation is really fast, it will affect the first fixation duration; if it is a bit slower, it may still affect gaze duration. In the present discussion, we will use gaze duration as our indicant of lexical access while noting any discrepancies in the data provided by the two measures.

In arguing for the utility of fixation time on a word, Just and Carpenter (1980) spelled out two important theoretical arguments: the eye-mind assumption and the immediacy assumption. The eye-mind assumption states that there is not a significant lag between processing of information by the eye and processing by the mind; thus, how long someone looks at a word while reading will directly reflect the ease or difficulty associated with processing that word. The immediacy assumption states that all processing associated with a given word is completed while the eyes are still fixating on that word; when the processing is completed, the eyes move on. Recent research has tended to suggest that the eye-mind assumption is quite reasonable (Rayner and Pollatsek 1987). However, with respect to the immediacy assumption, there is evidence that processes initiated on one fixation *spill over* onto the next word or words on subsequent fixations (Balota, Pollatsek, and Rayner 1985; Ehrlich and Rayner 1983; McConkie, Underwood, Zola, and Wolverton 1985). Thus, a strict interpretation of the immediacy assumption does not appear to be warranted. Of course, the important question for the present discussion is: What types of processes are completed before the eyes move on?

One variable that has a strong impact on fixation time on a word is word frequency (Just and Carpenter 1980; Inhoff 1984; Inhoff and Rayner 1986; Kliegl, Olson, and Davidson 1982; Rayner 1977; Rayner and Duffy 1986). When words are matched on word length (and number of syllables) and are equally likely in a sentence frame, readers look at low-frequency words about 90 msec longer (when measured by gaze duration and 40 msec longer when measured by first fixation duration) than high-frequency words (Inhoff and Rayner 1986; Rayner and Duffy 1986). We believe that this impact of word frequency most likely plays a role in both (1) the speed of identifying the currently fixated word and (2) the text-integration processes. Further evidence that fixation times reflect word-identification processes comes from work by Lima (1987) demonstrating that pseudo-prefixed words (e.g. *rescue*) receive longer fixations than prefixed words (*revive*) matched on word length and word frequency and from work by Inhoff (1987) showing that compound words (*cowboy*) are fixated longer than pseudo-compound words (*carpet*) and neutral words (*mirror*). Clearly, variables that one would *a priori* expect to influence lexical access processes do influence fixation times.

Priming effects from related words earlier in a sentence have also been demonstrated recently. Carroll and Slowiaczek (1986) asked subjects to read sentences containing a category name (e.g. *bird*) or a neutral prime word (e.g. *thing*), which was then followed by a target exemplar. The category prime word facilitated processing for both high-typicality (*sparrow*) and low-typicality (*vulture*) exemplars. However, high-typicality exemplars were processed more quickly than low-typicality exemplars in both primed and unprimed conditions. In a second experiment, Carroll and Slowiaczek extended the priming effect to primary associates. They also found that the priming effect was influenced by the syntactic structure of the sentence. When both the prime and the associated target word were in the same clause, semantic priming occurred. However, when the prime and the target were in different clauses, no associative priming was observed. Of course, such associative-priming effects could be totally intralexical.

Recently, there have also been many demonstrations that fixation times on words can be reduced by the relationship of the prior text to the currently fixated word. For example, words that are relatively predictable from the prior text receive shorter fixations than words that are not predictable from the context (Balota et al. 1985; Ehrlich and Rayner 1981; Inhoff 1984; Zola 1984). There is also a higher probability that predictable words will be skipped over than words that are not predictable from the prior context (Balota et al. 1985; Ehrlich and Rayner 1981; O'Regan 1979). Effects such as these appear to be accounted for by two factors. First, when words are predictable from prior context, readers can better utilize parafoveal information than when words are not predictable. Hence, they are able to skip over predictable words more frequently than over unpredictable words, because they can be identified on the prior fixation (Balota et al. 1985). Second, predictable words appear to be easier to integrate into the discourse structure that the reader constructs to comprehend text (Balota et al. 1985; Ehrlich and Rayner 1981). Thus, both levels of information may figure in the decision concerning when to leave a word.

