Word Processing in Reading: A Commentary on the Papers

Arnold D. Well
Alexander Pollatsek

The articles in this issue deal primarily with the perceptual aspects of reading. Questions are raised about what kinds of information are available and are particularly important in reading, as well as to how a variety of perceptual variables influence the reader. Characteristics of letters, words, and text are discussed, including possible features of letters and words, letter position within a word, delimiters between words, and size, type, case, and arrangement of print. The Brady and the Morrison and Inhoff articles give particular emphasis to the issue of what kinds of visual information are available at various eccentricities. On a more theoretical level, questions are raised about a number of processing systems that subserve reading, particularly those which isolate words, direct eye movements, and extract information about letters and words. The Ehrlich and Coltheart articles address some of these questions with evidence obtained from developing and abnormal readers.

There is little emphasis in these articles on linguistic analysis and higher-order aspects of reading such as comprehension, nor is there detailed discussion of the deployment of downward flowing higher-order knowledge. In fact for much of the work discussed, the story ends with the identification of a word, corresponding to what Ehrlich would refer to as access of the word in the lexicon as opposed to "word interpretation." It goes without saying that the issues discussed here address only a subset of those which must ultimately be considered in a comprehensive treatment of reading. However, we believe that the perceptual processes discussed here are a significant part of reading and that they can be investigated meaningfully without having to make detailed statements about higher level processing and about the nature of the interactions between downward flowing cognitive information and upward flowing information resulting from visual processing.

Of course, the assumption underlying this perspective is that the more perceptual aspects of reading operate with a minimal amount of adjustment

Visible Language, XV 3, pp. 287-308.
Well's address: Department of Psychology, University of Massachusetts, Amherst, MA 01003.

and direction from higher-level processes. This is inconsistent with theories of reading that depend heavily on hypothesis testing (e.g., Goodman, 1967) in which only a small part of the available visual information need actually be used by the skilled reader, and with theories (e.g., Rumelhart, 1977) inspired by heterarchical programs for understanding natural language such as Hearsay II (Lesser and Erman, 1977) in which a number of "knowledge sources" interact in a complex fashion.

We prefer to retain the notion of a basic bottom-up flow of information as a baseline against which more complex theories can be compared, both because we believe it is important to explore fully what lower-level perceptual information can provide and because theories that rely heavily on top-down control of information flow have a number of serious problems. First of all, the complex interactions among knowledge sources that characterize heterarchical accounts of reading are difficult to understand and analyze. If such theories are free to invoke control strategies in an ad hoc fashion they run the risk of being vacuous. Secondly, as discussed cogently by Brady, heterarchical programs did not work as well as had been expected in machine perception and, moreover, it repeatedly became evident in working with such programs that a small increase in early processing capacities could have a far greater impact on the performance of a program as a whole than a vastly greater amount of "higher level reasoning." Thirdly, there is little compelling empirical data in the field of reading that forces us to adopt complex interactive or hypothesis-testing models. Hypothesis-testing models are on particularly weak ground. For one thing, readers are not particularly good at anticipating specific words in normal text (McConkie and Rayner, 1976). For another, despite the fact that according to the hypothesis-testing position, readers should be able to identify highly predictable words without really fixating them, even target words that can be identified with 80%-90% accuracy in a cloze task are fixated most of the time in silent reading (Ehrlich and Rayner, 1981; Zola, 1981).

Ehrlich has reviewed a body of literature concerned with the influence of contextual processing on visual analysis. A number of studies provide evidence that the "visually driven" and "contextually driven" word identification systems are relatively independent in younger readers and that readers' dependence on contextual constraint for individual word identification decreases with age and level of skill (e.g., Biemiller, 1970; Perfetti, Goldman, and Hogaboam, 1979; West and Stanovich, 1978). While many studies demonstrate that context affects word perception – particularly when visual information is impoverished – we believe that existing data are consistent with the view that both context and visual processing can increase the activation of word detectors or logogens (Morton, 1969). While in this view contextual information can operate to reduce dependence on visual processing, the activities of lower-level perceptual processes need not be qualitatively altered from above.

THE USE OF PARAFOVEAL INFORMATION

Probably one of the greatest advances in reading research during the past decade has been the increase in knowledge about where in the para-fovea useful information can be extracted from during the reading of text and, to a lesser extent, how this information is used. This issue is dealt with in both the Brady and the Morrison and Inhoff articles.

