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EYE MOVEMENTS AND PERCEPTION DURING READING

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Center for the Study of Reading

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Abstract

This paper reviews recent research investigating visual perceptual processes occurring as people are engaged in the act of reading. Issues dealt with include the control of eye movements, perception during a fixation, and perception across successive fixations. Finally, consideration is given to problems involved in trying to obtain information about higher mental processes from eye movement data.

Eye Movements and Perception During Reading

The purpose of this paper is to review some of the issues about perception during reading which have been raised in studies involving eye movement recording, to try to put these issues in perspective and to evaluate our present knowledge where appropriate. First, however, it is important to recognize that the range of activities that can be called reading is very broad, and that the perceptual activities involved in such different tasks are likely to be sufficiently different as to lead us astray if we assume that what is occurring during one is necessarily the same as what is occurring during another (Hochberg, 1976). The goal of this paper will be to consider the perceptual processes involved in the fairly careful reading of continuous text for the purpose of comprehending and remembering its message.

Since it has been difficult to study the perceptual processes involved in this type of reading, which I will refer to as careful reading, most investigations have used other types in which greater information can be obtained about details of the processes involved. This continually raises the question of generality of findings. Are the perceptual processes involved in the task used in a particular experiment sufficiently similar to those involved in careful reading that the results should be accepted as constraining theories of this type of reading?

This issue is of particular concern when dealing with the hundreds of studies employing tachistoscopic presentation. These studies were motivated by a need to gain the type of experimental control necessary to investigate perceptual processes in detail. A tachistoscopic presentation was taken as being similar to a single fixation during reading; hence, findings from such studies were assumed to generalize to fixations during reading (Huey, 1908).

There is one way in which a tachistoscopic presentation and a fixation during reading are similar; in both, the visual system is exposed to a relatively stable retinal pattern for a brief period of time. Given our recent history of theoretical behaviorism (as opposed to methodological behaviorism, which we still largely abide by), it is understandable that there would be a bias toward believing that similar stimulus patterns might evoke similar perceptual processes. However, the growth of cognitive approaches to theorizing has been stimulated by the recognition that, in fact, this is not necessarily true. The organism often processes the same information in different ways,

depending on the task being performed.

Even a cursory comparison of a fixation in reading and a tachistoscopic exposure shows significant differences, some inherent in the nature of the tasks appropriately associated with the two types of text presentation, and some more associated with the nature of the stimuli typically used. They typically differ in the complexity of the stimulus pattern (which Bouma, 1978, has demonstrated has substantial effects on perceptibility), in the end toward which the information obtained is used (reporting words and letters or making semantic judgements vs. extending one's representation of a message being communicated), in the momentary context within which the exposure is set (having time to become set for a brief exposure and prepared to do identification, vs. being only a momentary part of a flow of skilled behavior supported by a series of such brief exposures to the text), and the types of language variables involved (exposure to only one or a few words precludes the influence of most of the language factors involved in normal text).

It seems reasonable for these types of differences to produce substantial differences in the nature of the perceptual processes employed in these two reading tasks. The state of the organism is certainly different at the onset of the exposure to the text, and the nature of the mental activities being carried out during the exposure and the time following must be quite different. To the extent that perceptual processes, especially those involved in selectively attending to available information, are in the service of the mental processes engaged to carry out the task at hand, we would expect quite different activities to result from these situations.

Additional difficulties for generalizating are seen when we consider what typically serves as data in studies employing these two different reading tasks, and the ways in which those data are analyzed and interpreted. The complexity of the data can be much greater in the careful reading task; in fact, its potential complexity is one force driving researchers to adopt simpler tasks. Added complexity does not necessarily just add new factors to an additive model; it frequently changes the relation among factors already entered. One reason why the phenomenon of lateral masking has been of such interest is that it produces data patterns different from those expected from simpler displays (letters further into the visual periphery can frequently be identified more readily than letters closer to the fovea [Bouma, 1973]). Introducing a saccadic eye movement into a task changes the degree to which stimulus information at different retinal locations influences performance on the task, due to associated

attentional processes (Rayner, McConkie, & Ehrlich, 1978; Remington, 1980). Also, concepts that are useful in accounting for data in the tachistoscopic task, and which are then generalized to discussions of reading, can lead us astray in our theorizing. The usefulness of the concept of the icon for an understanding of careful reading has been challenged (Haber, Note 1) and the notion of a "word superiority effect" seems irrelevant. In studies of reading, the effects of nonwords are not taken as a baseline against which to judge the superiority of words, but rather are taken as indications of the difficulties produced when a letter string does not map nicely onto a known word. These two concepts have, of course, been central to the study of perception from tachistoscopic presentations.

My purpose here is not to argue against conducting research on certain types of reading tasks. All aspects of reading need investigation, and it is often the case that, since there is no way to investigate some aspect of the reading processes in one type of task, another must be employed. Rather, I wish to emphasize two points. First, we need to be more careful to recognize the diversity of tasks involving reading and the differences in perceptual processes that may be involved, thus being more careful not to overgeneralize than has often been the case in the past. Second, at the same time, we need to be more creative in finding ways of directly studying the types of reading we wish most to understand. In fact, this is one of the primary contributions that recent eye movement research has made to the field of reading. It has provided the means of investigating many perceptual issues by studying people directly engaged in the task of careful reading. It is this literature that is the primary focus of this review.

The issues to be dealt with mainly fall into three areas. First will be a discussion of the control of eye movements, since this determines what visual information will be available to the reader, in what sequence and for how long; second, a discussion of perception during a fixation in reading; and third, a discussion of what is involved in maintaining perception across fixations. In each of these, the focus will be on understanding relatively skilled reading, with comments on the development of reading or on reading disabilities where appropriate.

Since there have been two excellent reviews of eye movement studies recently, this review will not try to be exhaustive of much of the earlier literature (Rayner, 1978a; Levy-Schoen & O'Regan, 1979).

CONTROL OF EYE MOVEMENTS

During continuous reading and most other real-world visual tasks, the eyes are free to move, and they do so at a rapid rate. Where they go and how long they stay at each location is considered to be part of the perceptual process, since this determines the degree of clarity of different parts of the display at any given time.

For present discussion, eye guidance will be considered as involving two factors: a decision of when to launch the eyes to the next location, which will be referred to as the _temporal decision_, and a decision of where the eyes will be sent, which will be referred to as the _spatial decision_. The temporal decision determines the duration of the fixation, and the spatial decision, the length of the eye movement (saccade) and the location of the next fixation. Other aspects of eye movement will not be considered here.

It is well established that the variability observed in these two aspects of eye behavior is not simply due to error, noise, or inaccuracy; to some extent (and the degree is a matter of dispute) both aspects of eye behavior reflect moment-by-moment brain state changes induced by interaction of the stimulus pattern and the task of comprehending. Before turning to a discussion of the nature of the control in these decisions, it is first important to review timing considerations of when these decisions are made.

Timing of Decisions Regarding Eye Behavior

McConkie and Underwood (Note 2) have provided an analysis of the timing of the decisions regarding eye behavior that will be briefly summarized here and is presented in Figure 1.

Insert Figure 1 about here.

This figure represents a fixation of approximately median duration, 220 msec. Above the line, the times of observable events during the fixation are noted: The termination of one saccade, the onset of the next saccade, and the point after which stimulus changes have no effect on the time of onset of the following saccade, here called the saccade deadline. The saccade deadline occurs about 100 msec prior to the saccade onset. Nonobservable (by non-neurological means) events are indicated below the line in the figure. The first of these, the time at which the visual information from a new fixation becomes available to the visual centers of the brain, is estimated at 60 msec after the onset of the fixation. The second, the point of no return, is the time at which the brain centers actually become

committed to the time of onset of the next saccade. This is estimated at 30 msec prior to the saccade onset. Both of these these estimates come from physiological data reviewed by Russo (1978).