In addition to priming effects and context effects, there are other effects that appear to reflect higher-order comprehension influences. That is, one finds variations in fixation times on target words as a function of (1) lexical ambiguity (Rayner and Duffy 1986; Duffy, Morris, and Rayner 1988) and (2) the distance between a target word and a prior mention of that word (Schustack, Ehrlich, and Rayner 1987) or a related referent (Ehrlich and Rayner 1983). In addition, research on syntactic parsing strategies that are employed by readers has shown that the record left by the eyes is a good reflection of the ease or difficulty readers have parsing sentences and recovering from misanalyses (Frazier and Rayner 1982, 1987; Ferreira and Clifton 1986; Rayner, Carlson, and Frazier 1983; Rayner and Frazier 1987).

All of the results discussed in this section are quite consistent with the idea that lexical access processes are reflected in fixation times on a target word in text. However, as we have noted, most of the results are also consistent with the idea that fixation times on words reflect both lexical access processes and text-integration processes (Balota et al. 1985; Carroll and Slowiaczek 1986; Ehrlich and Rayner 1981; Rayner and Duffy 1986; Schustack et al. 1987). To date it has not been easy to tease these two alternatives apart. Perhaps words that are relatively easy to access in the lexicon are also easier to integrate into an internal discourse representation that is constructed by the reader to comprehend the text.

Hopefully, it is clear from the research that has been discussed in this section that lexical access processes are reflected in fixation times on words. While other higher-order cognitive processes undoubtedly influence how long the reader remains fixated on a word, our argument is that much of the decision involved in deciding to move the eyes to another word is influenced by whether or not the fixated word has been identified. In fact, our suggestion is that the higher-order effects primarily exert their influence when the comprehension process breaks down. This would suggest that higher-order processes typically play a relatively minor role in determining when the eyes move next during normal fluent reading. Of course, the alternative suggestion is that they *always* play a role. As was noted above, the research to date cannot discriminate between these two possibilities. The important point for the present discussion is that lexical variables clearly play a role in the decision to leave the currently fixated word.

We shall now turn to the impact of parafoveal information on the decision to move the eyes. As we shall see, the research in this area provides information regarding the impact of identification processes on the decision when to move the eyes.

4 The Parafoveal Preview Effect

There are basically two ways in which parafoveal information can be utilized during an eye fixation in reading. First, as we indicated earlier, on some fixations the fixated word and the word to the right of fixation can both be identified. In such cases, the word to the right of fixation is generally skipped over by the ensuing saccade (Ehrlich and Rayner 1981; O'Regan 1979; Pollatsek et al. 1986; Schustack et al. 1987) and the duration of the fixation prior to skipping the word is increased (Hogaboam 1983; Pollatsek et al. 1986). Second, partial information acquired about the word to the right of fixation on fixation n could be integrated with information about that same word (in foveal vision) following the saccade on fixation $n + 1$.

A recent experiment by Blanchard, Pollatsek, and Rayner (1988) demonstrates that both things happen in reading. In their experiment, subjects read text with alternating one- or two-word windows; if on fixation n they received a two-word window, on fixation $n + 1$ they received a one-word window, and vice versa. An analysis including as a factor the length of the word to the right of fixation revealed that if readers received a two-word window (the fixated word and the word to its right) and if a short word was to the right of fixation, there was a much higher probability of skipping over the word than if the reader had a one-word window. On the other hand, if the word to the right of fixation had six letters or more, the probability of fixating the word was not influenced by whether or not the reader had a preview of that word. However, fixation times on that word were significantly shorter when there was a preview than when there was not. The results of the study by Blanchard et al. thus suggest (1) that short words to the right of fixation are sometimes identified and (2) that when words are not identified partial information is obtained and used on the next fixation. In the remainder of this section, the focus will be on cases in which the word to the right of fixation is not skipped (which are more frequent than instances in which the word is skipped). Under such circumstances, a parafoveal preview of the word to the right of fixation leads to faster processing of that word (we will henceforth refer to this as the *parafoveal preview effect*).

