# CHAPTER FOUR
# THE WORK OF THE EYES

When we read, we have the impression that the eyes (and mind) sweep continuously across the text except for a few places in which we encounter difficulty, and at those points, we pause to consider what we have just read or regress (go back) to reread earlier material. However, that impression is an illusion.

The two eyes move pretty much in synchrony with each other across the page (Rayner 1978a; Tinker 1958), but their progress is not continuous. The eyes come to rest for periods that are usually between 150 and 500 milliseconds (msec): These periods when the eye is close to immobile are called *fixations*. Between the fixations are periods where the eye is moving rapidly. These eye movements are called *saccades* after the French word for "jump." Saccades are *ballistic movements;* once started, they can not be altered. When we read, our eyes generally move forward about 7 to 9 character spaces with each saccade. The duration of the saccades in reading varies with the distance moved, with a typical saccade taking about 20 to 35 msec. Since, for all practical purposes, no visual information is extracted from the printed page during saccades, all visual information comes in during fixations.

The pattern of information extraction during reading is thus a bit like seeing a slide show. You see a "slide" for about a quarter of a second, there reading. We claim, in fact, that eye movements are by far the best tool to understand the process of normal silent reading (which undoubtedly accounts for well over 90 percent of the reading adults do). At the end of the next chapter, we will discuss alternative methods for studying reading of text (as opposed to individual words).

This chapter and the next deal with how visual information is extracted from text. The present chapter focuses on what useful information readers extract during fixations, while the next chapter focuses on how the eyes are guided through text. Necessary to understanding both topics is some basic information about eye movements in reading. These data will be far more meaningful, however, if we make them concrete by examining an example of an eye-movement record.

## BASIC CHARACTERISTICS OF EYE MOVEMENTS

Figure 4.1 shows part of a page of text with a record of a reader's eye movements superimposed on the text. The average saccade length is about 8.5 characters, but the range is 1 character to 18 characters. Actually in some cases, fixations on the same letter have been combined in the record shown (the capability of doing this is contingent upon having a very accurate eye-movement recording system). The average fixation duration is 218 msec, but the range is 66 to 416 msec.

Notice that, for the most part, words are fixated only once. However, *enough* is fixated twice and *pain* and *least* are not fixated at all. Since a fixation lands on or near almost all words, it appears that a major purpose of eye movements is to bring all words close to the *fovea,* the region in the center of vision that is best for processing fine detail (see Chapter 1). However, what is causing the variability? Why are some words not fixated while others are fixated twice? Is this just miscalculation of the eye movement as in return sweeps, or does it reflect something deeper?

Similarly, why are fixation durations different? Does a long fixation time on a word indicate that the reader is taking more time processing the fixated word, or are these variations in fixation time random as well? Moreover, assuming that fixation times are not random (which indeed they are not), what fixation time do we use to index the processing time for a word? If there is a single fixation on a word, there is little choice: we simply measure the *fixation duration* on the word. However, consider the case of *brainstorm* in Figure 4.1. There are three likely candidates to measure processing time for the word. The first is the duration of the first fixation (or *first fixation duration*) which is 277 msec. (Using this measure assumes that later fixations on the word are getting at other processes, such as relating the material to earlier material, or are just mistakes of eye programming.) The second is *gaze duration,* which is the total fixation time on the word before the eye moves off (or 277 msec + 120 msec = 397 msec). (This measure assumes that the second fixation was needed to finish processing the fixated is a brief ''off time,'' and then a new ''slide'' of a different view of the page appears for about a quarter of a second. This pattern of fixations and saccades is not unique to reading. The perception of any static display (such as a picture or a scene) proceeds the same way, although the pattern and timing of fixations may differ from that in reading. The only exception is when the eyes track a moving target. In that case, the eyes move relatively smoothly and useful visual information is extracted during the eye movement.

The second way in which our subjective impression is an illusion is that the eyes do not move forward as relentlessly as we think. While most saccades in reading move forward, about 10 to 15 percent move backward and are termed *regressive saccades* (or *regressions* for short). Think of regressions this way: since we make about four to five saccades in a second, we make a regression about once every two seconds. Thus, we are certainly unaware of most regressions. While some regressions reflect major confusion requiring us to go back a considerable distance in the text to straighten things out, the majority are quite short, only going back a few characters.

Another type of eye movement that is worth mentioning is the *return sweep*. This is when the eyes move from near the end of one line to near the beginning of the next. While return sweeps are right to left, they are not usually counted as regressions because they are moving the reader forward through the text. Return sweeps are actually quite complicated as they often start 5 to 7 character spaces from the end of the line and they generally go to about the third to seventh character space of the next line. While there is often an additional short right-to-left saccade after the large return sweep, the leftmost fixation is still sometimes on the second word of the line. Thus, most of the time about 80 percent of the line falls between the extreme fixations on it. (We shall explain why readers often may fail to fixate the beginning and end words of lines a bit later.) The small saccades following return sweeps are probably corrections for errors in aiming the eyes; it is difficult to execute a long saccade perfectly, since the eyes usually undershoot the target position. Since the details of such motor execution are peripheral to the concerns of most people studying reading and to our concerns here, most of the interest in eye-movement records is on what the eye does on the middle four-fifths of the line. Of course, return sweeps must be counted as well if one wants to get global measures of reading, such as the overall reading speed.

To summarize, the eyes move forward (about 7 to 9 character spaces on average) in reading, but not relentlessly so. They pause for periods of approximately 200 to 250 msec, and move backward about 10 to 15 percent of the time. In this chapter and the next, we will discuss in considerable detail much of the cognitive processing during all this activity and its relation to the ongoing pattern of eye movements. This topic is interesting in itself, as it is at the core of understanding visual cognition in reading and visual cognition more generally. In addition, understanding the details of the work of the eyes in reading is an invaluable tool for understanding the process of

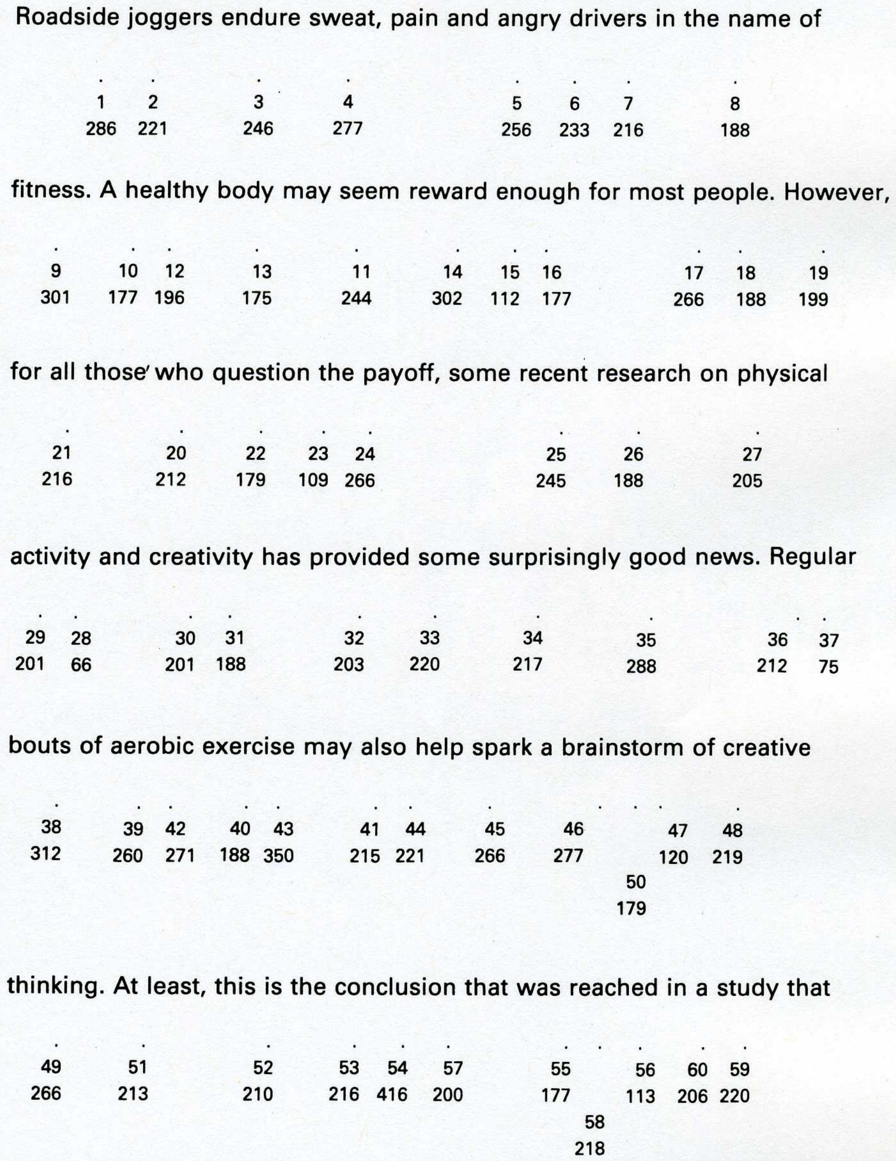


**FIGURE 4-1** **An excerpt from a passage of text with fixation sequence and fixation durations indicated.**

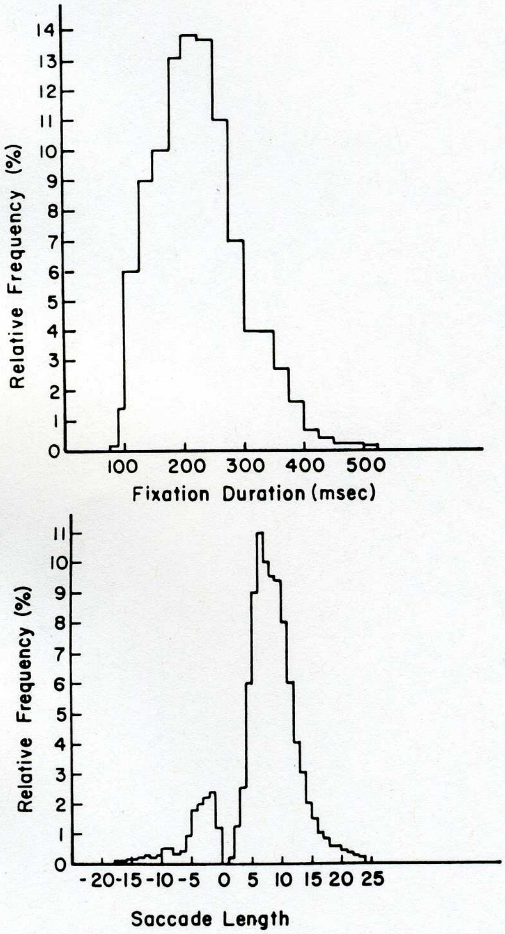
word.) The other obvious possibility is the *total viewing time,* which includes later fixations on the word that are the result of regressive saccades. In the case of *brainstorm,* the total viewing time would be 576 msec. (This measure assumes that the regression was made in order to continue processing the word in some way.)

### Variation of Reading Measures

The record in Figure 4.1 is typical of adult readers. Figure 4.2 shows the distributions of individual fixation times and saccade lengths from a large corpus of data from adult readers. As can be seen in Figure 4.2, both the average saccade size and average fixation duration of our little segment (and the variability as well) are reasonably in agreement with the larger aggregation of data.

*Text differences* The averages and distributions in Figure 4.2 should not be regarded as numbers engraved in stone: reading measures such as

**FIGURE 4-2** **Frequency distribution of fixation duration (upper graph) and saccade length (lower graph) for eight college-age readers. Return sweeps of the eye have been excluded from the distribution. Short fixations following the return sweep, which are followed by corrective saccades, have also been excluded. (Reproduced with permission from Erlbaum.)**



reading rate, mean fixation duration, mean saccade length, and percent of regressive fixations vary from text to text. Table 4.1 shows some of the variability for adults reading text on various topics, with apparently more difficult text requiring longer fixations, smaller saccades, more regressions, and hence a slower reading rate.

*Typographic differences* Is the pattern of eye movements dependent upon typographic features, such as letter size, type of font, length of line? Tinker (1963, 1965) studied this question in some detail for English (see Morrison and Inhoff 1981 for a review of this work). His data are complex, but we believe the following brief summary captures the essence. First, the type of font made a minor difference, although all of the fonts that Tinker studied were (subjectively) relatively easy to read. There are some fonts that appear to be pathologically difficult (such as the elaborate script used in German known as "fractur"), and these may slow the reading process appreciably. However, we know of no experimental evidence of this.