One final estimate is of the earliest point at which stable textual information (as opposed to stimulus changes) can influence the present fixation duration. This is estimated at 140 msec, or 40 msec longer than the saccade deadline (McConkie & Underwood, Note 2). Thus, it is assumed that language aspects of the text must be having their influence on processing within about 100 msec after the onset of the fixation. This is labeled as the textual influence threshold in Figure 1.

From this figure, it is possible to estimate the amount of time elapsing between the textual influence threshold and the point of no return, the time during which processing of the visual stimulus encountered on that fixation can influence the duration of that fixation. This varies, of course, with the duration of the fixation, but for a 220 msec fixation this period is only 90 msec. On the other hand, for a fixation of the same length, the stimulus is available to the brain for 120 msec after processing can no longer influence the duration of that fixation (assuming a 30 msec saccade). It seems most unlikely, given this timing pattern, that all processing of information obtained on any given fixation has been completed in time to affect the following saccade, or even that all processing which might be capable of affecting the saccade has been completed. This would result in a 120 msec "dead time" (Russo, 1978), which turns out to be over half of the total time for the median fixation-saccade cycle, which would seem to be extremely inefficient.

The inevitable conclusion to be drawn from these considerations is that, contrary to Just and Carpenter's (1980) eye-mind assumption (see also McConkie, Hogaboam, Wolverton, Zola, & Lucas, 1979), processing of the information available during a fixation is not completed by the end of that fixation, and that the onset of the next fixation is not triggered by a completion of processing of information obtained on the present fixation. It appears that most of the time available for processing the information from most fixations, prior to the arrival of information from the next fixation, actually occurs after it is too late to influence the duration of that fixation or probably the length of the next saccade. A second conclusion is that the durations of the shortest fixations (and probably the lengths of the saccades following them) are not being influenced at all by the information perceived from those fixations. This raises many questions, including what processing is typically

completed prior to the point of no return, and what is the processing event that triggers the onset of a saccadic eye movement during reading. Some of these issues will be discussed later.

Some Issues

Saccadic eye movements in reading are typically grouped into three or four categories. These include forward movements, regressions, and return sweeps (Levy-Schoen & O'Regan, 1979) and sometimes "corrective movements," regressions frequently seen immediately following return sweeps (Hartje, 1972). This section will deal primarily with forward movements, to some degree with regressions, and the remaining categories will be largely ignored.

How to Conceptualize Eye Movement Control

As indicated earlier, the control of eye movements during reading can be considered to involve _temporal_ and _spatial_ decisions. There is a variety of ways in which one can conceptualize these decisions. For instance, it is possible that they are both the result of a single decision: The eyes are moved at the time the spatial decision is made.

On the other hand, assuming that a separate temporal decision is made, one can think of it as being either a true timing decision or simply as the mind responding to some processing state. In the first case, the mind is seen as a timing device, attempting to make optimal estimates of how long the eyes should pause at each location. Such timing decisions could, of course, be made early in a fixation or even prior to its onset, anticipating the time that will be required to process the information expected at that location. In the second case, the mind is not perceived as making temporal decisions at all, but rather as acting on an interrupt-driven basis, with eye control events occurring as they are called for in support of the mental task at hand, or by external attention-capturing events. By this view, the mind does not decide how long the eyes will be left centered at a given location; rather, the eyes are simply left there until some critical mental event occurs which elicits a saccadic movement.

Likewise, there are different ways of thinking of the nature of the spatial decision. Here a primary distinction is between a push vs. a pull view: Does the mind decide to send the eyes a certain distance in a certain direction, or are the eyes drawn to a certain location in the text? Either view can take several forms. In the push view, the eyes might be considered to be sent

some general distance (perhaps a standard amount modified by some parameter reflecting local text or processing conditions, as with Kolers' [1976] "kicker" plus gain control) or some distance that has been calculated to be likely to be optimal under present information-seeking or hypothesis-testing conditions. Once again it would be possible for such a decision to be made early in a fixation, or even prior to it. In the pull view, on the other hand, the eyes are considered to be drawn to a certain location. As examples, during a fixation a reader may attend to different regions at different times, with the eyes being drawn to a text region when the level of visual detail needed to support the identification process is not readily available (McConkie, 1979), or the eyes may be drawn to the centers of words (O'Regan, 1981; Rayner, 1979).

A basic distinction underlying these different ways of conceptualizing eye movement control is whether these mental activities are thought of as being planfully calculated and executed, or as being interrupt driven, responding to certain critical mental events when they occur. I do not believe that present evidence on eye movement guidance during reading is capable of selecting among most of these alternatives.

There are some specific issues on which evidence is accumulating, however, and some of these will be briefly reviewed.

Relation of Temporal and Spatial Decisions.

It would have seemed reasonable to find that there was a close relationship between the temporal and spatial decisions, such that when processing difficulties occur, reading is slowed both by shortening saccades and by extending the fixation periods, resulting in a respectable autocorrelation between successive fixation durations and between successive saccade lengths, and correlations between the durations of fixations and the lengths of saccades preceding or following them. This pattern has not been found (Rayner, McConkie, & Ehrlich, 1978; Andriessen & deVoogd, 1973; Kliegl, Olson, & Davidson, Note 3). This stands as evidence for independent control of fixation durations and saccade extents, and for individual control of each of these measures from fixation to fixation. Certain relationships can be found (regressions are more likely to occur following longer saccades [Andriessen & deVoogd, 1973] and fixations prior to regressions tend to be shorter than normal [Hawley, Stern, & Chen, 1974; Kliegl, Olson, & Davidson, Note 3] for instance), but the more global relationships appear to be largely absent. This fact has given encouragement to those who

suspect that the variability in eye fixation patterns reflects local cognitive and stimulus pattern effects.

Global, Local, or Immediate Control

A second issue around which much controversy has centered has to do with the degree of global, local, and immediate control of eye movements. Global influences are those which operate over entire texts or large segments of texts. The tendency of early eye movement research to use mean eye movement measures as data encouraged a focus on global influences of such factors as age, reading ability, passage difficulty, or reading strategy (Woodworth, 1938). While these studies showed differences in averaged measures, it is not clear whether they resulted from the setting of general parameters in the eye movement system or from the cumulative effects of hundreds of local decisions. A more recent proposal is that prior to reading (in fact, prior to any visual task), the subject establishes a general scanning routine and that while there may be local adjustments, these are simply modifications of, or overrides to, the routine initially established (Levy-Schoen, 1981).

The demonstration of local influences on eye movement control has been a primary contribution of the recent wave of eye movement research in the study of reading. Some examples are

Insert Table 1 about here.

provided in Table 1. Both the durations of fixations and the lengths of saccades have been shown to vary with local stimulus and information processing characteristics. However, this has raised the further issue as to whether these local variations are examples of immediate control; that is, whether the fixation durations and the following saccade lengths are being influenced or controlled on the basis of information obtained during those very fixations. The problem of establishing the existence of immediate control is more difficult than simply demonstrating that local characteristics of texts influence eye movement patterns. It is always possible that the information having the effect was acquired from the periphery during a prior fixation, rather than during the present one. Thus, in order to establish the existence of immediate control, it is necessary to know on what fixation certain information was in fact acquired by the reader.

The recent development of eye movement contingent display techniques has made it possible to investigate this issue. It is now possible to make changes in the text display, contingent upon the reader's eye movements, thus ensuring that certain stimulus information was in fact not available to the reader until a

particular fixation of interest, or a particular time during that fixation. If the information in question is then found to have an influence on the duration of that fixation, or on where the eyes go during the next saccade, this is evidence of immediate control. The danger in using this technique, of course, is the possibility that the stimulus change itself is in some way producing the differential effects, a problem that requires great care in the selection of control conditions.