It has been known since the classic work of Dodge (1906) that a parafoveal preview of a word facilitates processing of that word. More recently, a number of experiments have verified this result and attempted to determine the locus of the effect (Balota and Rayner 1983; McClelland and O'Regan 1981; Rayner 1978b; Rayner, McConkie, and Ehrlich 1978; Rayner, McConkie, and Zola 1980). In these experiments, subjects were asked to fixate on a fixation cross and a letter string was presented parafoveally. When the subject made an eye movement to the letter string, it was replaced by a word, which the subject named (or categorized). The amount of time taken to name the target word was influenced by how far from fixation the string was initially presented and by the similarity between the string and the target word. If the initially presented string and the target word shared the same two or three beginning letters, the naming was faster than if they did not. While these experiments do not address an actual reading situation, experiments in which subjects are reading have yielded very similar results. For example, Rayner, Well, Pollatsek, and Bertera (1982) compared reading performance when (1) only the fixated word was available on each fixation and all letters to the right of fixation were replaced with other letters (*X*s or other letters), (2) both the fixated word and the word to the right of fixation were available on each fixation (with letters further to the right replaced), and (3) the fixated word was available and partial information about the word to the right of fixation was available. In the third condition, either one, two, or three letters of the word to the right of fixation were available on each fixation. When the first three letters of the word to the right of fixation were available and the remainder of the letters were replaced with visually similar letters, the reading rate was not much different from when the entire word to the right of fixation was available. These data, like the naming-time experiments discussed above, show quite clearly that when readers are given a parafoveal preview of the beginning letters of the next word they read faster than when no such preview is provided.

That the parafoveal preview effect is not simply due to the perceptual salience of the beginning letters of a word is clear from a recent experiment by Inhoff (1987). Inhoff asked subjects to read sentences with the word order going from left to right (normal English text), or with the words printed from right to left but with the letter order within words going from left to right. Subjects read the sentences with either (1) a one-word window (the fixated word), (2) a two-word window (the fixated word plus the next word in the sentence), (3) a one-word window plus the first three letters of the next word, or (4) a one-word window plus the last three letters of the next word. Inhoff then examined the fixation time on target words (all of which were six letters long). Because the first three letters of a word are closer to fixation than the last three letters when one is reading from left to right but further away when one is reading from right to left, Inhoff's experiment provides a good test of the extent to which the parafoveal preview effect is due merely to the fact that the beginning letters of the next word are closer to fixation. Inhoff found that having the last three letters of the six-letter target word parafoveally available provided no facilitation in comparison with the one-word window. However, a preview of the first three letters provided significant facilitation for both right-to-left and left-to-right reading. Thus, simple perceptual salience does not appear to be an adequate explanation of the parafoveal preview effect.

Although a number of experiments have demonstrated a parafoveal preview effect in reading, the results of one experiment (McConkie et al. 1982) are inconsistent with the conclusion that partial word information is obtained parafoveally. McConkie et al. had subjects read sentences with the letters in specific target locations alternating with each eye movement. For example, *bears* changed to *peaks* after a saccade and then back to *bears* after the next eye movement. After reading, subjects were required to make forced choices indicating which words they identified as they read. Subjects generally indicated that they had read only one of the target words, and they did not combine the beginning letters of the target word (when it was parafoveally available) with other letters following the saccade. That is, in our present example, subjects never reported seeing *beaks* or *pears*. McConkie et al. also compared fixation durations on the target word in the alternating condition against a control condition in which the letters in the target location did not alternate back and forth. In the alternating condition, fixation duration was 10 msec longer than in the nonalternating condition (a nonsignificant difference). On the basis of the results, McConkie et al. concluded that partial word information is not obtained parafoveally and that information used to identify a word is obtained only on the fixation in which the word is completely identified. According to their conclusion, words can be identified parafoveally or they can be identified foveally, but partial word information is not obtained.

However, a more recent experiment (Balota et al. 1985) provides evidence that partial word information is obtained parafoveally and clarifies the results reported by McConkie et al. (1982). Balota et al. asked subjects to read sentences in which a target word was either predictable from the prior context or unpredictable (but not anomalous) from prior context. They used the boundary technique described previously, and they initially presented visually similar or dissimilar nonwords which changed to the target word when the reader's saccade crossed the invisible boundary. Comparing the visually similar and dissimilar conditions, Balota et al. found that first fixation durations were 15 msec shorter (which was significant) when the initially presented stimulus was visually similar to the target word than when it was dissimilar. When gaze duration was examined, the difference between visually similar and dissimilar conditions was much greater. Notice that the procedure of McConkie et al. only allowed them to examine first fixation on a word; each time the reader made an eye movement, the letters changed, so that a subject who fixated twice on the target word would see two different words. Balota et al. (see also Balota and Rayner 1989) discussed in detail some other issues that may have led McConkie et al. to prematurely reject the notion that readers can use partial word information from parafoveal vision.