First of all, what is the area of text from which readers can extract useful information on a given fixation? For fluent readers of English, the effective visual field extends leftward from fixation only 4 character positions or to the beginning of the currently fixated word, whichever is less (Rayner, Well, and Pollatsek, 1980). On the other hand, we know that information to the right of the currently fixated word is important. If all letter information to the right of the fixated word is removed in a moving window experiment, reading speed for single sentences declines from about 340 words per minute to about 210 words per minute, a reduction of about 40% (Rayner, Well, Pollatsek and Bertera, 1981). What information is available to the right of fixation? Experiments using spaced and filled text (e.g., McConkie and Rayner, 1975; Rayner and Bertera, 1979) have suggested that word length or word boundary information (i.e., information that the reader could use to "parse" the array into words) is available up to 15 character spaces to the right of fixation.[1] Information about specific letters is available up to perhaps 10 character spaces to the right of fixation and may serve to facilitate word identification on the current or future fixations.

Extraction of word boundary information.

The ability to extract information about word boundaries to the right of fixation is important for at least two reasons. As Morrison and Inhoff have indicated, a number of recent experiments suggest that word length information is the primary determinant of saccade length. Dunn-Rankin (1978), O'Regan (1980), and Rayner (1979) have clearly indicated that readers do not fixate on random positions within words. Readers tend to fixate the center of short and medium length words and somewhat to the left of center for longer words. Rayner (1979) and O'Regan (1980) have concluded that saccade length is primarily a function of the length of the word to the right of fixation. We also know that readers can extract information from letters in the parafovea (to be discussed in the next section). If letter features are to contribute effectively to word identification on the current fixation or subsequent fixations, they must be encoded in terms of their position within the word.

The importance of boundary information in reading has been investigated by eliminating and/or changing the space information in text and observing the resultant decrement in reading. However, care must be taken in making inferences from this procedure since it is difficult to remove word boundary information without otherwise interfering with the processing of text. Eliminating spaces between words not only removes the major cue for word boundaries, but because of lateral masking effects is likely to interfere with the processing of the letters previously adjacent to the space. Inserting filler characters into the spaces not only results in the same kind of problem, but also, to the extent that the filler looks like a letter, adds irrelevant features to the display. There is another difficulty in drawing conclusions about feature extraction or other early perceptual processing in the parafovea from the results of experiments such as those of Fisher (1975) and Brady. Such experiments produce varying degrees of inference, but it is not clear to what extent they are studying parafoveal processing. The experimental manipulations employed would be expected to produce a certain amount of interference in processing in the portion of text that is foveated as well.

In an experiment just completed, Pollatsek and Rayner (1981) manipulated which spaces were filled in, using the moving window procedure. In one condition, filler material was inserted into all spaces to the right of fixation (all-filled condition), while in another, only spaces beyond the first space to the right of fixation were filled (first-preserved condition). The text was otherwise unaltered.

When random lowercase letters were used as fillers, reading rate was about 130 words per minute in the all-filled condition and about 275 words per minute in the first-preserved condition, compared to about 310 words per minute in the control (normal text) condition. Thus most of the effects of filling spaces are due to filling the first space to the right of the fixated word. The first space usually falls within 2 degrees of fixation and will often fall within the fovea. The results from the first-preserved condition indicate that space information further out in the parafovea has significant but smaller effects.

Two interesting findings from the first-preserved condition were (1) fillers have no effect if delayed more than 50 msec from the beginning of the fixation, and (2) letters, digits, and "gratings" (which have minimal letter-like features) used as fillers all produce significant decrements in performance, although the letters produce slightly larger effects. These findings suggest that information at the position of the second "space" is extracted rapidly and is relatively crude, since gratings interfere almost as much as letters. It is still possible, however, that some of the performance decrement is due to interference with letter identification rather than to the loss of boundary information per se.

It is unlikely that any experimental manipulation will allow us to assess precisely the effect of boundary information per se. The identification of the fixated word is clearly interfered with by filling the first space to the right with a letter, and similar interference would be expected with other fillers to the extent that they share features with letters. Fillers that are relatively devoid of letter features may also be less effective in destroying boundary information. However, the best estimate of the effect of destroying boundary information we can offer is the 80-100 word-per-minute decrement in reading rate that results from filling all spaces to the right of fixation with gratings. Any underestimation of the word boundary effect that occurs because gratings are less than perfect space fillers will be partially offset by any masking of the boundary letters that interferes with their identification.