Secondly, it is difficult to make inferences about how the size of the characters influences reading speed from Tinker's data because the size and the number of characters per line were confounded: there were more characters per line when the print was smaller (Morrison and Inhoff 1981). However, he also varied line length (keeping the size of the characters constant) in another study, and the differences he observed for differing size of characters appear to be explained by line-length effects. He found that there was an optimal line size of approximately 52 characters. This optimality is parsimoniously explained by a trade-off between two opposing factors. First, if the line is too long, return sweeps become increasingly difficult to

**TABLE 4.1 Mean fixation duration, mean saccade length, proportion of fixations that were regressions, and words per minute (WPM) for 10 good college-age readers reading diferent types of text.**

| TOPIC | FIXATION DURATION[a] | SACCADE LENGTH[b] | REGRESSIONS (%)[c] | WPM |
|---|---|---|---|---|
| Light fiction | 202 | 9.2 | 3 | 365 |
| Newspaper article | 209 | 8.3 | 6 | 321 |
| History | 222 | 8.3 | 4 | 313 |
| Psychology | 216 | 8.1 | 11 | 308 |
| English literature | 220 | 7.9 | 10 | 305 |
| Economics | 233 | 7.0 | 11 | 268 |
| Mathematics | 254 | 7.3 | 18 | 243 |
| Physics | 261 | 6.9 | 17 | 238 |
| Biology | 264 | 6.8 | 18 | 233 |
| *M* | 231 | 7.8 | 11 | 288 |

[a] In msec.

[b] In character spaces (4 character spaces = 1° of visual angle).

[c] Percentage of total fixations that were regressions.

execute and people may wind up on the wrong line. On the other hand, as we will shortly see, readers can extract information from more than one word on a line during a fixation (McConkie and Rayner 1975), but if lines are too short, readers can not take full benefit, as in the extreme case of one word per line. The optimal line length thus appears to be the best compromise between these opposing design considerations. We should remark, however, that all these effects are relatively minor, so that the fundamental conclusion to be drawn from the work on typography is that reading appears to proceed at about the same rate if the type font, size, and length of line employed are at all reasonable.

*Reading distance differences* In reading, the average saccade is about 7 to 9 character spaces long, or about 2 degrees of visual angle at normal reading distance. However, the value of 7 to 9 character spaces appears to be the more fundamental in that the average saccade size is 7 to 9 characters regardless of the retinal size of the text. Thus, for example, regardless of whether a given text is 36 cm or 72 cm from the eyes, the average saccade length is still about 8 characters even though 8 characters subtends twice the visual angle at 36 cm as it does at 72 cm (Morrison and Rayner 1981; O'Regan 1983). This fact suggests that the visibility of the text is relatively invariant to absolute size over an extended range of distances. (You can try this out by holding this book at varying distances and see whether varying the distance affects the ease of reading.) As a result, all the data on saccades will be expressed in ***character spaces,*** which appear to be the natural metric in reading, rather than degrees of visual angle.

The fact that the distance of the text (and hence the absolute size of the characters) makes little difference on saccade size is probably due to a tradeoff between two factors: when the text is nearer, the letters are bigger and easier to see; however, when the text is nearer, a given letter will be further from the center of fixation, hence harder to see (see Chapter 1). Of course, there are limits; the text will be impossible to read if a mile away or against your face. By the way, when text is moved further away it is a bit harder to read: fixation durations become slightly longer, presumably because the letters are harder to discriminate.

*Orthographic differences* A question related to typographic differences, but more difficult to answer, is whether the writing system influences the process of reading. All of the information we presented in this chapter so far concerning eye movements is based on data collected from readers of English. Do the characteristics of eye movements change when people read text which uses other writing systems?

Some experiments have examined the patterns of eye movements of Chinese and Japanese readers. A major problem with comparing saccade sizes in English with either of these languages is what unit of measurement to use. The previous section implied that the letter (or character space) may be the fundamental unit of measurement for English. However, there are no letters in either of these languages: the characters stand for syllables or morphemes, or both (see Chapter 2). If one measures by "characters" (i.e., a letter is a character), then eye movements of Chinese and Japanese readers tend to be much smaller than eye movements of readers of English. Chinese readers move their eyes on average about 2 characters (Shen 1927; Stern 1978). (Remember that a character is a morpheme rather than a word, so that this is less than two words.) Readers of Japanese text, which is made up of morphemic characters (Kanji) and syllabic characters (Kana) on average move their eyes 3.6 characters (Ikeda and Saida 1978). This again is less than 3.6 words, since it often takes several characters to make a word. Since the average saccade length in English is about 7 to 9 characters, or about a word and a half, it appears that the average saccade length is if anything a bit less in English than in Chinese and Japanese if one equates for number of words or morphemes.

Readers of Hebrew also have smaller saccades (about 5.5 characters) than readers of English (Pollatsek et al. 1981). Hebrew varies structurally and orthographically from English in some important ways. First, not all vowels are represented orthographically in Hebrew. In addition, many function words in Hebrew are clitic, meaning they are attached like prefixes or suffixes to content words. The effect of these differences is that Hebrew sentences normally contain fewer words and fewer letters than their English counterparts. In short, though Hebrew is basically an alphabetic system, the information is more densely packed than in English.

The average saccade lengths of Chinese, Japanese, and Hebrew readers suggest that the informational density of the text determines how far the eyes move in each saccade. This finding seems consistent with the finding that, for readers of English, as the text becomes more difficult (and hence, the informational density is greater) saccade length decreases. However, it is an open question whether the differences in informational density across languages are best thought of in terms of the density of the meaning or the amount of visual information per character (measured perhaps by the number of strokes or lines in the character). For Hebrew, the characters seem of approximately equal complexity to English, so the differences between Hebrew and English are more likely to be explained by differences in amount of meaning per character. However, the Chinese and Japanese writing systems are so different from English that it is hard to say which type of informational density is operating to produce the differences in reading. We suspect that both the visual and semantic factors are contributing.

For readers of English, difficult text also increases the average fixation duration. Fixation durations tend to be longer for readers of Japanese, Chinese, and Hebrew than for readers of English. For example, the average fixation duration for Chinese readers is around 300 msec (Shen 1927) and for Israeli readers about 265 msec (Pollatsek et al. 1981). Despite the fact that reading in these languages is slower when measured superficially (saccade lengths are shorter and fixation durations are longer), reading rates, when measured in terms of amount of meaning extracted per unit time, seem to be equivalent. In fact, when the reading rate in Hebrew is based on the number of words in the English translations of the Hebrew sentences, the average reading rate for the Hebrew- and English-speaking subjects is nearly identical (Pollatsek et al. 1981).

One final dimension of orthographies is the direction in which the characters proceed. As we pointed out in Chapter 2, there were no clear conclusions that could be drawn about the effect of the direction of print on the eye movements or the efficiency of reading. In general, the results were consistent with the hypothesis that differences in the direction of print do not matter and that all differences observed in reading speed were because the more familiar orthography is read more easily (Shen 1927; Sun, Morita, and Stark 1985). A similar conclusion follows from laboratory experiments which manipulated the direction of print.

Tinker (1955), for example, found that readers of English initially read vertically arranged English 50 percent slower than horizontally arranged text. However, with 4 weeks of practice their reading speed was only 22 percent slower than for the horizontal text. In a number of studies, Kolers (1972) has also shown that with practice readers of English can read text arranged in a right-to-left fashion fairly well. Children learning to read can also read from right to left as easily as they read left to right (Clay 1979).

Relatively short amounts of practice in the laboratory did not abolish differences in reading rate as a function of the arrangement of text (Kolers 1972). However, Kolers' studies suggest that differences between arrangements of print, if they exist, are likely to be quite small. There is some physiological reason to believe that a horizontal arrangement in any language may be better: visual acuity falls off faster in the vertical direction than in the horizontal direction. However, the evidence that no direction of text appears to be preferred over any other suggests that this physiological fact may have a negligible effect on reading.

## A Few Comments about Saccades and Fixations

At the beginning of this chapter, we claimed that reading was a "slide show" in which the eyes remained glued to the spot on the page for a certain period of time (the fixation) and then moved quickly with no visual information extracted during the move (the saccade). While these claims are essentially true, they are slight oversimplifications. We will briefly discuss the complexities, so that we can set the record straight. However, for the remainder of the chapter and book, these complexities are so insignificant that we can safely use the "slide show" metaphor.

*Saccades* First, let us consider the assertion we made that no visual information is extracted during a saccade. You can demonstrate for yourself that little is perceived during saccadic eye movements by looking in a mirror and trying to watch your eyes move. You will not see them do so. This reduced perceptability of stimulation during saccades was discovered almost 100 years ago (Dodge 1900; Holt 1903).

Why don't we see anything during the saccade? First, the eye is moving so fast during a saccade that the image painted on the eye by a fixed stimulus would be largely a smear and thus highly unintelligible. However, we aren't aware of any smear. Thus, there must be some mechanism suppressing the largely useless information that is "painted" on the retina during the saccade. One possible mechanism is "central anesthesia": when the brain knows that the eye is making (or about to make) a saccade, it sends out a signal to the visual system to ignore (or attenuate) all input from the eyes until the saccade is over. There is in fact evidence (Matin 1974) that the thresholds for stimuli shown during a saccade (or even a bit before it begins and after it ends) are raised, with the effect much more pronounced for stimuli presented during a saccade. This threshold raising before and after the saccade is not of much importance for reading, since the letters seen in text are far above threshold. Thus, it is not clear whether these relatively small threshold effects would mean that the ability to extract information from the text would be altered significantly. (That is, it might be like the difference between reading with a 60 watt bulb and reading with a 150 watt bulb.) However, the threshold effects are more likely to be significant with the moving eye, where the contrast between the light and dark parts of the smear would be far less.

For many years, central anesthesia was accepted as the main mechanism by which information during saccades was suppressed. However, more recent experiments indicate that a different mechanism explains at least part of the suppression and perhaps all of it. It can be demonstrated that under certain (unnatural) circumstances visual input during the saccade can be perceived (Uttal and Smith 1968): when the room is totally dark prior to and after the saccade and a pattern is presented only during the saccade, a smeared image of the pattern is perceived (Campbell and Wurtz 1978). Since the blur is thus seen if no visual stimulation precedes or follows it, the implication is that the information available prior to and after the saccade during normal vision *masks* the perception of any information acquired during the saccade. This phenomenon has been related to laboratory phenomena of masking, such as those used in subliminal priming experiments (see Chapter 3).

In sum, while we can't say for sure that absolutely *no* visual information is extracted during saccades in reading, the bulk of the evidence indicates that if visual information gets in during a saccade, it is of little practical importance. Indeed, Wolverton and Zola (1983) presented a mask during each saccade as subjects read text and it was not perceived nor did it affect reading in any way.

*Fixations* Our claim that the eye is immobile during a fixation is a bit of an oversimplification. As indicated in Chapter 1, very small rapid movements, called *nystagmus,* go on constantly to help the nerve cells in the retina to keep firing. However, these are so small as to be of little practical importance in studying normal reading. There are also somewhat larger movements called *microsaccades* and *drifts.* While the reasons for these movements are not completely clear, it appears that the eye occasionally drifts (i.e., makes a small and rather slow movement) because of less than perfect control of the oculomotor system by the nervous system. When this happens, there is often a small (1 character or less) microsaccade (i.e., a much more rapid small movement) to bring the eye back to where it was. Many experimenters assume that such small movements are "noise" and adopt scoring procedures in which these small movements are ignored. For example, some scoring procedures will take successive fixations that are separated by a character or less and lump them together as a single fixation. Some microsaccades may be under cognitive control as other saccades are, and thus some experimenters believe that microsaccades should be treated no differently from other saccades. Another alternative is a more sophisticated pooling procedure in which fixations are pooled if the intervening saccade is a character or less *and* at least one of the fixations is short (100 msec or less).