The extraction of useful partial word information from parafoveal vision implies that it must be integrated in some way with the foveal information from the subsequent fixation. How that information is integrated may provide an important tool for understanding which codes are important in lexical access as well as for understanding the skilled performance of reading. In particular, it seems important to know whether the codes being extracted from words in parafoveal vision are visual features, sound codes, morphemes, abstract (case-independent) letters, or something else.

The evidence against the use of visual codes in integration across saccades is quite strong. McConkie and Zola (1979) asked subjects to read text presented in alternating (i.e., upper and lower) case. During each saccade, all the letters on a line of text changed case (e.g., *cHaNgE* to *ChAnGe*). McConkie and Zola found that the change of case was not noticed by subjects and, furthermore, that subjects read as rapidly when the case changed after each saccade as when there were no case changes. It could be argued, however, that the difficulty of reading alternating-case text may have prevented the extraction of any parafoveal information. To guard against this, Rayner, McConkie, and Zola (1980) investigated case changes using the naming paradigm described earlier. Subjects were asked to fixate on a cross, and a letter string was presented parafoveally. When the subject made an eye movement to the letter string, it was replaced by a word that the subject named. Rayner et al. found that case changes (even of the form *change* to *CHANGE*) had no effect on naming time and, more important, did not modulate the parafoveal preview effect. Thus, it appears that abstract letter codes extracted parafoveally influence lexical access for the to-be-fixated word.

Although the naming paradigm is more artificial than reading, it allows the experimenter somewhat greater control than when the subject is reading text; in fact, the results from the two paradigms are in almost perfect agreement. The typical size of the naming-facilitation effect (about 30 msec) agrees quite well with the reduction in mean gaze duration observed in reading. The parafoveal naming paradigm also allows for a test of whether sound codes are important in information integration. If they are, then the amount of facilitation should be less in a case like *write-walks* (where the first phoneme changes) than in *write-rough* (where the first phoneme stays the same). In fact, there was no facilitation in either case (Rayner et al. 1980). Other results reported by Rayner et al. (1980) are consistent with the conclusion that sound codes do not form the basis of the parafoveal preview effect.

Another candidate for a code conveying partial information is the morpheme. To test this possibility, Lima (1987) constructed sentence frames that could include either a true prefixed word (e.g. *revive*) or a pseudo-prefixed word (e.g. *rescue*) in the same target location. If extracting morphemes is a significant part of the benefit of parafoveal preview, then one should observe a larger parafoveal-preview benefit for the prefixed words. In fact, there was equal benefit in the two cases, suggesting that morphemes (or at least prefixes) are not active units in integration across saccades. However, Lima acknowledged that her results do not eliminate all possible models of parafoveal morpheme extraction.

A related candidate for the parafoveal access code is semantic information. It has been hypothesized that an unidentified parafoveal word is semantically preprocessed, which aids later identification of the word (Underwood 1980, 1981). Results testing this hypothesis are mixed (Bradshaw 1974; Inhoff 1982; Inhoff and Rayner 1980; Stanovich and West 1983), with at best small effects indicating such preprocessing, and with possible methodological problems. For example, Bradshaw (1974) reported results supporting a semantic-preprocessing model, but when certain potential methodological problems were eliminated no support for the model was obtained (Inhoff 1982; Inhoff and Rayner 1980). However, all these studies relied upon tachistoscopic exposures of pairs of words, which may be quite unlike normal reading. A more direct test of the semantic-preprocessing hypothesis was carried out by Rayner, Balota, and Pollatsek (1986) using the boundary technique described above. Each sentence contained a single target word (e.g. *tune*), and the parafoveal preview was either visually similar (*turc*), semantically similar (*song*), or unrelated (*door*). (The semantically similar pairs were shown to produce the standard foveal priming effect in a separate naming experiment.) Gaze durations on the target word were appreciably shorter when the preview was visually similar to the target word, but there was no difference between the semantically similar and unrelated conditions. Thus, semantic preprocessing or extraction of semantic features is not a viable explanation for the parafoveal-preview benefit in reading.

Thus, by exclusion, the experiments discussed so far suggest that the only units active in integration across saccades appear to be abstract letter codes. However, a different approach to the use of parafoveal information is to ask whether constraint can influence the use of such information. There have been two approaches to investigating constraint, one of which has addressed intralexical constraint and one of which has addressed the impact of sentential constraint.