Extraction of letter information from the parafovea.

Although it is difficult to assess the exact size of the decrement in reading due to removing word boundary information, it is clear that more is available from the parafovea than information about word boundaries. In a recent experiment (Rayner, Well, Pollatsek, and Bertera, 1981), space information was preserved but letters to the right of the window were replaced by X's. Reading rate was about 210 words per minute when text only as far to the right as the currently fixated word was presented, 310 words per minute when an additional word was made available to the right, and about the same as in the normal control condition (340 words per minute) when two words were made available to the right of the fixated word. Thus readers extract more information about words to the right of fixation than where they begin and end, with the most useful information coming from the word just to the right of that currently fixated. To test whether readers are able to extract partial information about words to the right of fixation or whether they simply process one word on some occasions, two on others, and three on still others, subjects were presented with a window in which the fixated word and all text to the left was preserved and in which either one complete additional word was presented to the right or 0, 1, 2, or 3 letters of that word were presented (making sure never to present the whole next word in the 1, 2, and 3 letter conditions). All space information to the right of the window was preserved, but letters were replaced with others which could be either similar or dissimilar in appearance. Each additional letter presented to the right of the currently fixated word resulted in an increase in reading rate, and when letters outside of the windows were replaced by visually similar letters, presenting three additional letters had almost as large an effect as adding the whole word (301 words per minute as opposed to 329 words per minute). It thus seems clear that partial information can be extracted about words to the right of that currently fixated.

We agree with Brady that an extremely important question is how information extracted from a word in the parafovea is integrated with information extracted when that word is subsequently fixated. Two important experiments suggest that visual features of the type which specify the difference between uppercase and lowercase letters are not integrated across fixations during reading. McConkie and Zola (1979) presented lines of text in AlTeRnAtInG uppercase and lowercase. Subjects were instructed to understand the basic content of passages of text so as to be able to answer comprehension questions. During some saccades, the case assignments were reversed (e.g., MaNgRoVe became mAnGrOvE). During other saccades, no case changes were made. Switches of case assignments were not noticed by subjects and had no effect on eye movements. A similar finding (Rayner, McConkie, and Zola, 1980) with words displayed in letters of alternating case was that a word displayed in the parafovea facilitated the naming of the same word following an eye movement to that position, regardless of whether case assignments were switched or not. These data are inconsistent with the notion of an "integrative visual buffer" dicussed by Rayner (1978) and McConkie and Rayner (1976), since they suggest that it is more abstract information about letters that survives an initial fixation to facilitate processing on the next.[2]

We believe that such data can be handled adequately by a model in which letters activate a variety of detectors including case-specific letter detectors and abstract letter detectors. Letters in the parafovea will activate their appropriate detectors to a greater or lesser degree. Data from the two experiments cited above suggest that the activation of case-specific letter detectors by information in the parafovea does not survive beyond the current fixation. We think the same kind of explanation can account for the finding that the availability of "word shape" information outside of the window facilitates reading (e.g., McConkie and Rayner, 1975). As pointed out by Morrison and Inhoff, facilitation due to word shape is most likely a by-product of specific letter information. If a letter outside of the window is replaced by one with similar shape, there should be some activation of the detectors corresponding to the "correct" letter because of the features it shares with its replacement. We might add that this facilitation by letters of similar shape appears to occur only if the letters are located far enough from fixation not to be fully identified. The introspection in experiments in which letters outside the window are replaced by letters of similar shape is that one does not notice substituted letters as long as the window is as large as the fixated word. For such windows, however, one is aware that reading is progressing more slowly than normal even though nothing looks wrong.

To conclude this section, it should be noted that several of the typography effects described in the Morrison and Inhoff and the Haber and Haber articles seem explainable in terms of the use of parafoveal information. Short lines with few characters provide readers with reduced opportunity to use their parafoveal vision, and so it is not surprising that they result in reading decrements. Even if total line length is kept constant in terms of visual angle, the same explanation would seem to account for part of the decrement that occurs when large (14-point as opposed to 10-point) type is used. The importance of parafoveal vision is also consistent with the finding that fixation durations are particularly long on the first fixation on a line (for which no parafoveal information could have facilitated processing) and short near the end of a line (where there is less parafoveal information to be extracted).