A few studies presently available meet this strict criterion for demonstrating immediate control of eye movements. The duration of a fixation can be increased if errors or gratings occur in the text on that fixation (Rayner & Pollatsek, Note 4; Underwood & McConkie, Note 5), if the fixated word is different from what that word had been on the prior fixation (Rayner, 1975a), or if the text was shifted during the prior fixation so that the eyes are not centered at the text location they normally would have been (O'Regan, 1981; McConkie, Zola, & Wolverton, Note 6). The latter manipulation also influences the immediately following saccade. In addition to demonstrations of immediate effects, there are also clear instances of delayed effects, where manipulations on one fixation influence the following fixation or the saccade following it (Rayner & Pollatsek, Note 4; Underwood & McConkie, Note 5). Thus, both immediate and delayed effects have been demonstrated, and a goal of future research must be to establish the conditions under which each occurs.

So far, all studies which have provided unambiguous demonstrations of the presence or absence of immediate effects on eye movements during reading have employed stimulus manipulations involving gratings, errors, and shifting of the text, a point noted by Levy-Schoen and O'Regan (1979). There has not yet been a conclusive demonstration of variables in normal text encountered during a given fixation influencing the duration of that fixation or the following saccade. While it seems highly probable that some of the local effects noted in Table 1 are indeed immediate in nature, the final evidence is not yet in.

The issue of whether or not eye movements are primarily under immediate control is an active one in theories of reading. Some have argued there is not sufficient time during a fixation for such immediate control to occur (Bouma, 1978; Bouma & deVoogd, 1974; Kolers, 1976; Shebilske, 1975). Others have opted for a strong immediacy assumption (Hochberg, 1970; Hochberg, 1976; Just & Carpenter, 1980; McConkie, 1979), which often plays a critical role in their theories. Investigation on this issue should be lively during the next few years.

Information on Which the Spatial Decisions are Made

In considering the nature of eye movement control during reading in 1970, Hochberg noted that there are two sources of information which might be employed in determining where the eyes should move next. The first was visual information, primarily that from the periphery since the eyes typically (but not always) travel to a region not located foveally on the last fixation. Use of this source of information was labeled Peripheral Search Guidance, or PSG. The second was knowledge of language patterns that reduces uncertainty about the not-yet-fixated text, and which therefore might influence where the eyes are sent next. This source of influence was called Cognitive Search Guidance, or CSG. Hochberg proposed the beginnings of a theory of reading based on the combined use of these two sources of information to gain processing efficiency, primarily through: (a) minimizing the amount of visual information required from words for their recognition, thus permitting more effective use of peripheral visual information, (b) optimizing the locations of the fixations using PSG and CSG, and (c) reducing the amount of visual processing required by suggesting that readers use their knowledge to form hypotheses which are tested against visual information. The CSG-PSG distinction is further clarified in a later publication (Hochberg, 1976). Whether or not later writers have accepted Hochberg's analysis-by-synthesis basis for perceptual processing, all have accepted as fundamental the distinction between visual and cognitive sources of information used in guiding the eyes, and the controversy has centered around whether neither of these is used (recognizing the possibility of global control operating alone), whether one predominates, or whether both are involved (Bouma, 1978; Carpenter & Just, 1977; Haber, 1976; Kennedy, 1980; Kolers, 1976; Rayner & McConkie, 1976), and if both, how the combining occurs. Other possible sources of control include the establishment of a basic scanning routine that provides the general pattern required for reading (Levy-Schoen, 1981) and the possibility that the states of perceptual or cognitive processes can themselves be a basis for eye movement control (Rayner & McConkie, 1976).

Visual information in spatial control. The primary contender at the present time for the use of purely visual information guiding the eyes is found in the "preferred viewing position" hypothesis (O'Regan, 1981; Rayner, 1979), which indicates a tendency for readers to fixate toward the centers of words (slightly prior to the centers of long words). Rayner suggested that the basis for eye guidance may be simply to send the eyes to the middle of the word beyond the last one identified. The fact that many fixations were not at the

expected location, however, was of some concern, and three possible explanations were put forward: inaccuracy in the guidance system, lack of preciseness in the intended positioning of the eyes, or other semantic and/or syntactic factors (as yet unspecified) that may override this basic algorithm. This hypothesis is also closely allied with the observations that readers tend to send their eyes further when a long word lies to the right of their fixation location than when shorter words do (O'Regan, 1979), and that an initial fixation early in a long word is frequently followed by a short forward saccade, whereas an initial fixation toward the end of a long word is frequently followed by a regression (O'Regan, 1980). Apparently whether one or two fixations are needed to recognize a long word depends on where the initial fixation lies, suggesting an efficiency in fixating near the center.

It should be pointed out that here, as with other eye fixation tendencies, the observation of a pattern in the data is not itself proof that guidance is based on an attempt to achieve that pattern. For instance, the fact that extreme letters in a word are more easily identified due to less lateral masking (Bouma, 1973) indicates that any theory suggesting that the eyes are sent to a region where identification did not previously succeed would predict that more fixations would be centered on the internal parts of words.

A second aspect of strictly visual control of eye positions is a tendency to avoid fixating on blank regions in the text (Abrams & Zuber, 1972-73) including the region between sentences (Rayner, 1975a).

Cognitive information in spatial control. One example of cognitive control is found in recordings of regressive movements. Readers sometimes move directly to a relevant previously read word when some processing difficulty is encountered (Carpenter & Just, 1977). Apparently the location of the word was retained and that information was used to guide the eyes.

It has often been suggested that language constraints are involved in spatial control; good readers presumably do not need to fixate highly constrained words, either because they can be identified in peripheral vision, or because they can be identified on the basis of cognitive information alone and visual analysis is not necessary (Haber, 1976; Hochberg, 1970; O'Regan, 1979). However, this notion has been challenged by one study which found no difference in the fixation patterns on a word under high- and low- constraint conditions (Zola, 1981).

Combined visual and cognitive information in spatial control. At present, the most frequently stated position on eye movement guidance in reading involves a combination of visual and cognitive information. For instance, optimal eye position may be selected on the basis of some combination of knowledge of language constraints and of patterns available in peripheral vision (Hochberg, 1970), or language constraints may increase the likelihood of recognizing certain words in the periphery, thus leading them not to be fixated (Haber, 1978b; McClelland & O'Regan, in press; McConkie, 1979; O'Regan, 1979; Rayner, 1979, Rumelhart, 1977). In this latter proposal, the combination of vision and cognitive information enhances peripheral recognition, thus allowing longer saccades, but is not specifically used in the spatial decisions themselves. This may by why the visual region within which erroneous letters disrupt reading is the same for poor fifth-grade readers as for college students (Underwood, 1981), yet the college students make longer saccades. If average saccade length reflects the region of perceptibility rather than visibility (O'Regan, 1979), this increased saccade length may reflect a more efficient use of peripheral visual information by the more skilled readers (Hochberg, 1970).

Finally, it may be that semantic preprocessing of peripheral visual information may aid in eye guidance (Neisser, 1967), but present evidence makes this possibility unlikely (Inhoff & Rayner, 1980; Kolers & Lewis, 1972).

Bases for Temporal Decisions

Gilbert (1959) suggested that fixations have three purposes: (a) to allow transmission of the visual stimulus while the eyes are at rest, (b) to provide a period free from interfering stimuli, and (c) to provide time to comprehend the ideas and relations involved. The first two purposes suggest that there may be some minimum time required in fixations for basic perceptual processes to occur; the third suggests that most will be longer than the minimum, the length of which should then be related to the time required for comprehension of the ideas and relations to occur. However, Gilbert did not deal with the question of what the event is which triggers the initiation of the next saccade. While Table 1 makes it clear that many local factors influence the durations of fixations (characteristics of the word fixated, characteristics of the next word, characteristics of the language context), it is still not clear just how much of the processing induced by a word or words perceived during a fixation has been accomplished by the point of no return on that fixation, nor just what it is that signals the fixation termination.

As an example, Zola (1981) found that the initial fixation on a word was 23 msec shorter when it was highly constrained by the prior context than when it was less highly constrained, an amount comparable to the facilitation in recognition time which Tulving and Gold (1963) obtained when appropriate contextual constraint was introduced. Thus, this indicates some efficiency in processing resulting from the language constraints. However, the nature of the mechanism underlying this savings is still not known. For example, it may be that in any of several ways, recognition of the critical word was sped up by the constraints, thus reaching sooner the processing state which triggers a saccade. Or it may be that once the word was recognized it was also noted that it fit easily with the developing structure, so less processing time was allotted. Or it may be that during the prior fixation the fact that this was a region of high constraint (low information value) was detected, and thus a shorter fixation was planned at the next location.