With respect to the issue of intralexical constraint, Lima and Inhoff (1985) presented sentences in which one of two words appeared in a target location (e.g., "The weary *dwarf* ..." or "The weary *clown* ..."). The target words (such as *dwarf* and *clown*) were selected to have equal frequency in the language and to be equally predictable in the context, but were chosen so that the first three letters (e.g. *dwa*) of one word are shared by few words in the lexicon whereas the first three letters of the other (*clo*) are shared by many words. Since prior studies had demonstrated that seeing the first three letters of the parafoveal word produced a large benefit, Lima and Inhoff reasoned that, if lexical constraint were a potent variable in parafoveal processing, the preview benefit for *dwarf* should be greater than that for *clown*. In fact, there was an equal preview benefit in the two cases, indicating that lexical constraint does not operate on parafoveal information. Lima and Inhoff did find that the fixation time on *clown* was actually less than that on *dwarf*, regardless of whether there was a preview or not. They argued that the familiarity of a word's initial letter sequence affects the time required to process a word foveally.

The effect of sentential constraint on parafoveal processing was examined by Balota et al. (1985), who varied both the predictability of a target word and the availability of parafoveal information using the boundary technique. Two findings of interest emerged. First, earlier findings that a more predictable target word is more likely to be skipped than a less predictable target word (Ehrlich and Rayner 1981) were replicated. Thus, sentential constraint, unlike lexical constraint, does appear to influence the usefulness of parafoveal information. Of greater interest are those occasions when the target word was not skipped. The gaze duration on the target word was shorter when the word was more predictable, which again replicated an earlier result (Ehrlich and Rayner 1981). More important, the benefit of a parafoveal preview was greater when the target word was more predictable, indicating that (in some sense) extraction of parafoveal information is more efficient when guided by sentential context. Additional analyses indicated that more letters were extracted from the parafovea when context was high. Both of these findings run counter to a modular view of lexical access and are consistent with more interactive views (see, e.g., Paap, Newsome, McDonald, and Schvaneveldt 1982; McClelland and Rumelhart 1981). Balota and Rayner (1983), McClelland and O'Regan (1981), and Paap and Newsome (1981) have reported similar superadditive interactions between contextual constraint and the use of parafoveal information.

In this section, we have reviewed research that has attempted to determine the locus of the parafoveal-preview effect in reading. The evidence points to the conclusion that primarily letter-code information is being abstracted from the to-be-fixated parafoveal word. We prefer to interpret this effect as suggesting that lexical-level representations accumulate activation via letter-code information in the parafovea. Thus, when the reader brings the parafoveal word into fixation, there is already some activation for the lexical representations consistent with the first two or three letters of the target word. It is noteworthy that a simple extension of this framework can nicely handle the superadditive interaction between contextual constraint and parafoveal information. Our argument is based on a suggestion by McClelland and O'Regan (1981; see also Balota and Rayner 1983). The notion is that on some trials there is insufficient parafoveal activation for any single lexical representation to stand out from the other candidates. In these situations, all lexical candidates that are consistent with the parafoveal information receive some activation. However, there is no net influence on performance on such trials, because of an inhibitory influence that each partially activated lexical representation exerts on each other one. Likewise, on some trials, contextual constraint produces insufficient lexical activation for any single lexical representation to stand out among the potentially constrained candidates. On these trials, all constrained lexical representations receive some activation, which is again quickly reduced via an intralexical inhibitory mechanism. However, when the two sources of information combine there is sufficient lexical activation for a single representation such that it stands out from the other candidates. In this case, a single lexical representation can dominate the potential candidate set. McClelland and Rumelhart (1981) discussed a similar phenomenon, referred to as the "rich-get-richer" effect.

The important point for the present discussion is that such a framework can account for both the main effects of parafoveal information and contextual constraint, and also for the superadditive interaction between these two variables. The main effects of these variables reflect those trials in which there is sufficient lexical activation (due to contextual constraint and/or to parafoveal information) for a lexical representation to stand out from the other candidates. For the remainder of this chapter, we will be emphasizing the main effect of parafoveal preview and its relationship to lexical access and to movements of the eyes. Again, the parafoveal-preview effect simply reflects those situations in which the lexical representation for the currently fixated word is already activated via its earlier parafoveal preview.