Most eye-movement data in reading have been adjusted using some sort of procedure that pools some fixations and ignores at least some small drifts and microsaccades. In some cases, the eye movement recording system is not sensitive enough to detect these small movements, so that such movements are automatically ignored. Others, with more sensitive equipment, decide on some sort of criterion for pooling. Since drifts and microsaccades are relatively uninteresting aspects of the eye-movement record, and since there is enough complexity in the data without worrying about them, our subsequent discussion will ignore them for the most part.

## Summary

We have summarized the basic facts about eye movements during reading. The eye moves about four or five times per second and jumps an average of about 7 to 9 characters each time it moves. However, it moves back about 10 to 15 percent of the time and there is large variability in both the extent of the forward motion and the amount of time it stays in a fixation. Since virtually all the information is extracted during the fixations, the interest in fixations is on the information extracted. Since saccades exist to move the eye to another fixation, the interest in saccades is in how they help to control the flow of information extraction. In this chapter, we focus on the extraction of information during a fixation, while in the next chapter, we return to the details of the movement of the eyes and focus on the control of information flow during reading.

## THE PERCEPTUAL SPAN

Since the eyes move four to five times a second during reading, it seems reasonable to assume that they move to new locations on the page because the amount of information that can be extracted from a given fixation is limited. However, some people who promote techniques for increasing reading speed claim that many of our eye movements are not necessary and that large amounts of information can be extracted from a single glance (see Chapter 12). Thus, if we are to understand which view is true—whether eye movements are a central functional part of the reading process or just a bad habit picked up from old-fashioned reading methods—we have to discover how much information from the printed page is obtained from an individual fixation during silent reading of text. As we will see, the constant movement of the eyes is not a bad habit: the region from which we can obtain useful information during each eye fixation is relatively small.

One reason that people may believe that a large amount of information can be extracted from a single fixation is that it often seems to us that we can see many words on the page at the same time. However, this is an illusion. Many of the words are seen on a fixation only in the sense that the reader knows that some wordlike object is in a given location. The brain takes the details extracted from several fixations and integrates them somehow into a perception that the detail from a wide area is seen on *each* fixation. We will discuss this integration process in the next section.

In this section, we will briefly describe various attempts to determine the size of the effective visual field (or *perceptual span*) on a fixation in reading. We will first review tachistoscopic techniques, then simple techniques based on eye movements, and conclude the section by discussing the technologically more sophisticated ''moving window'' technique.

### Fixed-Eye Techniques

The tachistoscope, which we introduced in Chapter 1, was designed in part to determine how much useful information could be acquired during an eye fixation in reading. Psychologists hoped to measure the perceptual span by asking subjects to report all they could see when a sentence was exposed briefly, say 100 to 200 msec. Since such an exposure is brief enough to preclude the possibility of an eye movement during the presentation, the technique measures how much information can be reported from a single fixation. Thus, to some extent, the technique simulates a single fixation in reading.

An experiment by Marcel (1974) will serve to illustrate the logic of the method and its attendant problems. Marcel had subjects read a short fragment of a passage in a tachistoscope. When they reached the final word of the fragment, they read it aloud. The pronunciation of this word caused the text to disappear, and 100 msec later some more words were presented for 200 msec, just to the right of where the pronounced word had been. The subjects' task was to report as many words from the second set as possible. This second set of words was not actually text, but a sequence of words that varied in how closely they approximated normal English. When the sequence of words was essentially random, subjects were able to report just over 2 words on average (or roughly 13 character spaces), while when the sequences were close to normal English, they reported 3 or 4 words (or 18 to 26 character spaces). Since the stimuli in this last condition are most like normal text, perhaps 3 to 4 words provide a good estimate of the perceptual span in reading.

There are three potential problems with this type of research. The first is that the delay between the offset of the passage fragment and the onset of the target words is quite different from anything encountered during normal reading. The delay would be about 500 msec (about 400 msec to begin pronunciation of the last word of the first fragment plus the 100 msec experimental delay). The second problem is that the eye positions were not monitored so that the experimenter did not know where the subjects' eyes really were. The biggest problem, however, is that the experimenter has no control over the extent to which the subject is consciously guessing. In the experiment by Marcel, for example, since the subjects reported what had been seen, there was little control over the speed of the response. Thus, better performance on the sequences that closely approximated English may have been because the subject could simply guess which words were likely to follow from the constraints of the text (possibly aided by partial information obtained from the stimulus). The use of random sequences gets around the guessing problem but may disrupt the normal reading situation.

Another tachistoscopic technique that has frequently been used to make inferences about the perceptual span in reading (Feinberg 1949) involves asking a subject to fixate some point and then have him or her identify stimuli (words or letters) presented at various distances from fixation (again when no eye movement can occur). On the basis of the results from such experiments (see Figure 4.3), estimates of the perceptual span have generally been in the range of 2 or 3 words, or about 10 to 20 characters (Feinberg 1949; Woodworth 1938).

A strength of the latter method is that by the use of isolated words in the visual field, one can limit the guessing problem and get a better estimate of whether the word can be identified on the basis of the available visual information. The method has its problems, however. One was pointed out some time ago by Woodworth (1938) and later verified by Sperling (1960). As we discussed in Chapter 1, Sperling demonstrated that subjects are able to see much more than they can retain and later report. Thus, what subjects report from a brief word or letter presentation can not be taken as a complete specification of what they actually saw. Even if the verbal report coincided with what the person actually saw, there is no particular reason to believe that the estimate of the perceptual span obtained from either type of tachistoscopic presentation discussed here actually coincides with that of a fixation in reading. A second problem is that the responses are not timed.

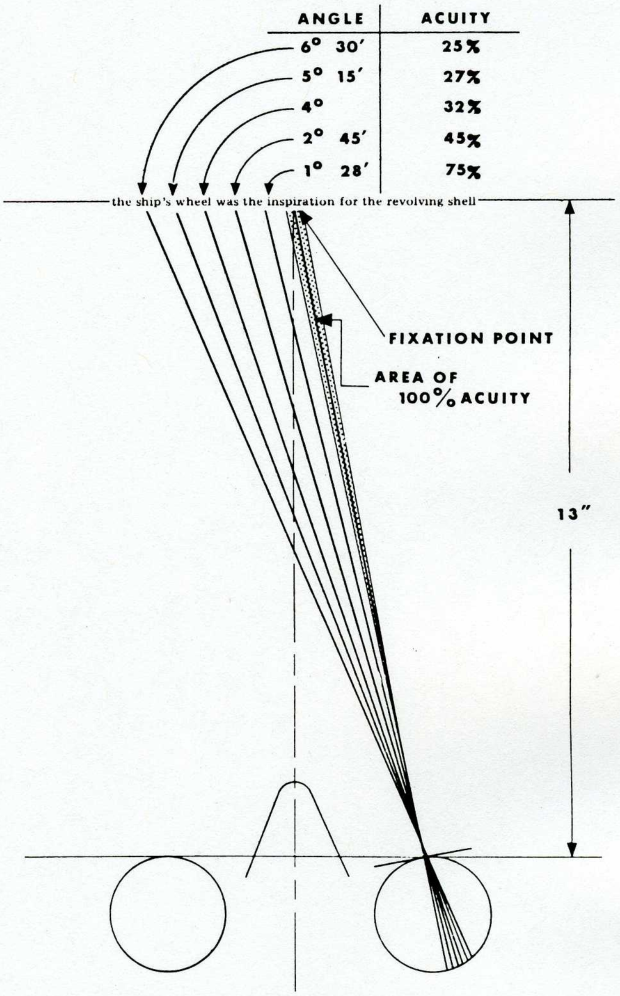


**FIGURE 4-3 Example of how perceptual span is estimated from tachistoscopic acuity data. [From Taylor 1965, reproduced with permission from the American Educational Research Association.]**

Thus, one discovers whether the word can be identified on the basis of the available visual information, but not whether it can be identified as quickly as it needs to be in normal fluent reading.

Even if all the guessing problems could be removed, there might be a real difference between the perceptual span in silent reading of text and in tachistoscopic presentation of words or sentences. The perceptual span in reading could be larger either because the contextual constraint in text allows a reader to identify words with less visual information than in tachistoscopic presentations or because the requirement to hold the eye still interferes with normal perception. On the other hand, the perceptual span in reading could be smaller because the rapid sequence of fixations and the complexity of the surrounding stimulus pattern may lead to "tunnel vision" (Mackworth 1965).

### Primitive "Window" Techniques

A somewhat different technique involving experimental control of what is seen on a given fixation is to present text but to limit the amount that is visible to a reader at a given moment. Poulton (1962) had subjects read aloud from text over which a mask containing a "window" was passed. Only the text in the window could be seen. Thus, the text was immobile and the window passed over it, allowing only a certain amount to be seen at once. The speed and size of the window varied systematically on different trials, and readers' eye movements were recorded. Newman (1966) and Bouma and deVoogd (1974) reversed the procedure by having the subjects' eyes fixed and having the text moving on a screen from right to left. The size of the "window" was manipulated by varying the number of letters on the screen at any moment.

These experiments have typically found that smaller windows create greater disruptions in reading than larger windows. These techniques, however, are suspect since they disrupt normal reading. The reader's natural eye movements were inhibited (in the latter case, fixation had to be maintained, while in the former, the reader had to follow the moving window); in neither situation could the reader reexamine text, as with regressions in normal reading; in addition, these particular experiments suffered because the subjects were required to read the text orally.

### Natural Eye-movement Techniques

The techniques mentioned so far seem to be unsatisfactory. They involve tasks that disrupt the normal reading situation. In addition, they provide rather discrepant estimates of the size of the perceptual span with the estimated size ranging from 1 to 2 to 4 words. It would clearly be better if one could estimate the perceptual span directly from normal silent reading.

One simple technique for estimating the perceptual span from natural reading is measuring the average number of words per fixation. That is, one simply records eye movements during reading and divides the number of words read by the number of fixations used to read those words (Taylor 1965). Using such a technique, Taylor estimated the perceptual span for skilled readers to be 1.11 words. While this method is simple and unobtrusive, it is unfortunately based on the assumption that the perceptual spans do not overlap on successive fixations. In other words, it assumes that a given word or letter is never processed on more than one fixation. As we shall see, this assumption is false.

The *moving-window technique* introduced by McConkie and Rayner (1975) uses the idea of the moving-window techniques discussed before—to manipulate what is seen on a given fixation—but does so in the task of normal silent reading, where the subjects can move their eyes wherever they wish. This is accomplished by making display changes in text presented on a televisionlike screen, called a *cathode-ray tube* (CRT). This research relies upon sophisticated eye-tracking equipment being interfaced with a high-speed computer, which is also connected with the CRT. The position of the reader's eye is sampled every millisecond by the computer and changes in the text are made contingent on the location of the eye. Because this type of research has been influential for our understanding of skilled reading and has provided some clear answers concerning the size of the perceptual span, we will describe it in some detail.

In the prototypical moving-window experiment, a version of mutilated text (in which every letter from the original text is replaced by another letter) is initially displayed on the CRT. However, when the reader fixates on the text, the display is immediately modified by replacing letters, within a certain region around the fixation point, with corresponding letters from the original text. This creates an experimentally defined *window* region of normal text for the reader to see on that fixation. When the reader makes an eye movement, the text in the window area returns to this unreadable form and a new window of normal text is created at the location of the new fixation. Thus, wherever the reader looks, there is a window of normal text to read in a *background* of mutilated text. Table 4.2 shows text in four successive fixations under moving-window conditions. (Because of the sophistication of the equipment, the display changes can be made in less than 5 msec, so rapid that the reader does not see that they are taking place.)

The basic assumption in this research is that when the window becomes smaller than the reader's perceptual span, reading will be disrupted. By varying the size and location of the window region, the experimenter can determine from what area of the text the reader is actually extracting useful information. By varying the type of information in the background area, the experimenter can maintain or destroy various types of information, which may be potentially useful during reading, and can thus be

**TABLE 4.2 An example of a moving window**

| FIXATION NUMBER | EXAMPLE |
|---|---|
| 1 | `Xxxxhology means persxxxxxxx xxxxxxxxx xxxx xxxx xxxxxxx.   Xxxx xx x`<br>`            *` |
| 2 | `Xxxxxxxxxx xxxxs personality diaxxxxxx xxxx xxxx xxxxxxx.   Xxxx xx x`<br>`                       *` |
| 3 | `Xxxxxxxxxx xxxxx xxxxxxxxxxx xiagnosis from hanx xxxxxxx.   Xxxx xx x`<br>`                                       *` |
| 4 | `Xxxxxxxxxx xxxxx xxxxxxxxxxx xxxxxxxxx xxom hand writing.   Xxxx xx x`<br>`                                                 *` |

Note: The asterisk represents the location of fixation on four successive fixations.

more analytical about the type of information that a reader is extracting from a region of the visual field.