While recent research has documented local effects on the durations of fixations, so far it has left us in ignorance as to the nature of the mechanism producing this variability. This fact has a bearing on attempts to use eye movement data as a basis for estimating the time required to process different segments of text, a topic which will be briefly discussed later.

The Basis for Small Saccades

One phenomenon which has been largely ignored in reading research, and which is something of an embarrassment to most present views of eye movement control, is the existence of small saccades. Why is it that readers at times move their eyes such a short distance that the new region fixated was within the fovea on the prior fixation? It seems unlikely either that the level of visual detail available from that region on the prior fixation failed to permit adequate discrimination among letters, or that it would be anticipated that critical new information would be available there that was not accessible on the prior fixation. The typical way of dealing with short saccades is to ignore them. This is done in either of two ways. First, for most equipment there is a limit on the size of the saccade that can be reliably detected. The definition of a saccade is often set in the data reduction program in a way that eliminates small saccades; for instance, Just and Carpenter (1980) declare the eyes to be in a fixation until they move outside a three-character window around that fixation location. How small a saccade can be detected depends on such factors as the noise level of the equipment and the sampling rate (McConkie, Zola, Wolverton, & Burns, 1978). Second, the investigator may choose to ignore detected saccades if they are less than a certain length (O'Regan, 1979) or if they

do not take the eyes out of some region of interest (Just & Carpenter, 1980).

The only available evidence on the frequency of microsaccades during reading (saccades of 11.6 minutes of arc or less, which is about 1/2 to 3/4 letter position in most displays used for eye movement research) indicates that for one subject they occurred on 1.7% of fixations and for a second, on 4.8% of fixations (Cunitz & Steinman, 1969). On fixations containing these microsaccades, median fixation durations were 535 and 520 msec, in contrast to 285 to 305 msec for fixations with no microsaccades. Furthermore, time from onset of the fixation to the onset of the microsaccade was 275 and 295 msec, very similar to the normal fixation time for these subjects. These authors claim that small saccades do not improve visibility, since low-velocity drifts are sufficient to accomplish that purpose. Rather, they suggest that, like larger saccades, they are scanning movements, made when a subject searches for very fine detail in a fixation target. Thus, they make no dichotomy between microsaccades and larger saccades.

This argument seems reasonable when a subject is attempting to fixate a small target or to examine a display made of very fine detail. It loses its credibility in reading, however, where the level of detail needed to discriminate among letters and words is not very fine, certainly not fine enough to require 1/2-letter or smaller saccades.

There seem to be two other possible explanations. One suggested by Cunitz and Steinman is that when a subject is examining a display for fine detail, small saccades are made that are "peripheral indicators of small changes in attention within a very circumscribed portion of the visual field." Thus, there may be a sufficiently close link between attention and the saccadic eye movement system that certain (perhaps discrete) movements of attention result in a small change in eye position, even when that change itself is not functional (McConkie, 1979). A second explanation is that the eye movement system operates with some base frequency of movement. That is, there may be some natural tendency for the eyes to move every 200-300 msec, and if the perceptual system has not called for such a movement by then, a discharge occurs to move the eyes anyway. In this case, the eyes would only be moved a short distance so as not to interfere with ongoing perception. This explanation seems most compatible with Levy-Schoen's suggestion of a pre-established basic scanning routine for reading, described earlier. Another bit of compatible evidence is that when the text is masked with a grating during the early part of a fixation, readers sometimes

initiate small eye movements even though there is really no useful stimulus pattern to attend to for reading (Rayner & Pollatsek, Note 4). At the present time, there seems to be no basis for selecting among these or other possible explanations of small saccades. However, the existence of small saccades raises the issue of whether every saccade is purposeful, initiated for the purpose of sending the eyes to some location where added visual information is needed, or whether some are elicited on some other basis.

Whatever the basis for small saccades, their effect on certain aspects of our data should not be overlooked. Obviously, the durations of fixations reported from an experiment depend to some extent on what is taken to be a saccade. To ignore some saccades (as is usually technically necessary, since the smallest saccades cannot be reliably detected with most equipment available for reading research) is to report longer fixations than actually occur. How much longer the average fixation duration is depends on the size of the saccades ignored, since the higher the threshold is set, the more are ignored, and hence the more "contaminated" fixation durations are included in the distribution. From Cunitz and Steinman's data, it appears that the primary effect of ignoring small saccades is to increase the number of fixations with long durations, thus increasing the positive skew in fixation duration distributions. It is also the case that such aspects of the data as the number of fixations made in reading a passage, the average length of saccades, and the number of regressive movements made are influenced by the saccade threshold of the study, as well.

The Basis for Regressive Movements

While most eye movements during reading are either rightward along the line, or leftward and down to the next line, a considerable number cast the eyes against this normal progression, seeming to take the eyes back for a reexamination of earlier-seen information. The question arises as to whether these regressive movements and the fixations that precede and follow them are perceptually any different than those bounded by forward saccades, or whether the basic perceptual processes are the same but these saccades are simply induced under different cognitive circumstances. There are differences in the eye movement patterns associated with regressions: The average duration of fixations prior to regressive saccades is shorter than those prior to forward saccades (Hawley, Stern, & Chen, 1974; Kliegl, Olson, & Davidson, Note 3), the average length of regressive saccades is shorter than that for forward movements (Taylor, Note 8), and the fixation following a regression can

also be shorter than normal (Hawley, Stern, & Chen, 1974). Whether these differences reflect differences in the perceptual processes associated with these fixations is not presently known.

Most speculation has focused on the conditions under which regressive eye movements occur. For example, it may be that regressions are stimulated by inaccuracies in eye positioning, habits formed in early stages of learning to read (Taylor, Note 8), comprehension failures (Shebilske, 1975), failure of recognition to be completed by the time the eyes are scheduled to move on (Bouma, 1978), the need for additional time for the reader to learn and remember high priority information (Shebilske & Fisher, Note 9), anticipations (Russo, 1978) or the failure to confirm expectations (Wildman & Kling, 1978-79), or certain semantic factors (Carpenter & Just, 1977). It is obvious that very creative studies are going to be required to establish, and distinguish among, these and other similar alternatives.

As with forward saccades, the control of regressions can be immediate. Encountering errors left of the center of fixation can induce an immediate regression (Underwood & McConkie, Note 5), as can shifting the text to the left during a saccade (O'Regan, 1981; McConkie, Zola, & Wolverton, Note 6). The length of regressions that commonly follow return sweeps of the eyes depends on the position of the immediately prior fixation relative to the left edge of the text; this correlation was .97 for 36 instances produced by a subject whose data were available to the author. At the same time, there are times when encountering errors has no effect on the immediately following saccade, but only on saccades following that (Underwood & McConkie, Note 5).

Thus, both immediate and nonimmediate effects have been observed in the control of regressive saccades, but as yet there is no unambiguous evidence for immediate effects based on semantic and other higher-level processing. This remains a challenge for the future.

PERCEPTION DURING A FIXATION IN READING

Given that the eyes have been sent to some particular location, there next arises a set of issues about the nature of the perceptual processes occurring during the fixation (or perhaps, more properly, during the period of time that the mind is responding to the visual information provided by that fixation). First, it should be noted that, although the visual system is sensitive during saccadic eye movements (Uttal & Smith, 1968), the type of visual detail needed to support reading

is not acquired during those periods (Wolverton, Note 10). Also, while there is some decrease in the sensitivity of the visual system immediately prior to and following each saccade (Remington, 1980; Volkman, 1976), this reduction is not sufficient to preclude perception of such high-contrast stimuli as are typically encountered in reading (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Wolverton, Note 10). Thus, reading is based on perception of stimulus patterns available during fixations, and the visual system is sensitive throughout the period of the fixation.