5 Lexical Access and Eye Movements

When a reader has a parafoveal preview of the word to the right of fixation, reading proceeds more efficiently than when no preview is provided. What is the relationship between parafoveal preview, lexical access, and eye movements? In an attempt to be more specific about the relationship between parafoveal-preview effects, lexical access, and eye movements, let us consider the sequence of events that occurs when a reader is fixated on a particular word. From the example shown in figure 2, assume that the reader is fixated on the word *fluent* and that the word *processing* is to the right of fixation. When the reader fixates on *fluent*, visual feature information is encoded at the outset of the fixation and, as indicated earlier, it appears that the initial visual encoding processes takes about 50 msec (Rayner et al. 1981). During this initial encoding, two processes are initiated simultaneously and independently: the reader begins lexical access processes for the fixated word, while at the same time a preliminary target location for the next saccade is computed (Pollatsek and Rayner 1982). This determination of where to look next is based on word-length information, and the computation is generally to send the eyes to the *preferred viewing location* (Rayner 1979) in the next word.

At some point, the processes associated with lexical access for the foveally fixated word (*fluent*) will be completed and attention will shift to the word to the right of fixation (*processing*). Morrison (1984) has suggested that this shift of attention to the word to the right of fixation serves as an impetus or trigger for an eye movement that follows the attention shift in a timelocked manner. As noted, in most cases the saccade will take the reader to the preferred viewing location in the next word; in the example, this would be the letter *o* or *c*. Because of acuity limitations, in most situations the reader will not be able to identify the parafoveal word prior to the saccade. However, the first two or three letters (*p-r-o*) will be identified and coded in an abstract form. After the saccade, the reader will complete the lexical access process. Thus, the preview of the parafoveal word enables the reader to identify that word more quickly than when a preview was not available. The parafoveal preview enables the reader to get a head start into the lexicon. However, should the beginning letters of the parafoveal word change during the saccade (which can only happen in the laboratory, through the use of eye-contingent display-change techniques), the letters at the beginning of the word are reprocessed and the reader does not misread the word (McConkie et al. 1982; Rayner et al. 1980).

In some cases, the reader completely identifies the word to the right of fixation after the attention shift. If identification occurs early enough, the reader can cancel the saccade programmed to the next word and move to word $n + 1$ (as in moving from *processing* to *words*). However, if identification of the word to the right of fixation occurs sufficiently late in the fixation, the reader may not be able to cancel the next saccade. In such cases, one of two things may happen: The reader may move to the word to the right of fixation, but with a very short duration on that word followed immediately by a saccade to the right, or the reader may make a saccade that ends somewhere between the word to the right of fixation and the word after it. Figure 3 shows examples of these scenarios. The idea in each of these examples is that parallel programming of saccades (Becker and Jurgens 1979; Morrison 1984) occurs when the word to the right of fixation is identified and the reader is not able to cancel the saccade already programmed. If the word to the right is identified early enough in the fixation, the reader can cancel the saccade programmed to move to that word. In this case the reader will reprogram the saccade to skip that word. However, if the program for the next saccade has passed the point of no return, the reader can begin programming another saccade while the already programmed saccade is in the process of preparation. In this case the reader might program a very short fixation on the first word (word $n + 1$) followed by a fixation in the normal range on the second word (word $n + 2$). Alternatively, the saccade might land midway between the first and the second word.

These examples demonstrate that there is a close relationship between lexical access processes and when the eyes move. While the arguments may