In the original moving-window experiment, McConkie and Rayner (1975) had subjects read text when the window was 13, 17, 21, 25, 31, 37, 45, and 100 characters wide. (With a window size of 100, the entire line was almost always present.) As shown in Table 4.3, a window size of 17 meant that the reader had normal text for the letter directly fixated (in this case, *d* in *diagnosis*) and 8 character positions on either side. The subjects also read the text in the six different text mutilations shown in Table 4.3. The texts were 500-word passages and the subjects were told that they would be tested on their comprehension.

McConkie and Rayner found that reducing the size of the window had a substantial effect on reading speed—as much as 60 percent, but had no effect on readers' ability to answer questions about the text. With windows as small as 7 character positions, readers can see little more than 1 word at a time. This reduces their normal reading speed by about 60 percent, but they can still read with normal comprehension. Rayner and Bertera (1979) also found no effect on comprehension unless the window was reduced to only 1 character (in which case readers are literally reading letter by letter).

The first question that McConkie and Rayner asked was how large the window had to be for subjects to be able to read at normal speed and comprehension. The answer was 31 characters, or 15 character positions to each side of fixation. When the window size was smaller than that, the rate of reading was reduced. This finding that the perceptual span extends to something like 15 character positions from the fixation point was subsequently replicated by a number of studies (DenBuurman, Boersema, and Gerrisen 1981; Rayner and Bertera 1979; Rayner et al. 1981).

Thus, readers appear to extract some sort of useful information from about 15 characters from fixation but little beyond that. But what kind of information is it? At 31 characters wide, do readers extract the meaning of

**ABLE 4.3 An example of a line of text and the various text patterns derived from it**[a]

| | |
|---|---|
| xt | Graphology means personality diagnosis from hand writing.  This is a |
| | Xxxxxxxxxx xxxxx xxxxonality diagnosis xxxx xxxx xxxxxxx.  Xxxx xx x |
| | XXXXXXXXXXXXXXXXXXXXXonality diagnosisXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX |
| | Cnojkaiazp wsorc jsnconality diagnosis tnaw kori mnlflra.  Ykle le o |
| | Cnojkaiaqpawsorcajsnconality diagnosisatnawakoriamnlflrqaaaYklealeao |
| | Hbfxwysyvo tifdl xiblonality diagnosis abyt wfdn hbemedv.  Awel el f |
| | Hbfxwysyvoatifdlaxiblonality diagnosisaabytawfdnahbemedvaaaAwelaelaf |

le: On each line a window of size 17 is shown, assuming the reader is fixating the letter *diagnosis.*

Letters replaced with *X*s—spaces preserved
Letters replaced with *X*s—spaces filled.
Letters replaced with similar letters—spaces preserved
Letters replaced with similar letters—spaces filled.
Letters replaced with dissimilar letters—spaces preserved
Letters replaced with dissimilar letters—spaces filled

words, only some information about the component letters, or merely some idea of where words begin and end, which might be useful in knowing where to place the next fixation?

One way to attack the question of how far from fixation different kinds of information can be extracted is by experimentally manipulating the information that is outside the window of normal text. McConkie and Rayner (1975) investigated the perceptual span for word boundary information by comparing two kinds of altered displays outside the window. In one, all letters in words were replaced by *X*'s but the spaces between words were preserved; in the other, the spaces were replaced by *X*'s as well. By comparing performance in these two background conditions, one can tell how far from fixation the presence of spaces makes a difference. When the window size was 25 characters or fewer, reading was faster when spaces were present among the *X*'s in the background than when they were not. On the other hand, when the window size was 31 or greater, there was no difference between the background conditions. Thus, it appears that out to about 15 character positions from fixation, subjects use the information of where spaces are to help guide their eye movements into that region.

McConkie and Rayner also attempted to determine how far from fixation information about the shapes of letters and words is extracted. They compared backgrounds in which the letters were visually similar (having the same pattern of ascenders and descenders) to the letters in the text with backgrounds in which the letters were visually dissimilar (shown in Table 4.3). If there is a difference between these two background conditions at a certain window size, then some information about the shapes of letters or words, or both, is being extracted beyond the end of the window. The data indicated that letter shape information was not extracted as far out as word boundary information, since there were differences between these two background conditions only for windows up to 21 character positions (10 to the left and right). It is worth noting that the "window of consciousness" for letter information is significantly smaller than that, extending little beyond the fixated word. If the fixated word is preserved and the background vaguely resembles normal text (e.g., spaces are left between the words but all letters in the background are replaced randomly), readers are rarely aware of seeing anything other than normal text (even readers who are told beforehand that it isn't normal). However, they are often aware that they are reading slowly and that something is holding them back.

Further studies have greatly increased our understanding of the perceptual span. We should point out that in many of these experiments single sentences were employed, since it is technically difficult to make display changes rapidly and not have a lot of "flicker" in the text display. Fortunately, these sentence-reading experiments have closely replicated those using passages of text, so we can be reasonably confident that the data from the sentence-reading experiments are a good approximation of what would be obtained under more natural reading conditions.

One question that was raised is whether the perceptual span is symmetric. In the original McConkie and Rayner (1975) experiment, the distance that normal text was extended was the same on both sides of fixation so that it was not possible to test whether readers extract more information from one side of fixation than the other. To test the symmetry of the perceptual span, McConkie and Rayner (1976) independently varied the left and right boundaries of the window of normal text and found that when the window extended 4 character positions to the left of fixation and 14 to the right, reading was virtually as fast as when the window extended 14 character spaces in both directions. In contrast, when the window extended 14 character spaces to the left of fixation and 4 to the right, reading was markedly impaired. Thus, for readers of English, the perceptual span is asymmetric, with information from the right of fixation being used much further out.

Rayner, Well, and Pollatsek (1980) and Rayner et al. (1982) extended the work on the size of the perceptual span. Their major finding was that the left and right boundaries of the perceptual span are somewhat differently constituted. They compared conditions in which the window was experimentally defined by the number of visible letters with those when the window was experimentally defined by the number of visible words. They found that the major determiner of the *left* boundary is the beginning of the currently fixated word. That is, when the left boundary of the window was manipulated, the speed of reading could be predicted by knowing whether the currently fixated word was visible. Beyond ensuring that the beginning of the fixated word was visible, the number of letters to the left of fixation had virtually no effect. On the other hand, the *right* boundary of the perceptual span doesn't appear to depend on word boundaries. When the window to the right of fixation was varied, the major determinant of reading speed was the number of letters visible. Given that a certain number of letters were visible, it made little difference whether whole words were preserved or whether a word was partially visible (even the fixated word). For example, the reading rate was the same when the boundary of the window was 3 letters to the right of the fixated letter as when the boundary was defined to be the end of the fixated word, in spite of the fact that in the former case, the fixated word was not entirely visible about a third of the time. The fact that reading speed did not appear to depend on whether the right boundary of the window maintains the integrity of words (see Table 4.4) suggests that readers acquire partial word information from parafoveal vision (or even from foveal vision in some conditions).

Rayner et al. (1982) reported further evidence that readers use partial word information from parafoveal vision. They asked subjects to read when (1) only the fixated word was visible and all other letters to the right of fixation were replaced by another letter; (2) the word fixated and the word to the right of fixation were visible and all other letters were replaced by another letter; or (3) the word fixated was visible and partial information about the word to the right of fixation was visible. In the third condition, either one, two, or three letters of the word to the right of fixation were

**TABLE 4.4 Examples of conditions in the Rayner et al. (1982) study and reading rates associated with them (in words per minute). In the *W* conditions word integrity is preserved, while in the *L* conditions the right boundary is determined by the number of letters visible. The values in parentheses are the average number of letters visible in the *W* conditions. In all cases, the fixated letter is the second *e* in experiment.**

| WINDOW SIZE | | SENTENCE | READING RATE |
|---|---|---|---|
| 1W | (3.7) | An experiment xxx xxxxxxxxx xx xxx xxx | 212 wpm |
| 2W | (9.6) | An experiment was xxxxxxxxx xx xxx xxx | 309 wpm |
| 3W | (15.0) | An experiment was conducted xx xxx xxx | 339 wpm |
| 3L | | An experimxxx xxx xxxxxxxxx xx xxx xxx | 207 wpm |
| 9L | | An experiment wax xxxxxxxxx xx xxx xxx | 308 wpm |
| 15L | | An experiment was condxxxxx xx xxx xxx | 340 wpm |

visible. When the first three letters in the word to the right of fixation were visible and the remainder of the letters were replaced by visually similar letters, reading rate was not much different from when the entire word to the right of fixation was visible. This result indicates that partial word information is utilized during reading and that an individual word may be processed on more than one fixation. These experiments, in which individual sentences were read, also indicated that letter information was obtained at least 9 characters from fixation. A similar result was obtained when subjects read longer passages (Underwood and McConkie 1985).

The moving-window technique demonstrates that information beyond 15 character positions to the right of fixation is of little use in normal reading. One possible reason for this is that the reader is busy enough processing the information that is closer to fixation, so there is little use for more information. One variation of the moving-window technique, the *moving-mask* technique, demonstrates information beyond 15 characters is of little value, even when you need to have it. The moving-mask technique is the inverse of the moving-window technique. The normal text is displayed outside the center of vision and a visual mask, moving in synchrony with the eyes, makes it impossible for the reader to obtain useful information foveally (Rayner and Bertera 1979; Rayner et al. 1981). Thus, foveal vision is completely masked (see Table 4.5), and an artificial *scotoma* of the retina—a lack of foveal vision—is created.

Rayner and Bertera (1979) found that when foveal vision (i.e., the central 7 characters around the fixation point) was masked, reading was still possible from parafoveal vision but at a rate of only 12 words per minute. When foveal vision and part of parafoveal vision (i.e., the central 11 to 17 character spaces around the fixation point) were masked, reading was almost impossible. Subjects in the experiments knew that there were words (or at least knew there were strings of letters) outside of the center of vision,

**TABLE 4.5 An example of a moving mask (of 7 letters). The asterisk marks the location of fixation on three successive fixations.**

```
An exXXXXXXX was conducted in the lab.
        *
An experiXXXXXXX conducted in the lab.
            *
An experimenXXXXXXXnducted in the lab.
               *
```

but could not tell what they were. They were more likely to be able to identify short function words like *the, and,* and *a,* particularly when they were at the beginning or end of the line. The errors that readers made when foveal and parafoveal vision were masked indicated that they were obtaining information about the beginning letters (and sometimes ending letters) of words in parafoveal vision, as well as letter shapes and word length information, and trying to construct coherent sentences out of the information available. For example, the sentence ''The pretty bracelet attracted much attention'' was read as ''The priest brought much ammunition'' and ''The banner waved above the stone monument'' as ''The banker watched the snow mountain.'' There was no indication that the gist of the sentences was comprehended if the words were not identified.

Let us briefly recap what we know about the span of perception during reading. We know that it is limited, and the limitation on the right side appears to be chiefly due to limitations in perception. Even when foveal information is eliminated, subjects still extract little useful information about letters and words beyond about 15 character spaces. On the left side, information is extracted from a smaller area, including, at most, the word currently fixated. You may be wondering if information is obtained from the line below the one you are reading. It seems unlikely because the time lag between obtaining such information and inserting it into the flow of discourse is so long.

Before going on to explore what information is extracted from the right of fixation, let us briefly discuss what is known about the perceptual span in other orthographies. Within our writing system, moving-window experiments have been done in Dutch (DenBuurman, Boersema, and Gerrisen 1981) and French (O'Regan 1980), and the results seem to be identical to those in English.