The issues to be dealt with in this section have been divided into two groups, those involving the functional stimulus, and those dealing with the dynamic of perception during a fixation.

The Functional Stimulus during a Fixation

An empirical issue, quite apart from questions of how perceptual processes proceed during a fixation, concerns just what aspects of the textual stimulus array that falls on the reader's retina during a fixation affect the reading process. This is the problem of identifying the functional stimulus. In considering this problem, it is first necessary to establish just what aspects of the stimulus pattern are actually available to the reader. Because of the small size of the fovea, the region providing the highest degree of visual resolution, together with the loss of acuity in more peripheral regions, different aspects of the visual pattern are available at different retinal locations. Furthermore, there are interactions within the visual system that result in letters located further into the periphery sometimes being more easily identified than letters closer to the fovea (Bouma, 1973). While Bouma and his colleagues have contributed greatly to understanding on these issues, much work remains to be done in order that the limits on what visual information is actually available to the reader might be fully known. This is needed in order to enable investigators to distinguish between failure to utilize stimulus information because it is not resolved by the visual system vs. because it was not attended.

In discussing the functional stimulus in reading, two basic issues will be considered. First, from what visual region is information of various sorts acquired during a fixation, and second, within this region what aspects of the visual pattern are used.

The Perceptual Span during Reading

The perceptual span will be defined as that region around the center of vision within which some aspect of visual detail of interest is used in reading (or affects the reading process). From this definition, it is clear that this region must be assessed for each aspect of visual information of interest. Furthermore, it is possible that this region changes as the nature of the task or of the text display changes. Thus, it is necessary to specify the nature of the information being studied and the nature of the task and stimulus characteristics in order for the concept of a span to be most useful.

In order to better understand what is being measured in studies that attempt to measure the perceptual span, it is necessary to make some further distinctions (Underwood & McConkie, Note 5). It is possible that the region attended on different fixations varies, so the "span" is not the same from fixation to fixation. It is further possible that different regions are attended at different times during a single fixation. Thus, we must distinguish among three "spans." The <u>momentary span</u> is that region attended at some moment during a fixation, the <u>individual fixation span</u> is a region consisting of all those regions attended during a single, particular fixation, and the perceptual span is a region which encompasses all the individual fixation spans, though, of course, it may be coterminous with none of them. Thus, the perceptual span, as measured in present studies, may not necessarily indicate the region being perceived during particular fixations, or at any particular moment. Furthermore, this points up a weakness in our present techniques for measuring the perceptual span, which typically involve modifying some aspect of the text pattern at some peripheral visual location during one or many fixations, and observing whether this has any effect on reading, as indicated by eye movement patterns or reading rates. Whether or not a study reveals the use of some aspect of the stimulus at some retinal location depends on three factors: the frequency with which that aspect of the information is used at that location, the nature and size of the effects that modifying this aspect of the text has on reading, and those characteristics of the design of the study that affect its sensitivity in detecting the types of changes in behavior being produced. Thus, if certain information is utilized from a particular region only occasionally, and the method used to modify that information produces relatively small changes in behavior, or if the design of the study is weak in its ability to reliably detect such changes, then the study will underestimate the size of the perceptual span for that

information. In fact, it is quite possible that our studies will consistently underestimate the span for most types of information, especially if its use at the most extreme locations occurs but rarely.

Finally, it should be pointed out that demonstrating that visual information is being utilized from a certain peripheral region during fixations does not establish that words in that location are being identified on those fixations. Certain aspects of the text may be useful in eye guidance, in providing information about upcoming text that will facilitate its processing, or for other purposes other than actual text identification. Also, the lack of use of certain visual information does not establish that words in that region were not identified, since it is logically possible that they may have been identified on the basis of contextual information. Thus, at the present time there is no well-established relationship between what information is utilized from given peripheral regions and whether words are identified in those regions.

Perceptual spans to the right of the fixation location. Inital studies on the perceptual span question which utilized eye-movement contingent display control techniques (McConkie & Rayner, 1975; Rayner, 1975a) suggested that different aspects of the visual pattern were being utilized different distances into the periphery, with word length, word shape, and initial and final letters being acquired and used further out than internal letters. In more recent work, it has been established that replacing the text in the periphery with a square-wave grating, thus removing all information other than an indication of where the line lies and perhaps what its end point is, has no effect on reading if it is no closer than 14 character positions to the right of the fixation location (Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). This suggests that some more detailed aspects of the stimulus are typically acquired and used up to about 14 letter positions, though it is possible that the very noticeable, homogeneous pattern presented by the grating may have been having some effect of its own perhaps by influencing the subjects' reading strategies (O'Regan, 1980).

At the other extreme, distinctions among letters may not be made more than about six letters to the right (Underwood & McConkie, Note 5; McConkie, Note 11), with uppercase letters being perceived somewhat further than this (O'Regan, 1980). Fifth-grade children, both those reading at and above their grade level and those reading below, appear to acquire and use letter information from the same region as do college students

(Underwood, Note 7). Thus there is no evidence that the region within which letters are identified increases as reading skill develops (Stewart-Lester & Lefton, in press).

Studies in which subjects are asked to read under conditions in which foveal information is masked, hence only peripheral visual information is available, indicate that little information beyond occasional letters (typically initial and final letters of words), word length, etc. can be acquired from words lying as much as six letter positions from the fixation location. Furthermore, studies designed to determine whether subjects can gain semantic, phonetic, or other such information from words in similar peripheral locations have failed to find such influences (Inhoff & Rayner, 1980; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980). These studies again indicate the narrowness of the region within which the type of visual detail normally considered to be the basis for reading can be obtained.

While considerable progress has been made in this area, further work is needed to explore individual differences and the effects of text and task factors, and to determine whether there is indeed variability in the individual fixation spans and momentary spans as people read.

Perception to the left of the fixation location. The perceptual span for letter information is asymmetric with respect to the fixation location, extending less far to the left than to the right (Rayner & McConkie, 1976). This asymmetry is greater than can be accounted for strictly on the basis of visibility of letters and words (Bouma, 1978) and has been attributed to attentional processes (McConkie, 1979). The fact that the region perceived during fixations by Israeli readers extends further to the left as they read Hebrew than as they read English (Pollatsek, Bolozky, Well, & Rayner, Note 12) adds further evidence for the attentional explanation. There is evidence that the region perceived during a fixation begins at the beginning of the presently fixated word if it is within four letter positions to the left of the fixation location, or at about four letters to the left if the word extends beyond that point (Rayner, Well, & Pollatsek, 1980). It has been suggested that the reason the perceptual span seems to extend such a short distance to the left of the fixation location in readers of English is that when a saccade is made the eyes are sent to a location just beyond that where the text has been identified, and hence text to the left has already been perceived (McConkie, 1979).

Variability in individual fixation spans. There is some evidence that individual fixation spans of a reader vary from fixation to fixation, but no basis yet for determining the degree to which this occurs. Present evidence indicates that the left-most extent of the span may be determined by where the fixated word begins (Rayner, Well, & Pollatsek, 1980) and that whether one detects errors in the periphery may depend partially on the location of the fixation in the sentence (Rayner, 1975b). When the text is masked and removed during occasional saccades as subjects are reading, and they are asked to report the last word read, they sometimes report the last word fixated and sometimes a word or two to the right of it (Hogaboam, Note 13).

There are a number of reasons why variability in individual fixation spans might be expected. Retinal factors such as lateral masking influence whether a given letter or letter combination will be visible at the same retinal location on different fixations (Bouma, 1978). If perception is in word units, then the individual spans will tend to be determined by the locations of word boundaries (Rayner, Well, & Pollatsek, 1980). Language constraints may influence how far into the periphery visual information is acquired and used (Haber, 1976; Hochberg, 1970; Wanat, 1971), though this has not been clearly demonstrated in reading.