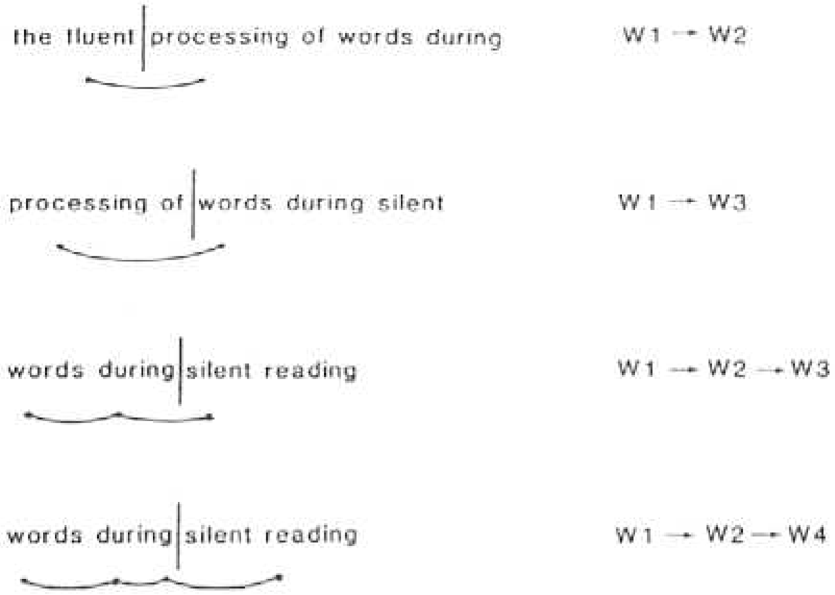

Figure 3
Examples of four different eye-movement patterns. In the top example, W1 was identified on fixation 1 and W2 on fixation 2. In the second example, W1 and W2 were both identified on fixation 1 and the eye moved to W3. In the third example, W1 was identified on fixation 1 and attention shifted to W2. However, W2 was identified prior to the saccade with a short fixation on W2 followed by a saccade to W3. In the fourth example, the same sequence occurred as in the third example; however, fixation 3 was halfway between W2 and W3, with the next saccade going to W4.

be regarded as somewhat speculative, they do provide a principled account of (1) why there are fixations in the range of 50–100 msec in reading (which should not occur, given that the minimal oculomotor reaction time of the eyes is around 150–175 msec) and (2) why there is some variability in where readers fixate (most fixations are around the preferred viewing location, but some are at the ends of words and on the blank spaces between words). Although the arguments presented above based on Morrison's model (1984) can thus account for two previously puzzling aspects of eye movements during reading (very short fixations and fixations not near the preferred viewing location), the model cannot be complete since it does not explain why a reader would ever fixate a word more than once or why regressions would ever occur. It thus appears that some additional mechanism is needed, one that can interpose relatively late in a fixation to cancel and/or alter the decision of where the eye is to move (i.e., to remain on the current word or to move back). Our suggestion is that "higher-order" cognitive operations, such as text-comprehension processes, express themselves through this additional mechanism. Thus, when the reader encounters some type of comprehension difficulty (garden-path effects, text-integration problems, or when something simply does not make any sense), the normal process is aborted and either the eyes are held in place, or the word is refixated, or a regression is programmed. Of course, if the program to make the next saccade is already too far along, the next fixation ($n + 1$) will then be longer (or there might be an immediate regression launched from fixation $n + 1$). Many studies have demonstrated that words that are difficult to process often have a second fixation on them. In such instances, it appears that the decision to refixate a word can be made later in a fixation than the decision of when to terminate the fixation.

A recent experiment by Pollatsek et al. (1986) provides some evidence concerning refixations on words. They used a boundary technique in which initially presented words or nonwords were replaced by the target word when the saccade crossed the boundary. As in a previous experiment by Rayner (1975), they examined fixation time on a target word as a function of where the reader was fixated on the prior fixation and as a function of the relationship between the initially presented stimulus and the target word. They found that visual similarity of the initially presented stimulus to the target word had an effect on the first fixation duration of the target word when the reader had been fixated close (3–5 characters from the beginning of the target) to the target word, but only had an effect on gaze duration (through the probability of refixating the word) when the reader had been fixated far (9 or more character spaces) from the target word.

Pollatsek et al. argued that these results suggest that refixation decisions are made later than decisions about when to terminate the fixation. The notion is that the visual similarity of the preview to the target word appears to influence the time needed to process the target word. Most of the effect is probably due to the fact that letter information has been extracted from the preview which aids lexical access (Balota et al. 1985; Rayner, McConkie, and Zola 1980). When the preview information is good (i.e., when fixation $n - 1$ is near the target word), lexical access is rapid enough to affect the decision of when to move the eyes. However, when fixation $n - 1$ is further from the target word, poorer preview information will be extracted and lexical access is likely to be slower. Thus, the most plausible explanation for the fact that first fixation duration is not affected when fixation $n - 1$ is at the far distance (in the study of Pollatsek et al.) is that letter information extracted parafoveally from the target location does not speed lexical access sufficiently to be able to beat the decision to move the eyes. The fact that letter information influences the probability of refixating the word at the far distance indicates that some letter information has been acquired, and that this information is unable to influence the decision to terminate the first fixation but is able to influence the later decision of where to fixate next. (It is important to remember here that our operationalization of lexical access is *when* the eyes leave the word, not simply the termination of the first fixation.) The same conclusion follows from an analysis of an experiment by Inhoff and Rayner (1986).