*The perceptual span in other writing systems* Moving window experiments have been conducted with Japanese and Hebrew readers. Not only does the writing system affect eye movement characteristics, it also influences the size of the perceptual span. Ikeda and Saida (1978) and Osaka (1987) used the moving-window technique to study Japanese readers. (Remember, Japanese is a hybrid language consisting of morphemic characters, Kanji, and syllabic characters, Kana.) They found that the perceptual span extended about 6 characters to the right of fixation. Thus, for the Japanese writing system, the perceptual span is considerably smaller than for English if one equates a Japanese character with a letter. However, Japanese text is considerably more dense than English, leading to the observation that more information is processed per fixation. It is hard to compare across languages (since the perceptual span in English seems to be defined mainly in terms of letters), but it appears that the perceptual span is roughly two to three words in the writing systems that have been examined.

With Hebrew text, the major interest has been in the asymmetry of the perceptual span. Pollatsek et al. (1981) found that for native Israelis reading Hebrew, their perceptual span was asymmetric to the left of fixation, and that when these same subjects read English, their perceptual span was asymmetric to the right of fixation. Thus, the asymmetry of the window is not "hard-wired": asymmetry varies from language to language. Furthermore, bilingual readers can alter the area from which they extract information when they switch from language to language. The major difference between Hebrew and English, of course, is that Hebrew is read from right to left. That means that the dominant pattern of eye movements is opposite in the two languages. Thus, readers concentrate their attention on the material that is in the direction where they are about to move their eyes.

*The "perceptual span" in Braille* As long as we are talking about other writing systems, it might be of some interest to discuss what is known about how tactual information is "read" by the blind. The most common system for alphabetic languages is known as *Braille*. In Braille, a 3-by-2 matrix of raised "dots" represents a letter; dots thus can potentially appear in any one of six locations, and the pattern of present and absent dots defines the letter. The arrangement of the letters is from left to right with spaces between the words.

For many Braille readers, the size of the perceptual span is one letter (Bertelson, Mousty, and D'Alimonte 1985). They read with one finger (almost always the index finger) one letter at a time. Surprisingly, there appears to be no overall superiority for the right index finger; however, individual Braille readers usually show a marked superiority for either the right or left index finger (Mousty and Bertelson 1985). Braille readers also typically never skip words and maintain physical contact with the page even on "return sweeps" (although they move faster on the sweeps than when they read a line of text).

Some Braille readers use the right index finger to read and the left index finger mainly as a marker to help them find the appropriate line on the return sweep (Bertelson, Mousty, and D'Alimonte 1985). Using two fingers instead of one increases their reading speed by almost 30 percent. The most skilled Braille readers appear to use both index fingers to extract information. Some will keep their two index fingers on adjacent letters while they read the entire text. However, a more typical pattern is to move the two in synchrony on adjacent letters to the middle of a line; then continue the right index finger to the end of the line, and move the left to the beginning of the next line. The left finger starts ''reading'' the next line while the right is finishing the previous one (Bertelson, Mousty, and D'Alimonte, 1985). The right index finger usually rejoins the left after a word or two has been read by the left.

The perceptual span of these most skilled Braille readers thus appears to be two letters, at least some of the time, since they can read more than 30 percent faster with two fingers than with one. However, the details of what is happening are somewhat unclear. Since using the left index finger as a place marker provides appreciable benefit in itself, it is hard to know exactly how much benefit is actually a result of extracting information from both fingers simultaneously. Using this two-hand method, however, the best Braille readers can read from 100 to 140 words per minute (Bertelson, Mousty, and D'Alimonte 1985).

### What Is a Reader Doing on a Fixation?

We are closing in a bit on what information the reader is extracting on a fixation. The information to the left of the fixated word in English (or to the right in Hebrew) is irrelevant because the subject is not attending to it. The moving-mask experiment and various tachistoscopic experiments suggest that information further than about 15 character spaces to the right of fixation is not used because of acuity limitations in processing text.

However, we are still not at all clear about how the information from the fixation point to the right-hand boundary of the perceptual span is used. The Rayner et al. (1982) experiment cited earlier makes it clear that more than the fixated word is processed. When the window only included the fixated word, subjects read about 200 words per minute in contrast to about 340 words per minute when there was no window. The simplest conceptual model to handle that fact would be that readers make sure to encode the fixated word on each fixation but that on some fixations they may also encode another word or two. However, the other data from Rayner et al. (1982) indicated that reality is more complex. Since readers were not particularly bothered by incomplete words—in fact, the major variable affecting reading speed was the number of letters available to the right of fixation—readers must be doing something more complex than extracting words as visual units (see also Chapter 3).

One possibility is that words are encoded only a limited distance from fixation, but that more primitive letter information is extracted further out. This conclusion emerged from a study by Rayner (1975a) which used the *boundary technique,* another variation of the moving window. In this technique, the experimenter attempts to determine what kinds of information are acquired from a particular word location in a paragraph (called the critical word location—*CWL*) when readers fixate different distances from it. This is accomplished by changing the contents of the CWL when a saccade crosses an invisible *boundary* location. The logic of the method is that if a certain aspect of the stimulus in the CWL has been encoded in the parafovea and then changed when the word is fixated, some disruption of normal reading would be expected. In particular, we might anticipate a longer-than-normal fixation after the change had been made, since the reader would have to resolve the conflict in the information obtained from the two fixations. The advantage of the boundary technique over the moving-window technique is that more precise control over parafoveal information is possible since one word is selected for manipulation. In addition, since the region of abnormal text is small, normal reading is even more closely approximated. In Rayner's experiment, the stimulus in the CWL when it was fixated (the *base word*) was always a word that fit into the text. However, the stimulus in the CWL before the boundary had been crossed was sometimes a word and sometimes a nonword (see Figure 4.4 for an example).

Rayner was able to observe a large number of instances on which the reader's eyes fixated different distances to the left of the CWL on the fixation prior to the stimulus change and then directly on the CWL after the change. It was assumed that if the reader's fixation was sufficiently far to the left of the CWL, no information would be acquired from that region. If this were the case, the reader would then fail to "notice" any of the different types of display changes. (We use the words *notice* and *detect* to mean that there is some effect on the reader's eye behavior, not that the reader is conscious of these changes; in fact, in such experiments, readers are not aware of the changes.) On the other hand, if the fixation was closer to the CWL, the reader might obtain some information, perhaps word-shape or letter information, and if the stimulus change caused a change in that kind of information, a longer fixation would result. However, if the stimulus change was a type that did not cause a change in the kind of information the reader had acquired, no change would be detected and no disruption of reading would occur.

Since some of the initially displayed stimuli in the CWL were

**FIGURE 4-4** **Boundary study: An example of the type of display change that occurred in Rayner's boundary experiment.**

I. The old captain put the chovt on the . . .
1 B

II. The old captain put the chart on the . . .
B 2

Key:
B—Location of the boundary which triggers a change in the display.
1—Location of the last fixation prior to crossing the boundary.
2—Location of the first fixation after crossing the boundary.

Alternatives in target location for base word *chart:*
chart—identical word (W-Ident)
chest—word with similar shape and letters (W-SL)
ebovf—nonword with similar shape (N-S)
chovt—nonword with similar shape and letters (N-SL)
chyft—nonword with similar letters (N-L)

nonwords, this raised an interesting question: How near to the CWL did the reader's eyes have to be before the nonword letter string in the CWL affected reading? One way to investigate this was to examine fixations (grouped according to how far they were from the CWL) prior to the display change and then calculate the average fixation duration at each distance. Rayner found that the existence of a nonword in the CWL did not affect the fixation duration unless the CWL was no more than 3 letter positions to the right of the fixation point. If the CWL began 4 or more letter positions to the right of the fixation point, the "wordness" of its temporary occupant had no effect on the length of this fixation.

The duration of fixations on the CWL immediately after the display change were also examined and classified according to (1) the type of display change that had occurred and (2) the location of the previous fixation. These data are shown in Figure 4.5. Reading was unaffected by any stimulus change if the fixation prior to crossing the boundary was more than 12 character positions to the left of the CWL. When the previous fixation was 7 to 12 character spaces to the left of the CWL, the subjects did pick up information about the shape of the word (or its component letters) and information about the identity of the extreme letters of the stimulus in the CWL. If either of these changed when the boundary was crossed, the first fixation on the base word was increased. In contrast, if the initially displayed stimulus had the same word shape and the same extreme letters as the base word, very little disruption was noted. Finally, the fixation on the base word was affected by the "wordness" of the preview when the preview was as much as 6 characters away from fixation. Thus, the fixation on the base word appears to be a more sensitive measure of whether lexical information was extracted parafoveally than fixation prior to the base word.

Rayner's results were originally interpreted as evidence that word shape information is obtained from parafoveal words that the reader cannot identify. However, subsequent research (to be discussed soon) has demonstrated that when word shape effects emerge, it is really because words that begin with the same letter and share the same overall shape (as in Rayner's study) have many letter features in common. Thus, we will argue that it is letter information that is obtained beyond the region in parafoveal vision where words can be identified. Rayner's results also suggest that the meanings of words to the right of fixation are not extracted very far from the point of fixation, since the reader appears to be unaware that a nonword was present if it started further than 3 to 6 characters from it. This conclusion is reinforced by a study (McConkie and Hogaboam 1985) in which subjects were reading silently with their eye movements monitored. At certain places in the text the screen went blank and subjects were asked to report the last word that they had read. There is a guessing problem here, since the subject may be able to figure out a word not actually seen on the basis of prior context. Nonetheless, the results are consistent with Rayner's study. McConkie and Hogaboam found (see Figure 4.6) that the word readers reported most frequently was the word on which they had last fixated,

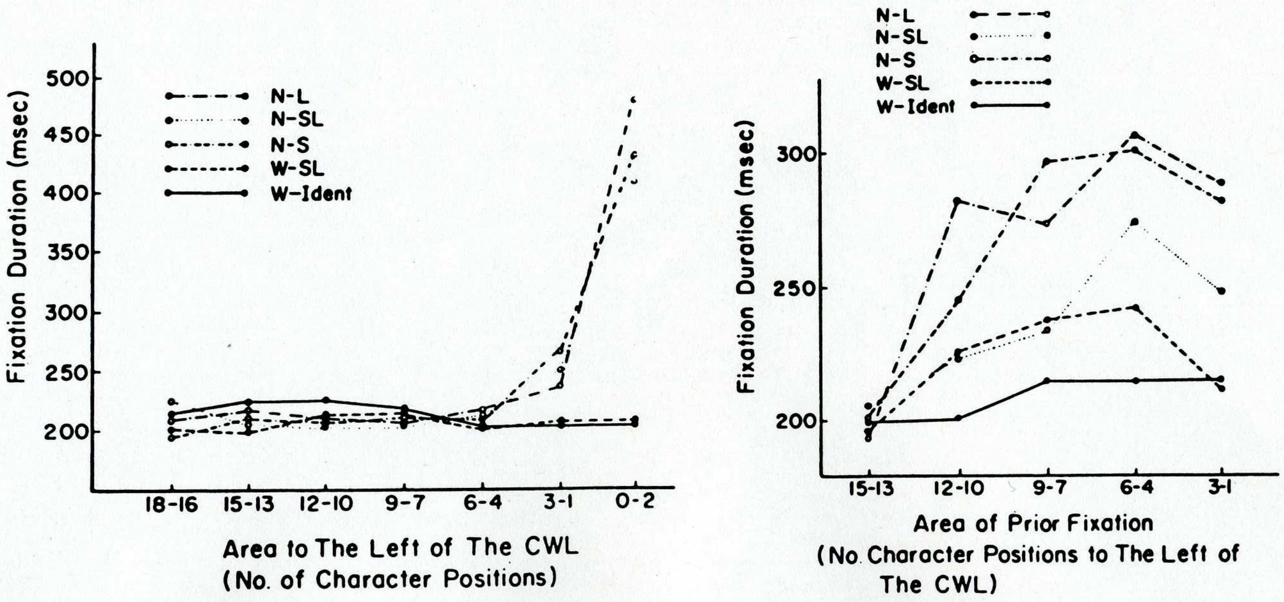


FIGURE 4-5 Data from Rayner's study. Panel on the left shows fixation time or last fixation prior to crossing the boundary; panel on the right shows fixation time on target word after crossing the boundary. In our example, the base word is *chart,* and previews of *chart, chest, ebovf, chovt,* and *chyft* would represent the W-Ident, W-SL, N-S, N-SL, and N-L conditions, respectively. (Reproduced with permission from Academic Press.)