PROCESSING WORDS THROUGH LETTERS

We will take as a first approximation or baseline model of the visual processing of words one that has a series of levels of detectors. First the word must be isolated from the rest of the display, or at a minimum the left-hand boundary must be isolated. Certain features are then extracted from positions in space relative to the left boundary and information from features in the same character positions is combined to provide information about letters. As evidence about letters begins accumulating, it can be used to identify the word. We know from many experiments (e.g., Carr, Posner, Pollatsek, and Snyder, 1979) that readers are sensitive to orthography. This knowledge could be represented in the model by inserting a layer of letter-cluster detectors between the letter detectors and the word detectors. A word presented in isolation would be identified when some weighted sum of the inputs from letter and letter-cluster detectors exceeded a threshold. Evidence presented in this section suggests that there is need to have both "abstract" letter detectors (in that their output does not contain information about visual characteristics of letters such as case) and detectors that are case specific.

The description of visual information about letters.

As discussed by Haber and Haber, two general categories of descriptions for information in letters have been proposed, template and prototype models on the one hand and feature models on the other. The arguments marshalled against template descriptions (e.g., Neisser, 1967), especially given our ability to read with ease from many different typefaces, have been considered sufficiently convincing to result in general agreement that description of letters is based in some way on separate features. However, as Haber and Haber point out, despite a century of research on the visual characteristics of letters, we know little about what these characteristics really are.

The methods used to determine the features of letters can all be criticized. They deal with letters in isolation, not in words. The reasoned intuition of one armchair psychologist is probably as good as that of another. Similarity scaling techniques require subjects to make similarity judgments about letters, not to identify them; moreover, the average data from a large number of subjects may not characterize the performance of individual subjects contributing to the average. There are severe problems in generalizing conclusions about features from error data obtained in various situations in which the stimulus is degraded. Haber and Haber point out that the particular way the stimulus is degraded may strongly influence which letters are confused and hence which features seem important. It is relevant to note here that Tinker (reviewed by Morrison and Inhoff) found that factors which make letters and words more readable in a number of threshold determination paradigms do not necessarily make them more legible in a normal reading situation.

While most work on features has been done with foveal presentation (where if error data were desired, performance decrements could be induced by limiting presentation time), we are becoming increasingly aware of the importance of featural information from the parafovea. It is by no means obvious that the relative importance of different features remains constant as eccentricity of presentation is varied. Here the Marr-Hildreth theory (Marr and Hildreth, 1980) described by Brady may provide a systematic basis for studying the kinds of featural information that is important at various eccentricities.

The techniques of computer pattern recognition may be able to give some insight into what minimal sets of feature detectors are sufficient for letter recognition in words. Performance with such sets of features could be compared with human performance across such manipulations as changing typeface, removing the upper or lower part of the line, etc.

Progress to date has been limited by the fact that there has been little in the way of theory to be tested. Candidates for feature sets have largely been generated on the basis of intuition, although a certain amount of inspiration has been derived from the work on single cell recording, especially the early work of Hubel and Wiesel (e.g., Hubel and Wiesel, 1962, 1968) and from the work on selective adaptation (e.g., Pritchard, Heron, and Hebb, 1960). Criteria for the adequacy of a feature set, such as that the number of features should be substantially less than the number of symbols to be described, and that the number of features should increase only slightly as new typefaces are added, seem too weak to reduce the number of contenders significantly. It should also be noted here that although descriptors such as lines, edges, and corners are consistent with our intuitions about what features should be, useful descriptors may be extracted from a level of representation that follows the filtering out of high spatial frequencies. Finally, as stated clearly by Haber and Haber, readers may very well capitalize on the redundancy of the situation by using a larger than minimal feature set. While this would make it difficult to demonstrate that any particular feature system is being used at a given moment, it is not inconsistent with models in which the input to each lettter detector is a weighted sum (some of the weights may be negative) of feature information. If that sum is greater than some preset value and/or significantly larger than the sums for the other letter detectors, the letter corresponding to that detector is available to be recognized. In such a model, there may be no single feature that is critical for the identification of a letter. "Defining" features may be missing or degraded (as when the bottom portion of the line is removed) but the letter identified with high probability and reasonable speed.

The case for abstract letter identities.