Inhoff and Rayner (1986) varied both the frequency of a target word (holding the number of letters constant) and whether there was a parafoveal preview of the word. They measured both the mean first fixation duration and the mean gaze duration on the target word when it was fixated. The results indicated that word frequency affected both first fixation duration and gaze duration when there was a parafoveal preview of the target word, but affected only gaze duration when there was not a parafoveal preview. This pattern of data is easily explained by making the same two assumptions we used to explain the data of Pollatsek et al.: (1) that lexical access is slower if there is poorer parafoveal information (in this case none) and (2) that the decision to refixate can be made later than the decision of when to terminate the first fixation. Thus, when there is no parafoveal preview, lexical access—even for the high-frequency words—is not fast enough to influence the decision to end the first fixation; however, lexical access for the high-frequency words is fast enough to influence the decision of whether to refixate the word and can affect gaze duration. On the other hand, when there is a parafoveal preview, lexical access for high-frequency words is fast enough to influence both decisions and can therefore affect both measures.

Thus, the experiments of Pollatsek et al. and Inhoff and Rayner suggest that first fixation duration on a word is unlikely to be affected by the time of lexical access unless a healthy dose of parafoveal information has been acquired on the prior fixation. Accordingly, both experiments also suggest that gaze duration may in many cases be a more sensitive measure of processing than first fixation duration, since the gaze duration may reflect processing events later in the first fixation than the duration of the first fixation. The argument also implies that the decision to move the eyes is made before lexical access is complete under conditions in which good parafoveal previews are not obtained. However, in such cases, the reader does not typically leave the word but rather refixates that same word to ensure the completion of the identification process. Further work is needed to determine whether the decision to move the eyes before lexical access is, in some cases, "automatic" and unaffected by ongoing cognitive processes or whether there are processing stages short of full lexical access that trigger the decision to move the eyes ahead in reading.

Conclusions

The major goal of the chapter was to provide a framework for discussing the complex relationship among lexical access, parafoveal processing, and eye movements in reading. In providing a tentative operationalization of lexical access in reading, we have suggested that lexical access is reflected by the decision when to move the eyes from the currently fixated word. Clearly, this is not all that is going on during a fixation on a given word. The data reviewed earlier indicate that readers utilize varying levels of parafoveal information during a given fixation. Moreover, we have argued that whether or not there has been a healthy dose of parafoveal preview on the prior fixation can modulate the eye-movement behavior.

The data reviewed converge nicely on a model of parafoveal processing, lexical access, and eye movements according to which the completion of lexical access on the current word triggers a shift in attention to the parafoveal word to the right of fixation. The work by Morrison suggest that this shift in attention triggers the programming of a saccade to that word. Moreover, it appears that, as the reader is fixating a given word, parafoveal information is accumulating about the to-be-fixated word. The research addressing the type of information that is accumulating indicates that it is primarily abstract letter code information. Thus, parafoveal information utilization facilitates the lexical access process on the next fixated word, thereby influencing both the shift of attention and its accompanying eye-movement process.

Although this sequence of lexical access, attention shift, and eye movement is the most typical sequence in reading, there are exceptions to this normal sequence. These include (1) the abortion of the decision when to leave the currently fixated word because of some disruption in higher-order comprehension processes and (2) sufficient analysis of a parafoveal word that leads to the identification of that word. Although there is little doubt that these exceptions often occur, we believe that, because of the oculomotor processes involved in reading and the temporal characteristics found in normal reading, lexical access of the currently fixated word is the *main* driving force for the decision concerning when to leave a word.

Acknowledgments

The preparation of this chapter was supported by Grant BNS86-09336 from the National Science Foundation. Much of the chapter was written when both of the authors were Fellows at the Netherlands Institute for Advanced Study, and we express our appreciation to that organization. We also would like to thank William Marslen-Wilson and an anonymous reviewer for their very helpful comments on an earlier version of the chapter. We would especially like to acknowledge our collaborations with Sandy Pollatsek and Bob Morrison, both of whom played major roles in the development of many of the ideas presented herein.

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