Another likely possibility is that variability in individual fixation spans arises from different fixations serving different functions. It has been speculated that on the fixation at the end of a return sweep, and followed by a regression, the only information attended has to do with the location of the left edge of the line of text, so a corrective movement can be made. However, Hogaboam has found in pilot studies that when the text is masked and removed following such fixations subjects can typically report the word fixated. The observation that on fixations in the region between sentences subjects are less likely to be influenced by errors in the periphery raises the possibility that such fixations may not have visual analysis as their primary purpose (Rayner, 1975b). When people read along with a slowly paced oral rendition of a passage, they make cycles of regressive and forward saccades (Levy-Schoen, 1981). Some of these fixations may be for the purpose of biding time rather than for visual analysis. Finally, some fixations preceding and following regressions may have a somewhat different function than those bounded by forward saccades (Just & Carpenter, 1980; McConkie, Hogaboam, Wolverton, Zola, & Lucas, 1979). We have observed many instances in which a reader regressed back to a word that, in the interim, had been changed, and even though fixating the word directly, gave no indication that a different

word was in that location.

Finally, the individual fixation spans may vary for reasons related to temporal characteristics of the visual system described earlier. As indicated earlier, the eyes are probably advanced prior to completing processing of the visual information available on any given fixation; in fact, the full visual array may be available in the visual centers for about 60 msec after a saccade is initiated, the time required for the saccade-associated stimulus changes to reach the brain. Thus, what is seen on one fixation may depend on how far processing has proceeded prior to the time the visual information arrives from the next fixation, which may in turn reflect processing difficulties encountered.

The possibility of variability in individual fixation spans raises the question of just how flexible readers are in their ability to read using information from different retinal regions. Bilingual Israeli-English readers show some flexibility, as they change languages (Pollatsek, Bolozky, Well, & Rayner, Note 12). However, other information suggests that, while it is true that the controls for eye movements and attention are not identical, there is a close relationship between where the next fixation will be and where one attends (Rayner, McConkie, & Ehrlich, 1978;

Remington, 1980). When a normally used region of the visual field is masked, readers do not seem to be able to change easily and read from a different region (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner & McConkie, 1976).

It is sometimes assumed that the lengths of saccades, which are quite variable, are related to the size of the region being perceived (McConkie, 1979; Taylor, Note 8). At present there is little evidence on this point (but see Hogaboam, Note 13). In further work on this issue, it will probably be important to distinguish between the region where certain visual information is available and the region where words are identified. For instance, a word at a given retinal location may be identified on one encounter, but not on another, not because of differences in the visual information avaiable from it, but because of language constraints. It may be that where the eyes are sent is related more closely to identification than to the individual fixation span.

Aspects of the Stimulus Used in Reading

Various claims have been made about just what aspects of the stimulus serve as the basis for reading. Some have suggested that each letter is encountered and in some sense identified (Geyer, 1970; Gough, 1972), while others have argued that due to

the redundancy of the language, or to frequency of experience with certain patterns, identification can occur on the basis of partial information: word length, characteristics of the word shape, or information from only certain letters, etc. (Rumelhart, 1977; Smith, 1971). This controversy raises questions about what aspects of the visual pattern within the perceptual span region are perceived and utilized in reading. There is good evidence that information such as word length or shape can facilitate guessing what word might be next in the text (Haber, Haber, & Furlin, Note 14), and that errors which change the shapes of words can be detected more easily (Haber & Schindler, in press), indicating that these types of information can be used when needed. The question, of course, is whether they are regularly used in reading, and whether finer detail is sometimes ignored.

Actually, there are two issues which need to be discussed. First is the question of whether full use is made of the available visual information in the regions attended; is it possible for the reader to extract only certain visual information needed for the decisions at hand and ignore the rest, as has so often been suggested? Second is the question of whether language constraints allow identification of words in the periphery to occur when only partial information is available.

Selective attending to available information. One of the most frequently made assumptions in theories of visual perception during reading is that, by some means, the reader is able to attend selectively to certain information that is of greatest value in the present context (Brown, 1970; L. Haber & R. Haber, in press; Rumelhart, 1977). It is assumed that in so doing, the reader gains efficiency through maximizing the use of available language information and minimizing the perceptual processing required. If this is true, then which aspects of the text serve as the functional stimulus may be highly variable, depending on the context at the time, and the degree and perhaps nature of the constraints in operation. Determining whether there is such variability in the functional stimulus is probably one of the most critical questions in the area of perception during reading, since it has played such a central role in recent theorizing. One study designed to detect whether skilled readers fail to process internal letters of highly constrained words found no evidence of this expected selectivity (Zola, 1981).

Identification on the basis of partial information. Even if readers do not selectively ignore available information, they may identify words on the basis of less than full visual detail where that detail is not available, for instance, in the visual periphery. In fact, gaining this ability is thought by some to

be a primary means by which reading fluency is achieved (L. Haber & R. Haber, in press; Hochberg, 1976). From an information-theory perspective, the context, an initial letter, and a few global characteristics of a word are often sufficient to uniquely specify it among the set of relatively common English words (R. Haber & L. Haber, in press). The question, however, is whether this actually serves as a sufficient stimulus for reading. The research reviewed earlier, indicating that visual detail more coarse-grained than that on which letter distinctions are made is available and used in the periphery, suggests that this might be the case. However, it is also possible that such information is not being used for identification directly, but rather that it is used for eye guidance, and in some way facilitates identification of information on the next fixation (Rayner, 1978b; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980). Some evidence for identification on the basis of incomplete information is found in studies where the text is masked and removed during certain saccades, and subjects report the last word read (Hogaboam, Note 13). Readers sometimes report words as many as two or more to the right of the last word fixated, words which had been some distance into the periphery. Whether this normally occurs during reading, or only when required by the task of reporting words, remains a question for further investigation.

The Dynamics of Perception

In addition to knowing what aspects of the visual stimulus serve as the functional stimulus for reading, it is necessary to know the dynamics within which this information is utilized. This will be discussed as two sets of issues: When during the fixation is information being acquired and used, and what is the nature of the perceptual processes involved?

Chronology of Perceptual Events

Another issue in the understanding of perception during reading is whether different types of perceptual activities occur at different times during a fixation, and whether different aspects of the stimulus pattern are processed at different times during a fixation. These issues are the topic of another paper by members of our laboratory (Wolverton & Zola, in press).

It has been suggested that the acquisition of visual information occurs early in a fixation, leaving the remainder of the fixation time for processing for comprehension and deciding where to send the eyes next (Gough, 1972). Just and Carpenter (1980) included this as a separate stage in their model, labeled "Get New Input." This view has been bolstered by evidence

that people can read short sentences when they are available for only the first 50 msec of each fixation just as accurately as when they are continuously available (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). Wolverton and Zola (in press) argue against this view.

In order to deal with this issue, one must make a clear distinction between when it is that the information becomes available to the brain, which will be referred to as _registration_, and when the language processes are modified by the presence of that information, which will be referred to as _utilization_. Registration is simply a matter of transmission of retinal encodings to the brain, and this, of course, occurs early in the fixation. However, our observations have led us to believe that utilization occurs throughout the period in which visual information is available from a fixation. While it may be possible for a reader to adopt a strategy by which reading can take place with the visual information available for only 50 msec of each fixation as efficiently (though not as easily, from my experience) as with a continuous view of the text, this does not appear to be the normal case in reading. Rather, readers frequently report having read stimuli present only later in the fixation, beyond even 100 msec. It seems possible that utilization occurs throughout the time the information is available, as needed to support the ongoing comprehension processing, though this possibility has not been established by firm evidence.

If there are stages during a fixation, that is, times when characteristically different perceptual activities are carried out such as visual input, testing hypotheses, generating hypotheses, calculating where to send the eyes, etc., then the fixation must be regarded as psychologically fundamental in the reading process. The fixations become the basic time periods of mental activity, and regular cycles occur with respect to them. This may in fact be the case, but an alternative should also be considered (McConkie, 1979). Suppose that utilization occurs throughout the fixation, as needed by the comprehension processes. Reading is then a continuous process with visual information being utilized whenever appropriate for advancing an understanding of the text, and the fixation loses much of its psychological primacy. At this level, there are no fixation-linked stages, since the nature of the mental activity is driven by the nature of the language processing occurring, rather than by eye movement characteristics. At some lower level, the problems of ensuring that the eyes are in appropriate locations are handled without specific direction from the language processing taking place. In the saccade control there are

obviously some events that must occur at specific times: Registration occurs early in the fixation, and at some point final information is provided to the saccadic system as to where to move next. These events, however, are peripheral, and may have very little effect on the more central cognitive processes taking place.