Coltheart argues strongly that there is a component in the reading system which is capable of assigning abstract letter identities (ALIs) to letters. ALIs are codes obtained from letters that contain information about their identities but no information about their visual forms (especially their case) and no phonological or semantic information, although phonological or semantic information may later be derived from ALIs. Although acknowledging difficulties in providing an account of the role played by ALIs in reading, Coltheart gives them a prominent role in his model for reading aloud and comprehending single words.

Several lines of evidence for ALIs are cited. Three separate studies with normal subjects (Scarborough, Cortese, and Scarborough, 1977; Rayner, McConkie, and Zola, 1980; Evett and Humphreys, 1981) all provide demonstrations in different tasks that responses to a word or nonword can be facilitated by prior presentation of a stimulus sharing at least some of the letters in the same position, even if the letters were presented in the opposite case. Also two interesting pieces of evidence come from work with individuals with brain damage. For example, a conduction aphasic who had a very severe impairment of the ability to derive phonology from print was shown to be able to perform without error in a same/different matching task with nonwords in which the two items in a pair differed in case (e.g., ANER/aner or ANER/aneg). Since neither direct visual matching (because of case differences) nor semantic information (because the strings were not words) can be used to perform the task and because the patient was unable to generate phonological code from print, the conclusion is that some additional abstract code must be involved. Other evidence is provided from work with deep dyslexics (Saffran, 1980). Moreover, the ALI cannot simply be regarded as the same thing as the name of the letter. The phonological dyslexic A. M. could match uppercase letters to their lowercase equivalents, but his naming of single letters was much impaired (Patterson, 1981).

While one might quibble with some aspects of the individual arguments, taken as a whole, they provide a strong case that there are components in the reading system capable of extracting and of using a code based on the abstract identities of letters. This ALI code can be used to perform tasks for which other relevant information is not available or in situations in which certain components which might otherwise contribute to task performance are not functional.

However, one can agree to the existence of ALIs without denying either the existence or utility of less abstract information about letters. Certainly subjects are able to discriminate among different visual forms of a letter, and capitalized and italicized letters probably provide useful information in fluent reading. FBI and Ruth have meanings that fbi and ruth do not. Presumably, however, for normal subjects there are a variety of tasks with words and letters that can be performed with either the ALI or less abstract, case-dependent codes. From this perspective, it is not surprising that tachistoscopic report should be worse (albeit only slightly) for case-alternated words like GaRdEnEr than for GARDENER or gardener (Coltheart and Freeman, 1974). It seems that there must be separate detectors for uppercase and lowercase letters since readers must be able to identify case while reading. Case can convey meaning and for at least some letters (e.g., a, d, r,), the feature sets for the uppercase and lowercase versions must be quite different. Presenting words in alternating case may force the subject to change the set of potentially active letter detectors and should incur some cost in reading. Moreover, alternating-case words are extremely unfamiliar.

An important question is whether, if normal subjects routinely extract both ALIs and case-dependent letter codes, the two codes have specialized roles in reading. As mentioned earlier, there is some evidence to suggest that it is abstract information about letters in the parafovea that survives the current fixation to facilitate identification when those letters are subsequently foveated (e. g., McConkie and Zola, 1979).

The use of word shape information.

If we accept for the moment that some sort of feature model is sufficient to account for the recognition of letters, it is still conceivable that we use additional visual information to help us recognize words. The additional visual information most often considered is word shape, that is, visual information about the entire word such as its overall outline (e. g., Haber and Haber, Figure 6). We feel the evidence that readers use such information over and above letter information is weak. In fact, since word shape information is confounded with letter shape information, it may not be possible to show that word shape information per se is important in reading.

A number of experiments performed by McConkie and Rayner (e. g., McConkie and Rayner, 1975; Rayner, 1975) have been interpreted as suggesting that word shape is an effective parafoveal cue. For example, McConkie and Rayner (1975) manipulated the availability of word shape information outside the window by replacing letters with other letters that were either visually confusable (in which case shape was preserved) or nonconfusable (in which case shape was disrupted). They found that the former condition resulted in shorter fixation durations, suggesting that readers were able to get more useful information from outside the window when shape information was preserved. The problem in interpretation is that some visual information about letters was also preserved in the former condition (since, after all, replacement letters were chosen to be confusable with the originals) as well as information about overall word shape. As mentioned earlier, Morrison and Inhoff have reviewed several subsequent experiments suggesting that the facilitation due to word shape is a by-product of specific letter information.