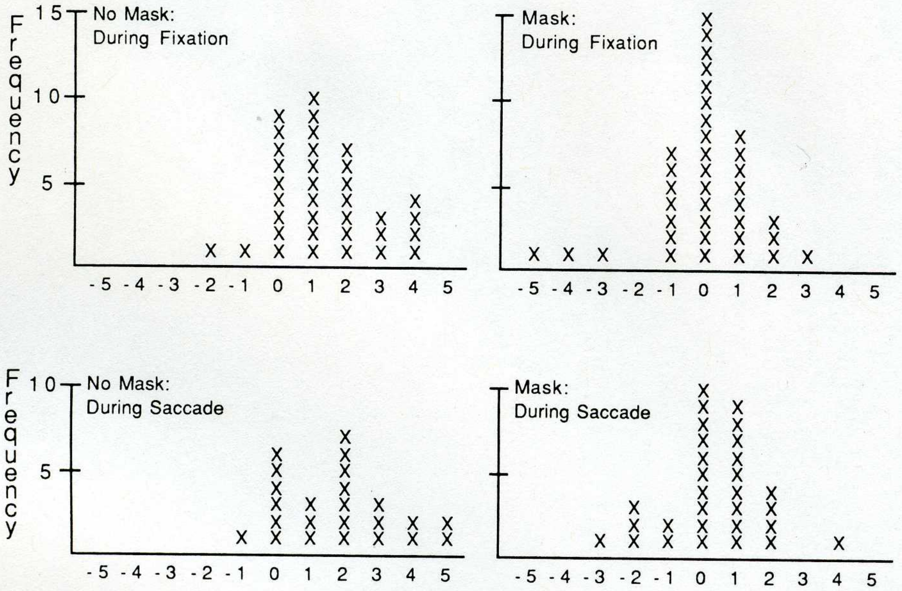


**FIGURE 4-6** **Fequency distributions of the location of the last read word with respect to the location of the last fixation on which text was present. 0 represents the last word fixated and 1 represents the word to its right. In the Mask conditions (right panels), a mask came on when the text went off, while in the No Mask conditions (left panels), the text just went blank. Distance is measured in word units, without regard for word length. (Reproduced with permission from North Holland Press.)**

although the word to the right of fixation was sometimes reported. However, words to the left of the fixated word—or two or more to the right of the fixated word—were rarely reported.

Word skipping is another index of how far to the right of fixation words can be identified. As indicated before, the area to the left of the fixated word is ignored by the reader; if a word is skipped, it either must have been identified before it was skipped or the reader simply made a guess as to what the word was without having seen it. Since word skipping is a ubiquitous part of the eye-movement record, identification of the word to the right of fixation is reasonably common if guessing does not account for most of the skipping. At times, words can be skipped from reasonably long distances. In a later boundary experiment (see Balota, Pollatsek, and Rayner, 1985; Pollatsek, Rayner, and Balota 1986), it was found that the CWL was occasionally skipped (though less than 1 percent of the time) when the prior fixation was greater than 9 character spaces from the beginning of the CWL. Thus, it appears that the meaning of a word in the parafovea can be extracted fairly far from fixation, though this is not usually the case even with highly predictable words.

In the Balota, Pollatsek, and Rayner (1985) experiment, the base word was highly predictable from the prior sentence context. Skipping occurred much less frequently when a word other than that predicted by the context was in the CWL, so that skipping in the experiment was not merely due to readers' guessing that the stimulus in the CWL was the predicted word. This experiment differed from the original Rayner experiment, in which the base word was not highly predictable from the prior sentence context. This difference suggests that variables such as the predictability of a word can influence how far from fixation words can be encoded and meaning extracted. We will return to this issue in greater depth in Chapter 7 when we discuss processing of sentences in more detail.

To summarize, the perceptual span is limited, extending from the beginning of the currently fixated word to about 15 character spaces to the right of fixation. The area within which word identification takes place is even more limited. Readers can sometimes identify the word to the right of the fixated word (and sometimes two words, particularly when the fixated word and the next two are short words). In fact, as we mentioned earlier, readers often do not fixate either the first or last word of a line in text. Apparently, the last word of a line is often fully processed in the parafovea. It is somewhat harder to understand why the first word of a line is sometimes not fixated. One possible explanation is that the first fixation on a line is approached by a (leftward) return sweep. If a reader's perceptual span mirrors the direction of eye movements (as with the Israeli readers discussed earlier), it could be that covert attention shifts leftward on the first fixation so that the span includes the word to the left of the fixated word on those occasions.

While readers can identify words that they do not fixate, the more usual circumstance is that no word beyond the fixated word is fully identified. Since we have seen that preserving some letters in a parafoveal word aids reading, it appears that partial information about a word can be encoded on one fixation and used to aid identification of the word on the subsequent fixation. We now turn to discuss what we know about how information is integrated across fixations.

## INTEGRATION OF INFORMATION ACROSS EYE MOVEMENTS

Several converging pieces of data from the last section suggested that some words are processed partially on one fixation and then finished on the succeeding fixation. Another indicant that words are processed on more than one fixation is the fact that the perceptual span is about double the average size of a saccade. (This is true in Japanese as well [Ikeda and Saida 1978].) This comparison is not completely fair, however, since the perceptual span is not an average: it is measuring the *maximum* distance that information can be extracted. However, the discrepancy between the perceptual span and the size of the average saccade reinforces the conclusion that the eye is moving to an area of text that it has processed to some extent.

Integration of information across saccades is by no means a conscious process, since we are generally not aware of our eye movements. Each eye movement changes the pattern of light on the retina, and yet we perceive a stable, coherent image of the words we are looking at. We never have the feeling of having stimulus input for a quarter of a second or so followed by a break in input due to the saccade. The research on saccadic suppression we discussed earlier explains why you don't see "junk" between the "slides." However, at present, we don't have a detailed understanding of why the gaps between fixations are not noticed. Somehow the brain is able to smooth out the discrete inputs from each eye fixation and create a feeling of a continuous coherent perceptual world.

If information about a word is obtained on two successive fixations, the first when the word is in the parafovea and the second when it is in the fovea, and if the integration process is useful in reading, the parafoveal preview of the word should facilitate later foveal processing of the word. We shall thus discuss integration of information across fixations largely in terms of such facilitation. It has been known as early as Dodge (1906) that parafoveal previews facilitate later identification. However, that facilitation, in itself, is not necessarily evidence for integration across saccades, since the word may have been fully identified in the parafovea. What is needed to document integration across saccades is to make the parafoveal preview and foveal target stimuli similar but not identical, and to determine whether there is still facilitation from the preview.

An experimental technique requiring subjects to name isolated words (originated by Rayner 1978b) has produced a lot of information about integration across fixations (Rayner, McConkie, and Ehrlich 1978; Rayner, McConkie, and Zola 1980; McClelland and O'Regan 1981; Balota and Rayner 1983). It is a miniaturization of the boundary technique. Subjects are asked to fixate on a central fixation point and when a letter string appears in parafoveal vision, they are to make an eye movement to it. During the saccade the initially displayed stimulus is replaced by a *target* word which they are to name as fast as possible. The parafoveal stimulus is thus visible for approximately 200 msec until the eye movement begins. In spite of the fact that it is visible for such an extended time, subjects are almost never aware of the identity of the parafoveal word and are rarely even aware that there has been any change! Thus they have no trouble deciding which word to name.

Figure 4.7 shows the basic pattern of results from the experiments. As seen in Figure 4.7, if the stimulus presented on fixation $n$ and fixation $n+1$ are identical, there is facilitation in naming the target word (compared to when a row of asterisks or unrelated letters are initially presented parafoveally). More important is the fact that facilitation occurs even if the parafoveal preview only has some letters in common with the target word.

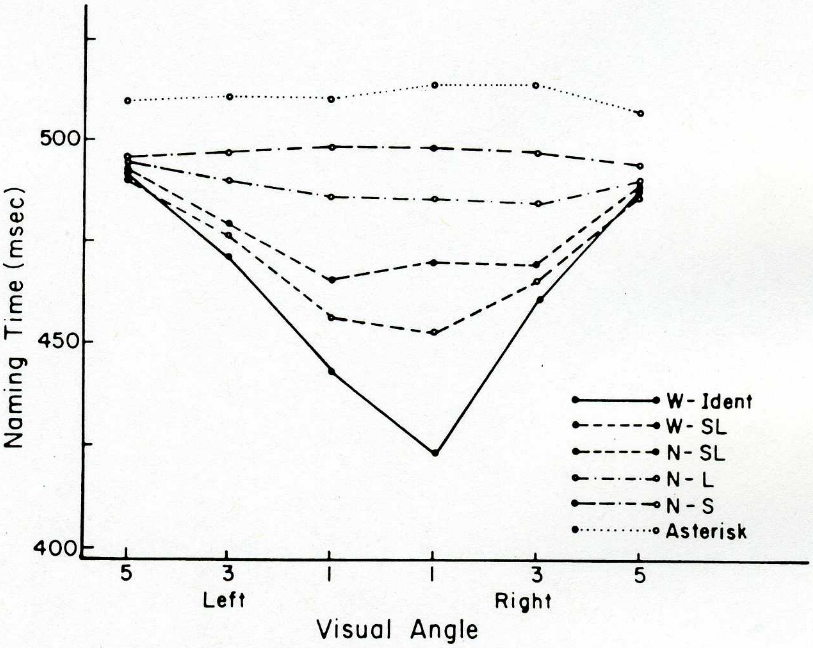


**FIGURE 4-7** **Mean naming times as a function of initially displayed alternative and visual angle. In our example, *chart* is the base word. The alternatives *chart, chest, chovt, ebovf,* and *chyft* represent the W-Ident, W-SL, N-SL, N-L, and N-S conditions, respectively. The asterisk preview was a row of asterisks. (Reproduced with permission from Plenum Press.)**

As one would predict from the perceptual span experiments, the amount of facilitation depends upon how far into the parafovea the preview is. That is, there is more facilitation when the initial stimulus is 1 degree from fixation than when it is at 3 degrees and hardly any facilitation at 5 degrees (i.e., 15 character spaces) from fixation. Thus, the results indicate that only when the preview is less than 15 character spaces from fixation, can subjects use partial parafoveal information about a word to aid their recognition of that word when it is later fixated.

The fact that *chest* in the parafovea facilitates the later identification of *chart* implies that some information extracted from *chest* was useful in the later identification of *chart*. We feel that the following five potential sources of facilitation are defined so as to be exhaustive: (1) some of the *visual features* of *chest* are stored and aid later identification of *chart;* (2) some sort of *sound codes* (e.g., phonemes or syllables) activated by *chest* (perhaps the initial /ch/) aid later identification of the word *chart;* (3) some aspect of the *meaning* of *chest* has been encoded by the parafoveal view of *chart* which facilitates later identification (although that seems improbable in this particular example); (4) some of the *letters* are identified and these abstract letter identities (not the letter forms) are what are facilitating; and (5) the lexical entry of "chart" is *partially activated* by the parafoveal preview of *chest* which aids in the later identification of *chart*. The distinction we wish to draw between (1) and (4) is that the information about letters is in a visual form in (1), but a more abstract form in (4). The distinction we wish to draw between (3) and (5) is that in (3), some aspect of the word's meaning as well as its identity is activated in the parafovea. Of course, these hypotheses are not mutually exclusive, as facilitation could have more than one source. As we will see, however, the evidence points at present to a relatively simple answer: there is no evidence for any of the first three mechanisms being operative, so that, by a process of elimination, (4) or (5), or both, appear to be the sources of integration. Let us discuss the evidence against the first three sources in turn.

### Is Visual Information Integrated across Eye Movements?

This alternative may seem the most plausible, since it corresponds to our intuitions that we see a single seamless world when visual information from two fixations is brought together into a single representation of the visual world (McConkie and Rayner 1976b). That is, readers may obtain gross featural information from parafoveal vision during a fixation and store it in a temporary visual buffer, which has been referred to as the *integrative visual buffer*. The visual information stored in the buffer would then be used as a base to which new information is added when the region (previously in parafoveal vision) is fixated. The alignment of the information from the two fixations would presumably be based on knowledge about how far the eyes moved and the commonality of the patterns from the two fixations. Of course, all this computation would generally be unconscious, since we are usually not aware of moving our eyes. The integrative visual buffer in reading can be thought of as being like iconic memory (see Chapter 1), except that information is preserved in the visual buffer across eye movements.