The purpose of this discussion has been to try to highlight one additional issue in our understanding of perception in reading: whether the eye movement activity which we monitor is a fundamental activity from which the higher mental processes are timed and sequenced, or whether they are are incidental to the more fundamental processes and simply reflect patterns that are necessary to provide the mind with the information needed for reading.

<u>Utilization from different regions at different times.</u> There are several reasons for expecting that visual information from different regions within the area perceived on a fixation are utilized at different times. Evidence is accumulating that this is indeed the case. Foveal stimulus patterns seem to have their effect earlier than more peripheral patterns, for instance (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; McConkie & Underwood, Note 2; Underwood & McConkie, Note 5). Whether this

is due to differences in transmission times (Bouma, 1978), to the use of peripheral information only later when eye movement decisions are called for (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981), or to a general tendency for readers to attentionally proceed along the line of text during a fixation (McConkie, 1979) is a question which requires investigation.

The Processes of Perception during Reading

As has been evident from prior discussion, a wide range of proposals have been made concerning the nature of the perceptual processes during reading. Some would see reading as involving letter-by-letter input followed by various stages of analysis of the information to gain its meaning (Geyer, 1970; Gough, 1972), others would see it as primarily creating and testing hypotheses from previously encountered information and knowledge of language plus perhaps some peripheral visual information (Goodman, 1976; R. Haber & L. Haber, in press; Hochberg, 1976; Russo, 1978), while still others would see it as involving the simultaneous operation of many processes, stimulated by information in a common memory space and entering the results back into that space (Just & Carpenter, 1980; Rumelhart, 1977). No attempt will be made here to review the various theories of perception during reading that have been advanced. The only point to be made is

that these theories differ in the nature and timing of the processes assumed to be occurring during reading and, as a result, make different predictions on the various issues that have been and will yet be raised in this paper: Issues concerning what serves as the functional stimulus and when the information is utilized, what information is used in determining the location of the next fixation, and what information is carried over from one fixation to the next during reading. Thus, advancing knowledge on these issues will not only provide a basis for judging the strengths and weaknesses of present theories; it will also force reconsideration of the types of mechanisms that might underlie perception during reading, and place constraints on future theories.

PERCEPTION ACROSS SUCCESSIVE FIXATIONS

In reading, as in most other visual tasks, a person makes several fixations per second, with each fixation providing a somewhat different view of the world. How the mind integrates information from successive fixations in a coherent, stable impression of the world is an issue of long standing in the field of psychology (Cumming, 1978; Huey, 1908), and underlies several questions about perception during reading, specifically. First, however, some differences between reading and many other visual tasks should be noted.

In most visual perception, the goal is to gain information about, or form a representation of, the figural characteristics of the stimulus array: shapes, spatial relations, and transformations of these over time. However, in reading, the figural aspects of the stimulus pattern are simply a vehicle by which the person attempts to understand the message communicated by the text; the visual shapes are of little intrinsic interest except in the case of certain forms of poetry or graphic design. It is not the shapes of letters, words, sentences, or paragraphs that are important to retain, as is evident to anyone inspecting text written in a language he has not learned. At the same time, perception of the image of the page, which will be referred to here as the "scene" of the text, may be useful in reading in ways other than simply providing the visual features for the identification of individual words and of sentence punctuation, paragraphing, etc.

It has been suggested that the frequent regressions made by less skilled readers have the effect of presenting the text to the mind in an inappropriate order, leading to confusions in understanding (Taylor, Note 8). Others have argued that this is not the case, but rather that the mind "smooths over" such

erratic sequences, and while the eyes may fixate the words in some order other than that of the textual sequence, the fundamental perception is in the spatial sequence that maintains the normal language order (Kolers, 1976). This smoothing-over process could be mediated by a mental image of the page which is to some degree independent of the fixation order (given that the degree of visual detail is available in the text region where reading is directly occurring). This suggests the existence of a mental representation of an image of the text, to which each fixation contributes, and which is in turn the basis on which further reading processes depend (McConkie & Rayner, 1975). It should be noted that the degree to which the mind can tolerate variations in exposure sequence to the text and still maintain comprehension, and whether this ability is one developed as part of the development of reading skill, has not been explored, let alone the question of whether this depends on a spatial image of the text. Furthermore, while this is an appealing notion in that it provides a nice account for several aspects of perception during reading, recent studies have called it into question.

Traditionally, two explanations have been given for how images from successive fixations might be integrated into such a composite mental representation (Cumming, 1978). One possibility is that this integration depends on knowledge of the length and direction of the saccade: The image from the new fixation is mentally displaced a direction and distance to compensate for this new viewing position, and it then matches and is integrated with the image constructed from previous fixations. The other possibility is that saccade information is not needed: The new image is simply justified with the old on the basis of pattern similarity.

If images are justified on the basis of knowledge of saccades, then great disruption should be produced if, during a saccade, the text were to be shifted so that the following fixation was not centered at the place in the text where it was originally destined. However, shifting the text in this manner to right or left by 2-3 letter positions is not detected by readers (Bridgeman, Hendry, & Stark, 1975; O'Regan, 1981; McConkie, Zola, & Wolverton, Note 6), and while changes are induced in the eye movement pattern by this manipulation, they do not appear to indicate the type of disruption that would be expected (McConkie, Zola, & Wolverton, Note 6).

If integration occurs on the basis of pattern similarity, on the other hand, then similarity of the visual pattern from one fixation to the next would be critical. This was put to test by having people read passages printed in AlTeRnAtInG cAsE, and

changing the case of every letter during certain saccades, so successive visual images would not be similar (McConkie & Zola, 1979). These changes were not noticed by the readers, and had no effect on their eye movement patterns. Similar results were found in a word identification study (Rayner, McConkie, & Zola, 1980). Thus, if justification of images is based on visual similarity, this cannot be at the level of similarity of letter or word shapes. In pilot studies we have found that this result is not peculiar to text in alternating case; if only occasional letters are capitalized, but which ones are capitalized is changed from one fixation to the next, this is not detected by readers. Furthermore, changing spacing between words does not appear to be detected. Thus, it is not clear at this time what aspects of visual similarity might be used as a basis for justifying an image from one fixation with some generalized prior image.

Turning to another related issue, it has often been suggested that information from the same word may be obtained on more than one fixation (that is, that successive individual fixation spans may overlap) (Haber, 1976; L. Haber & R. Haber, in press; Hochberg, 1976; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Smith, 1971). This may allow information gained from the visual periphery on one fixation to facilitate perception of a word brought into foveal vision on the next fixation (Rayner, 1978b), it may provide a second opportunity to test a hypothesis but this time with greater detail (Hochberg, 1976), or may reinforce perception of words in other ways (Bouma, 1978; Smith, 1971). A series of studies employing a multiple-fixation word identification task demonstrated that information acquired from a word in the periphery on one fixation can reduce the time required to name the word on the next (Rayner, 1978b; Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980), though this may only occur when the set of words being used is known in advance by the subjects (McClelland & O'Regan, in press; Paap & Newsome, in press). Interference from having a word change from one fixation to the next during reading has also been reported (Rayner, 1975a; O'Regan, 1980). These results are all consonant with the notion that perceptual images are integrated across fixations.