An estimate of the importance of word shape is supposedly given by comparing reading speed in normal text with reading speed in text constructed entirely of uppercase letters, in which little word shape information is available. Haber and Haber interpret the 5-10% difference in reading speed favoring normal (mixed case) type (Smith, 1969; Fisher, 1975) as suggesting that word shape is important. Unfortunately, even this manipulation does not entirely unconfound word and letter shape. It is possible that the exclusive use of uppercase text removes valuable cues that could be used to identify certain letters (especially ascenders). Uppercase text is also far less familiar to readers than normal text and deprives readers of the information that capital letters normally convey (proper nouns, beginnings of sentences). Given all this, we are impressed with how well people can read uppercase text.

In another type of experiment, Haber, Haber, and Furlin (1980) asked college students to read text which appeared on a CRT. A certain amount of text was presented, ending in the middle of a sentence. Subjects were asked to guess the next word, given different kinds of information, including length and word outline. Although we find it interesting that subjects were able to guess more accurately when they were given the outline shape of the word, we are reluctant to conclude from this that shape information is important in reading. First, we would expect judgment in such an experiment to be much slower than identification of words in reading (or even in isolation). Secondly, the "word shape" information is also information about letter shape, and may well be processed through the usual letter detection channels, supported by the surrounding context.

Importance of certain letter positions.

Three of the articles in this issue make reference to the fact that information from the extremities (especially the beginning) of words may be particularly important in reading. This may be the case for a number of reasons. As the extremities of words are bounded on one side by a space, they are less subject to lateral masking, a particularly important consideration for words in the parafovea (Bouma, 1973; Rayner, McConkie, and Ehrlich, 1978). Although Bouma (1973) found the most eccentric letter of a word in the parafovea to be more perceptible than the initial letter, a number of studies have suggested that it is the beginning parts of the word which are most important. The Ehrlich and the Morrison and Inhoff articles review evidence from a number of different paradigms which suggests that the beginning parts of words are particularly important both for children (Marchbanks and Levin, 1965; Rayner and Kaiser, 1975; Ehrlich, 1979) and adults (Oleron and Danset, 1963; Broerse and Zwaan, 1966; Rayner, McConkie, and Ehrlich, 1978). Ehrlich points out that at least for children, attention to beginning letters is encouraged by instruction which requires them to sound out words and may be related to the salency of beginning phonemes in auditory speech comprehension (Marslen-Wilson and Welch, 1978; Cole and Perfetti, 1980).

What are the implications of this discussion for an optimal typography? The first is that the legibility of the type will largely be determined by the ease of identification of individual letters, since "word shape" is probably relatively unimportant. The optimal type will probably most closely match the modal features for the various letters. However, the weightings given the different features will depend on the typographical experience of the reader and are probably not fixed. Readers have some ability to modify aspects of their performance when presented with a novel typeface in a manner analogous to that of a listener of English who can adapt rapidly with experience to understand more easily English spoken with a foreign accent. The ability of readers to adapt to novel typefaces seems like an interesting problem to study – one that might shed some light on the whole problem of letter identification. While intuition seems like a good guide in that most commonly used typefaces are probably adequate, the work described by Brady represents a promising step towards making font design less subjective.

EVIDENCE FROM WORK WITH READING DISORDERS

Normal silent reading is such a complex activity and proceeds with so few overt signs of how processing is taking place that it is extremely difficult to study. There have been a variety of approaches taken to render the study of reading more tractable. One approach is to study carefully those overt measures that may serve as indices of cognitive activity – hence the current emphasis on studies dealing with eye movements. Another approach is to study performance in simpler tasks, on the assumption that the components of the system used in performing these tasks are used in normal reading and that the components operate in essentially the same way in reading as they do in the simpler tasks. One implicit assumption often made is that the various components enjoy a certain amount of independence of operation. One way of testing this assumption is in working with other than normal adult readers. Developmental studies can be used to demonstrate that activities attributed to different components of the system change in different ways with age. For example, the findings of Biemiller (1970) that the numbers of graphically constrained and contextually constrained errors in oral reading follow qualitatively different courses as reading skill develops are interpreted as indicating that the contextually driven and the visually driven word identification systems are relatively independent.