While this view of information integration is perhaps the most intuitively plausible of the alternatives, the evidence against it is quite strong. First, Rayner, McConkie, and Ehrlich (1978) showed that proper alignment was not necessary in order to obtain the results shown in Figure 4.7. (Recall that alignment or justification of two successive images in the buffer should be based on keeping track of how far the eyes moved.) They found, however, that the same pattern of results was obtained in an experiment in which the stimulus pattern rather than the subjects' eyes moved. That is, an initially presented stimulus appeared in parafoveal vision, and after a period of time approximating the sum of the saccade latency and saccadic duration (about 200 msec), the target word to be named appeared foveally and the parafoveal stimulus simultaneously disappeared. Notice that the sequence of events on the retina is the same as when the eyes move to a parafoveal stimulus: an initial stimulus impinges on the parafoveal retina followed by a stimulus in foveal vision. In one condition an eye movement intervenes between two retinal events, while in the other condition the eye movement is simulated by moving the stimulus rather than the eyes. Now, if keeping track of how far the eyes move is important for the integration process, performance should be much worse in the no eye-movement condition than in the standard eye-movement condition described earlier. Rayner, McConkie, and Ehrlich, however, found no major differences between these two conditions.

More damaging to the integrative visual buffer notion were two experiments that directly tested whether visual features could be integrated. The first demonstrated that changes in the visual form of the information had no effect if the meaning was not altered. Rayner, McConkie, and Zola (1980) found that a case change between the preview and target words (e.g., (*CASE* changed to *case*) had no effect on how long it took to name the word, even though there were still clear facilitating effects from parafoveal previews. The second tested integration of visual information in a different way. O'Regan and Levy-Schoen (1983) presented half of the letter features of a word on one fixation and the other half on the subsequent fixation. (Both stimuli were in the same spatial location.) Subjects in this condition were rarely ever able to identify the target word. In contrast, when the two halves were presented in the same spatial location one after the other in quick succession, subjects readily identified the target word. Thus, the visual information that can be integrated within a fixation can not be integrated when a saccade intervenes.

At this point, you may well be saying to yourself that all of the experiments we've described in this section do not really involve subjects in the task of reading. Perhaps, as we've pointed out before, the task used in these experiments encourages a strategy that is different from what normally happens when we read. However, it turns out to be the case that a number of experiments in which subjects are actually reading yield results consistent with the conclusions we have reached from the experiments described up to this point.

The question of whether integration is dependent upon keeping track of how far the eyes move has been tested in the reading situation as well. In these experiments (O'Regan 1981; McConkie, Zola, and Wolverton 1980), subjects were reading text, and at selected points, the entire line of text was shifted to the left or right during the saccade. In the normal state of perception, the distance that the image has moved from fixation to fixation is explained by the distance that the eye has moved. If the alignment of the visual information obtained on two successive fixations is dependent on this calculation of how far the eye has moved, then great disruption should be produced when the text is shifted. Even if it is shifted only a few characters there should be massive disruption, since the letter information in the two images will conflict in all locations. The shift was sometimes registered in the brain (if not in consciousness) because small corrective saccades sometimes occurred after the shift. These eye movements could have been because the eye landed on a position other than intended. However, shifting the text 2 or

3 character positions resulted in no conscious awareness of the shift and produced negligible effects on reading speed and comprehension.

Similarly, the issue of whether integration occurs by integrating the visual forms on two successive fixations was tested in reading text. McConkie and Zola (1979) had people read passages printed in AlTeRnAtInG cAsE, and changed the case of every letter during certain saccades so that successive visual images would not be similar. Thus, cAsE on fixation $n$ would appear as CaSe on fixation $n+1$ and cAsE on $n+2$. These changes were not noticed by readers and they had virtually no effect on comprehension or on reading speed. In addition, the basic finding that partial information facilitates naming of the fixated word (e.g., *chest* facilitates naming of *chart*) parallels the finding described in the previous section (Rayner et al. 1982) that silent reading was faster when the first 2 or 3 letters of the word to the right of fixation were visible than when they were altered.

In summary, all the basic findings that emerged from the parafoveal naming experiments have been corroborated in experiments involving silent reading of text. The two experimental situations thus provide convergent validity for the conclusions, combining the ecological validity of the reading situation with the more tightly controlled naming experiments in which the response is transparently tied to word identification.

### Sound Codes

Let us next consider the possibility that the reader is extracting some sound-based code from the parafoveal stimulus such as the initial phonemes or the first syllable of the word. This possibility seems particularly appealing since all of the studies that we have described employing individual words required subjects to *name* the word that is present on the second fixation. Perhaps information acquired from the parafoveal word permits the subject to begin to form the speech musculature properly for saying the word. This would reduce the time needed to initiate an utterance when the target word occurs in the fovea following the eye movement.

Rayner, McConkie, and Zola (1980) assessed this possibility in two ways. First, subjects were required to make a semantic categorization (''Is it an animal?'') of the target word. In such a condition, the subject does not pronounce the target word and if the facilitation is merely due to activating the beginning of the appropriate response, the facilitatory effects should disappear. Yet the experimenters found the same pattern of facilitation when semantic categorization was the task rather than naming. However, it could still be that activation of sound-based codes does not facilitate the naming response, per se, but the more basic process of identifying the word that underlies both naming and semantic classification. If so, one would expect some facilitation when the initial phoneme of the parafoveal preview was the same as the base word. However, there was no difference between when the initial phonemes of the two were the same (*casts-count*) and when they were different (*chair-count*). The argument is weakened somewhat by the finding that there was no facilitation in either case. However, the experiments demonstrate that the facilitation observed in these experiments is not due to activation of the initial phoneme.

### Partial Encoding of Meaning

There are two different ways in which one might think the reader extracts partial meaning from a word. The first is that the whole word is processed, but only dimly. That is, the activation from the physical stimulation does not lead to identification of the word, but may lead to a vague idea of the meaning of the word. Perhaps a semantic feature is activated. The second way is that a specific meaningful segment of the word, a *morpheme,* is identified. We consider each of these possibilities in turn.

*Semantic preprocessing* As we look around the world, we feel we have a vague idea of what things in the parafovea and periphery are. For example, if we are not directly looking at a dog, we may be aware that it is an animal, have a vague idea of its size, but may not be able to make a precise identification of it. Moreover, there is evidence in picture perception that there are possibly unconscious influences of such partial meaning on processing. For example, in picture perception, the eyes quickly move to regions judged to be informative (Mackworth and Morandi 1967; Antes 1974) or semantically anomolous (Loftus and Mackworth 1978). These phenomena suggest that something similar may be going on in reading.

However, it is important to point out that there are rather substantial differences in the stimulus pattern between text and a picture (Loftus 1983; McConkie and Rayner 1976b). With text, the pattern is rather homogenous, made up of letters and spaces, and it is likely that lateral masking of words and letters (by adjacent words and letters) is much greater in text. A single distinctive and informative feature of an object in a picture may convey meaning in a way that no single visual feature of a word does. It may well be that these distinctive features allow for rough semantic classifications of objects and guide the movement of the eye in picture perception.

Another reason that semantic preprocessing seems like an attractive explanation for parafoveal preview effects is because of the "unconscious priming" experiments described in the previous chapter (e.g., Allport 1977; Balota 1983; Marcel 1983). In these experiments, briefly presented words followed by masks are presented in the fovea. If conditions are set up right, the subject will be unable to identify the word, but the speed in identifying a semantically related word that follows will be increased. Marcel (1978) has suggested on the basis of the foveal priming studies that meaning is simultaneously available from a number of places on a page. For example, Marcel notes that if you turn the page of a book and are reading the top line, something at the bottom of the page may "catch your eye." He further argues that this is only possible if its meaning has been analyzed independently of where attention is. A key assumption in this inference is that a brief foveal presentation of a word is analogous to a word in parafoveal vision during reading.

The analogy may be misleading. While a briefly presented foveal word and a parafoveal word are both visually degraded, they are degraded in different ways: brief foveal words by their duration and by backward masking; parafoveal words by acuity and lateral masking. In reading normal text these acuity and lateral masking considerations make it difficult to identify words at increasing distances from the fixation point. The phenomenon of foveal masking is still poorly understood, but it appears that there is some sense in which the stimulus is fully identified, but something about the mask dissociates it from awareness and direct access. On the other hand, it seems implausible that partial semantic access can occur from vague information about a word, such as global shape, length, or knowing a letter or two. One possible explanation for the phenomenon that Marcel describes—something at the bottom of the page catching your eye when you turn the page—is that when you begin to move your eyes to bring them to the top of the page you may make a short fixation near the bottom of the page. Thus, this phenomenon may be explained by something similar to the foveal masking experiments rather than by semantic preprocessing in the parafovea or periphery.

In reading, there is no clear evidence supporting semantic preprocessing. One attempt to demonstrate semantic preprocessing uses a variant of the semantic priming technique described in the previous chapter. A semantically ambiguous word such as *bank* is presented in the fovea and one of two words that could disambiguate the word, *river* or *money*, are presented in the parafovea. Both words are presented briefly and the subject is tested on which meaning he or she associates with the foveal word *bank*. If subjects are at above chance in choosing the meaning suggested by the parafoveal word, then it implies that the meaning of the parafoveal word has been processed.

In fact, subjects are above chance. However, we already know that parafoveal words can be identified from our previous discussion of skipping. The key question is whether partial meaning can be processed. This has been tested (Bradshaw 1974; Inhoff 1982; Inhoff and Rayner 1980; Underwood 1980, 1981) by determining both which sense of *bank* is selected and whether the parafoveal word has been identified. If subjects can select the appropriate meaning at above chance levels, *even when the parafoveal word has not been consciously identified*, one would have evidence that semantic preprocessing has taken place. Unfortunately, the results from these experiments are not completely consistent. Some have found above chance performance and others have not. However, even in those that obtained above chance performance, it was not much above chance. In addition, the experiments that obtained above chance performance are difficult to evaluate as certain factors (such as eye location, guessing, and read out from iconic memory) were not controlled. (For a more complete discussion, see Inhoff and Rayner 1980.) In sum, there is little evidence for semantic preprocessing from these experiments.

Rayner, Balota, and Pollatsek (1986) provided a more direct test of semantic preprocessing in reading using the boundary technique described earlier. The stimulus, which appeared in the target location before the base word (*song*) was fixated, was either a visually similar nonword (*sorp*), a semantically associated word (*tune*), or a visually and semantically different control word (*door*). While the visually similar preview facilitated processing of the base word relative to the control condition (fixation time on the base word was reduced), there was no difference between the conditions employing semantically related and unrelated parafoveal previews. That is, there was no evidence for "semantic priming" in these conditions. In contrast, the pairs of related words produced the usual semantic priming effect when they were presented sequentially in the fovea.

*Identification of morphemes* We appear to be down to three possibilities for integration. Either the entire lexical entry is activated, a meaningful subunit (a morpheme) is activated, or merely some of the letters are activated. Before discussing the involvement of morphemes we need to review some of the details of the parafoveal naming experiments.

Rayner, McConkie, and Zola (1980) demonstrated that significant facilitation was produced when the first 2 or 3 letters were constant across the two fixations (e.g., *chest-chart*). No facilitation was obtained when only the first letter was constant across fixations nor was there facilitation when all letters were the same except the first letter (e.g., *board-hoard*). Thus, it appears that encoding the beginning letters of the word is crucial to obtaining parafoveal facilitation. Interestingly, this was true even if the parafoveal preview was to the left of fixation and thus the beginning letters were furthest from fixation. Inhoff (1987) also found that when practiced subjects read text from right to left, a preview of the beginning 3 letters of a 6-letter word provided facilitation in reading. Of course, when reading from right to left, the beginning letters are further away from fixation so it is not just that the beginning letters of the word to the right of fixation are close to the current fixation point; there is something important about these letters. The pattern from moving-window experiments in which only the first part of word *n+1* was exposed also indicates that the information from the first 2 or 3 letters of a word provides much of the parafoveal benefit, particularly if the remainder of the word consists of letters that are visually similar to the real letters of the word. If the remaining letters are not visually similar, readers do not read as well as when the entire word *n+1* is present (Rayner et al. 1982; Inhoff 1988a; Lima and Inhoff 1985).