On the other hand, recent studies in our laboratory have caused us to wonder whether such integration exists. If sentences are written in which either of two words differing in a single letter are appropriate at a given word location (<u>leaks</u> - <u>leans</u>, for instance), and the distinguishing letter is changed from fixation to fixation during reading, subjects are unaware of this, and it produces no effect on the eye movement patterns

(McConkie, Note 11). Apparently the words are not being read on two successive fixations, or one would expect the change in meaning to be detected. If groups of four words differing in only two letter positions are identified <u>mushy</u>, <u>musty</u>, <u>gushy</u>, <u>gusty</u>, for instance and sentences written into which any of the words fit appropriately, the word can be switched from one fixation to the next without the reader's awareness, as well.

The difference between studies in which changes in words cause detectable problems and those studies where it does not, lies in the fact that, in the latter studies, whatever combination of letters the subject obtains from those that are on the screen at one time or another, a readable rendition of the text results. In the earlier studies, this was not the case. Thus, it seems likely that changing letters and words from one fixation to the next is not itself a detectable event during reading; the only question is whether the text (letter sequence) as perceived yields an appropriate meaning. This in turn suggests that information carried across fixations during reading may not be of the form of global perceptual images so much as of local letters or word parts (McConkie & Zola, 1979; Rayner, McConkie, & Zola, 1980).

At this point, then, there is reason to doubt that perceptual images are being integrated during reading in the manner described earlier. Both bases for such integration have been called into question, and it is not clear exactly what type of information is being carried across fixations at a perceptual level. This raises questions about the relation of perception in reading to that of viewing scenes and events, and thus about what one learns perceptually in learning to read. These would be easier to deal with if more were known about perception in viewing scenes. But assuming that a composite image is formed in that case, in learning to read does one just develop a further way of using visual information from that image, or could it be that one learns a different way of responding to visual patterns, learning to attend to and use local detail for the purpose of reading, perceiving the meaning communicated, rather than forming composite images? The time is right for applying eye movement contingent research techniques to the study of perceptual learning in learning to read.

LEARNING ABOUT MENTAL PROCESSES FROM EYE MOVEMENT DATA

One motivation for studying eye movements and perception in reading has been the hope that, once this is understood better, it may be possible to use eye movement data to test hypotheses about higher mental processes. It may be that eye movement data

can even yield a word-by-word indication of processing time (Just & Carpenter, 1980; McConkie, Hogaboam, Wolverton, Zola, & Lucas, 1979). However, there are complexities in achieving this that must be recognized. For example: (a) When the eyes are centered on a word, it is not necessarily only that word that is being seen on that fixation. (b) The period of time spent fixating a word is not the actual time spent processing it, though there is a relationship between these times. (c) The length of the saccade following a fixation is probably not being directed on the basis of the full processing of the information utilized from that fixation, and just what aspects of the information are coming into play in that decision is not known. (d) Regressions are not necessarily stimulated by information gained on the fixation immediately prior to them, but can be the result of visual patterns on fixations previous to that. (e) There are correlations in the language itself which can easily mislead us in attempting to establish the cause of certain eye movement patterns. (f) As with any psychological research, averaged measures may not be an appropriate representation of the nature of the effect of a variable in individual instances. Further clarification of the relationship between eye movements and cognitive processes involved in reading is an important goal for future research.

In spite of these difficulties, eye movement data are proving useful in studying cognitive processes. Their use is fully justified in several situations. First, eye movement data can provide measures of reading time over larger regions of text (regions that require several fixations). Second, the existence of differences in eye movement patterns as a result of some text or display manipulation is evidence for the existence of processing effects of some sort, and the pattern of the differences can be a basis for speculating about the nature of those effects. Third, locating the time at which eye movement patterns are first affected by some variable places contraints on the time when the processes differentially affected by the different conditions took place. The existence of lagged effects on eye movement behavior makes it important that we recognize that the processes have occurred at least by the point at which differences are observed in the data; they may have occurred earlier. Thus, in several important ways, eye movement records can provide useful data in the study of cognitive processes in reading.

CONCLUDING COMMENTS

Considerable progress has been made in the study of perception during reading in recent years. New findings have

been advanced, and issues have been clarified. Much of this progress has resulted from research involving the recording of eye movements and, particularly, controlling aspects of the text display contingent upon those eye movements. With the base that has now been laid in both technology and theory, we can anticipate even greater progress in the future. We can expect to see answers coming forth on many of the issues raised in this paper, and to see these research techniques extended to study children learning to read and people having reading difficulty. Hopefully, this work will lead to the identification of specific types of perceptual difficulties where they exist, and may suggest standard diagnostic techniques. Finally, it seems likely that the general approach being taken in the study of perception during reading will be extended to the perception of complex scenes and events as electronic graphics technology develops.

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Table 1

Local Influences on Eye Movement Patterns

<u>Fixation durations are</u>:	
Longer on low frequency words.	Kliegel, Olson & Davidson, 1981; Rayner, 1977
Longer on technical words, where readers have a poorer technical vocabulary.	Buswell (cited by Kolers, 1976)
Longer on shorter words.	O'Regan, 1980, 1981
Longer when erroneous letters were in the periphery on the prior fixation.	O'Regan, 1980; Rayner, 1975-a; Underwood & McConkie, Note 5
Longer if foveal letters are replaced by a grating.	Rayner & Bertera, 1979
Longer when text is masked for the first part of the fixation, or during the fixation (if not too near the end).	Rayner & Pollatsek, 1981; Wolverton, 1979
Longer on less constrained words.	Zola, 1981
Longer on "semantically primed" words.	Kennedy, 1980
Longer on words if indirect, rather than direct, inference is required.	Just & Carpenter, 1978
Longer on certain grammatical elements.	Wanat, 1971; Rayner, 1977
Longer on first fixations on lines.	Woodworth, 1938; Rayner, 1977

Table 1 (Cont'd)

Longer on words containing spelling errors.	Zola, 1981
Longer in regions of text containing more important ideas.	Shebilski & Fisher, Note 6
Longer on numbers whose names have more syllables.	Pynte, 1974
Longer when there is a single fixation on a word rather than two fixations.	Kliegel, Olson & Davidson, 1981
Shorter on a letter than on dot or space in 3-fixation sequence.	Arnold & Tinker, 1939
Shorter at the end of a return sweep.	Huey, 1908
Shorter when they are the final fixations on lines.	Rayner, 1977
Shorter when they are at the beginning and ends of words, rather than in the center.	O'Regan, 1980
Shorter on fixations prior to and following regressions.	Stern, 1978
Shorter prior to wide blank spaces in the text.	Abrams & Zuber, 1972-73
Shorter in the region between sentences.	Rayner, 1975-a
Influenced by the length & frequency of words not directly fixated.	Kliegel, Olson & Davidson, 1981

Table 1 (Cont'd)

<u>Saccadic movements are</u>:	
Longer when a longer word lies to the right of the fixated word.	O'Regan, 1979
Longer following a fixation on a longer word.	O'Regan, 1979
Shorter when erroneous letters lie in the near periphery or when peripheral letters are replaced by a grating.	McConkie & Rayner, 1975, 1976; McConkie & Underwood, Note 2; O'Regan, 1980; Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner & Pollatsek, 1981
Shorter, and with more regressions, in regions of text that are more important.	Shebilski & Fisher, Note 6
More likely to be regressive if the text is shifted to the left during a saccade.	O'Regan, 1981; McConkie, Zola & Wolverton, 1980.
<u>Fixations are less likely to be centered on</u>:	
The word "the" than on a 3-letter verb.	O'Regan, 1979, 1980; Rayner, 1977
The region between sentences.	Rayner, 1975-a
Blank areas on the text.	Abrams & Zuber, 1972-73

Table 1 (Cont'd)

<u>Fixations are more likely to be centered on</u>:	
The centers of words, rather than the ends.	Rayner, 1979; O'Regan, 1981; Zola, 1981
A short word, if the word to the left is longer.	Rayner, 1979
A letter, if it is in a word of medium length, rather than longer or shorter.	Rayner & McConkie, 1976
A prior context sentence after encountering a pronoun.	Carpenter & Just, 1977

Figure Caption

Figure 1. Some critical times during the period of a fixation in reading. The line represents relative eye position as in a temporally based eye movement record. Taken from McConkie and Underwood (Note 2).