Since information from the first 2 or 3 letters of a word appears to provide much of the benefit, the logical place to look for extraction of a morpheme from a parafoveal word is at the beginning. Moreover, it also suggests that it would help to look for relatively short morphemes. Lima

(1987a) hypothesized that the beginning letters may facilitate, at least in part, because they aid in identifying the initial morpheme of a word. She tested her hypothesis using prefixed words, since most of the common prefixes have from 1 to 3 letters and because prefixes form a small set of highly familiar word–initial-letter patterns. In particular, she wanted to determine whether there was any evidence that "prefix stripping" (see Chapter 3) could begin before a word is fixated. Words with prefixes (such as *revive*) were compared with pseudoprefixed words (such as *rescue*). The stimuli were matched on number of syllables, word length, and word frequency, and a sentence frame was prepared into which either of the words would fit ("They tried to revive/rescue the . . ."). In her experiments, the boundary technique was used. Prior to the display change, the critical word location (CWL) contained the letters common to the two words plus random letters or *x*'s (*rensbl* or *rexxxx*) or simply a string of random letters or *x*'s (*kmnsbl* or *xxxxxx*). When the reader's saccade crossed the boundary, the word *revive* or *rescue* (depending upon the condition) was displayed at the CWL.

Lima found that subjects looked at the target word for less time when the initial letters of the target word were present than when they were not. She also found, as mentioned in Chapter 3, that prefixed words were fixated for a shorter amount of time than pseudoprefixed words. However, the benefit of the parafoveal preview was the same for prefixed and pseudoprefixed words. There are two possibilities for this equality. If one assumes that prefix stripping is the first step of the *only* route to identification of both kinds of words (which then has to be followed by a second access in the case of pseudoprefixed words), then prefix stripping in the parafovea is tenable: the parafoveal preview would start off the identical first stage of word identification (prefix stripping) in the two cases. However, we argued in Chapter 3 that it is more plausible to assume that access of pseudoprefixed words can go on directly, rather than having to go through the false start of prefix stripping. If this is the case, one would expect greater parafoveal benefit for prefixed words, since access of them would be aided by identifying the initial morpheme as well as the first 3 letters. Since the parafoveal benefit did not differ between prefixed and pseudoprefixed words, we have some evidence that morphemes are not extracted in the parafovea.

A second experiment employing compound words provided additional evidence against morphemic units in parafoveal information extraction. Inhoff (1988b) employed 6-letter compound words such as *cowboy*.As with Lima's experiment, he employed preview conditions in which the whole word *cowboy,* the first morpheme *cowxxx,* or no letter information xxxxxx was present in the parafovea. Inhoff employed two controls: pseudocompound words such as *carpet,* where the first 3 letters are also a word but not a morphemic subunit, and monosyllabic words such as *priest*. He found the same preview benefit in all three cases, indicating that neither the first morpheme nor the first syllable was a significant unit in integration across saccades.

Inhoff's results appear to contradict those of Lima and Pollatsek (1983) discussed in Chapter 3. Lima and Pollatsek found that a preview of the first morpheme speeded lexical decision more than a preview of beginning letters that did not form a morpheme. However, the preview of the morpheme in the Lima and Pollatsek experiment was foveal and thus the integration was not across two fixations.

### Letters vs. Words

The evidence available thus suggests that parafoveal previews help in two ways (Blanchard, Pollatsek, and Rayner 1988). First, the word in the parafovea may be fully identified (and perhaps skipped). Second, it may only be partially activated, with this partial activation speeding later identification of a word. We have reviewed rather convincing evidence that visual codes do not play any significant role in partial identification of words. The evidence also indicates that semantic preprocessing plays no role. There is no positive evidence for the involvement of sound codes, but no particularly strong tests show that it is unimportant. Furthermore, there is no evidence for the involvement of morphemes in integration across saccades.

How is information integrated across saccades? As we argued earlier, one possibility is that several letters may be identified which speeds later identification of the word. Let us briefly sketch how the process may work. Suppose the reader is fixated 7 character spaces to the left of the beginning of the word *chart* (as in Fixation I in Figure 4.4.). The reader may be able to unambiguously identify the first letter (*c*) and make some preliminary identification of the next few letters. The letters *b* and *h* share many features in common, as do the letters *c, a, e,* and *o*. After the reader has identified the *c,* it seems likely that knowledge of orthography would rule out *b* as the second letter. Similarly, the *c* can be eliminated as the third letter, though orthography or context may or may not further constrain *a* as the most likely third letter. Thus, preliminary letter identification of the letters *ch* would occur on fixation *n*. Alternatively, it may be the case that the threshold for letter identification is not reached until fixation *n+1*. In this case, preliminary letter identification for the beginning letters of a parafoveal word begins on fixation *n,* but is incomplete. Information based partly on visual features and partly on orthographic rules would begin accumulating for the beginning letters of the parafoveal word, but identification would not take place until after the eye movement.

We should like to emphasize that preliminary letter identification, as described above, involves abstract letter identities. Thus, incomplete activation of letters would have to be of the form "this letter is likely to be a *b*" rather than in the form of visual features, since changing case (and hence visual features) made no difference in the amount of facilitation. This also reinforces a point made in the chapter on word recognition. The fact that changing the case of words from fixation to fixation does not interfere with reading strongly argues that word shape is not an important cue used in recognizing words. When word shape is found to have an effect (as with some of the parafoveal priming studies) the effect is likely to be merely a byproduct of letter features. That is, when two words have the same shape, it follows that the component letters share more distinctive features.

An interesting question is whether activation of letters (primarily but not exclusively beginning letters) produces partial activation of a word. One possible model for such partial activation was given in the last chapter by the models of Paap et al. (1982) and Rumelhart and McClelland (1982). In these models, letters in letter strings not only activate the letter detectors but a neighborhood of word detectors. Thus, *chest* in the parafovea could excite a neighborhood of similar lexical entries (e.g., "chest," "chart," "chalk"), and such subthreshold activation is what produces the facilitation of the later identification of *chart*. If one made suitable assumptions that beginning letters were weighted more heavily than end letters in determining the pattern of activation, the pattern of parafoveal facilitation could be explained.

One piece of data that suggests that the facilitation is in terms of partially activated word detectors rather than fully activated letter detectors is the absence of certain kinds of errors in the parafoveal naming experiments. Some of these experiments (Rayner, McConkie and Zola 1980) were set up with pairs such as *train* in the parafovea followed by *clash* in the fovea. If the first 2 letters *tr* of the parafoveal string are fully identified on some trials and then integrated with the information from the foveal string, one might expect the subject to identify the string as *trash*. However, such errors did not occur. That is consistent with viewing facilitation as due to partial activation of a neighborhood of lexical entries. While *trash* would get reasonable excitation from the stimulus *train*, it would get little further excitation from *clash*, since the mismatch in the first letters would be weighted heavily. McConkie et al. (1982) reported similar results in a reading situation.

That is not to say that the lack of "illusory conjunctions" rules out the possibility that parafoveal facilitation can be due to letter identification. What it does rule out is a model in which some letters are fully identified in the parafovea and then those letter positions are ignored when in the fovea. There is thus no strong evidence one way or the other about whether parafoveal facilitation works through the partial activation of lexical entries or the activation of component letters. We will thus assume that both are possible.

## SUMMARY

In this chapter we have discussed some basic features of eye movements. Primary among them was the fact that readers fixated a majority of words in text. The bulk of the chapter was spent in determining exactly what could be processed on a fixation. The amount of information that could be processed on a fixation was shown to be the fixated word plus some additional information to the right of it. We suggested a simple view that might explain this fact, namely that on some fixations, one word was processed, on some two, and possibly on some fixations, three words are processed. However, it appears that the story is more complicated than this, since parts of words appear to be extracted which aid identification of those words on later fixations. Thus, the task of identifying what is processed on a fixation in reading (which we will pursue in the next chapter) is not going to be simple. However, the fact that the information extracted from a fixation is limited means that there is a chance that the pattern of eye movements will be able to tell us something about the cognitive activities underlying reading. In the next chapter, we will discuss what is known about how the eyes are controlled in reading and what we can say about reading as a result.

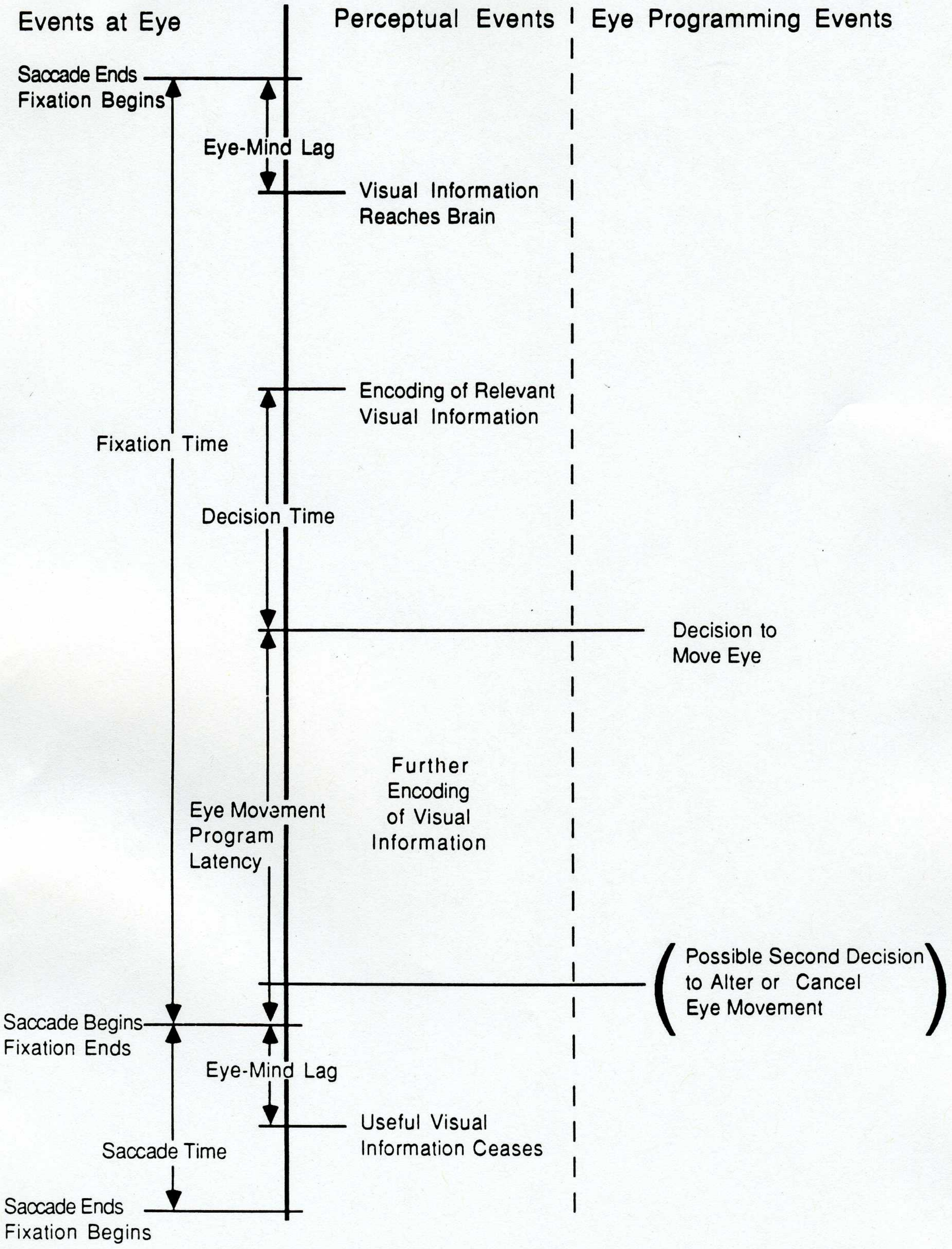


**FIGURE 5-2** **A simplified schema of events during a fixation relevant to eye movement control. There has been little attempt made to represent time intervals accurately by vertical distances. In addition, the eye-mind lag has been drawn to be shorter than the saccade time even though the opposite may be true. A realistic model of eye control needs to be more complex (see text). Among other things, the decision of where to move the eye is left out of the figure.**