Similarly, evidence from abnormal adult readers could be used to provide support for models of the reading system such as the modified logogen model displayed in Coltheart's Figure 1 which depends on a number of separable components. If one conceives of the reading system as consisting of a number of components and if one further assumes that anatomical considerations are such that some components may be rendered dysfunctional by brain injury while others are spared, then certain dyslexic syndromes should be readily and economically explained within the proposed model in terms of the impairment of certain components or the communication of certain components with one another. If such syndromes are found, then our confidence in models consisting of separable components is strengthened.

Some limitations.

The work with acquired dyslexias has indeed provided evidence that supports models of the sort described in Coltheart's Figure 1. However, several things should be noted: (1) Patients with the kinds of dyslexias discussed in the Coltheart article have been described almost exclusively in terms of their performance on simple tasks dealing with isolated words or nonword letter strings. Presumably, there are other, more subtle forms of acquired dyslexia in which performance with single words is spared, but some other aspects of reading text for comprehension are impaired. We know little if anything about these kinds of acquired disorders. (2) Although we believe that knowing how individuals read aloud and comprehend single words will help us to understand how words are processed in reading text for comprehension, it should be remembered that the reading of isolated words differs in some potentially important ways from the reading of words in text. For one thing, simple tasks like reporting words and letters, matching pictures with words, judging whether a letter string is a word or not, and judging whether two words are synonymous are quite different from reading text for meaning in which the goal is to process words in order to extend one's representation of the message being communicated. In addition, in normal reading words are usually fixated once, or perhaps twice, and although there is a tendency to fixate the words in a "preferred viewing position" (O'Regan, 1980; Rayner, 1979), many words are not fixated in this fashion and some are not fixated at all. Moreover, in normal reading, some information from the word currently fixated was probably extracted on the previous fixation when the word was in the parafovea. In tasks with individual words, the words are either presented foveally or are subjected to many fixations. (3) It is easy to oversimplify the characterization of the dyslexic syndromes and Coltheart has done an excellent job of keeping us aware of the complexity and variety of symptoms that occur within the different classifications. Certain symptoms seem explainable in terms of the impairment of one component of Coltheart's model. For example, phonological dyslexia seems to result from the impairment of a nonlexical phonological recoding mechanism. On the other hand, surface dyslexia, although often described in terms of the impairment of the lexical phonological component of the system, is in fact characterized by three separate types of errors. Two of these can be explained in terms of a failure of "visual reading" which forces the surface dyslexic to access the word comprehension mechanism using one or the other of the two types of phonological recoding. The third category of error is more difficult to explain. Six separate impairments in the model of Figure 1 are required to account for the variety of symptoms experienced by deep dyslexics. This fact forces Coltheart to consider the possibility that in deep dyslexia, the processing of linguistic stimuli is handled by an entirely separate system, one associated with the nondominant hemisphere. (4) It should also be noted that for certain syndromes, relatively few individuals have been studied. For example, it seems that data exist for seven phonological dyslexics (of which only one has been systematically tested for word comprehension), 22 deep dyslexics, and one woman suffering from what is termed an "unnamed dyslexia." In some cases it is possible to feel fairly confident about the nature of the symptoms despite the small number of subjects (e.g., all nine types of symptoms displayed by deep dyslexics are apparently experienced by all patients), although in other cases it is not (e.g., for phonological dyslexics, several patients were more likely to misread function words than content words, but this was not true for other patients classified as phonological dyslexics).

Alternative routes to phonology.

One of the major findings arising from work with acquired dyslexias is firm evidence for distinguishing between two distinct mechanisms for deriving phonology from print: (1) a nonlexical mechanism which can be used to read aloud letter strings that have not been previously seen and for which no specific information could have been stored regarding their pronunciation, and (2) a word pronunciation or lexical mechanism which can only be used for letter strings that have been seen before and for which the reader has previously stored information about pronunciation. This lexical mechanism would be required to pronounce correctly irregular words such as "one" and "two." It might seem obvious without any neuropsychological evidence that there must be two separate systems, since we know that normal readers can read both nonwords and irregular words aloud correctly. Indeed, until recently there has been broad support (e.g., Coltheart, 1978) for assuming that nonwords are read using grapheme-phoneme correspondences (GPCs) and words, especially irregular words, are read by accessing some previously stored phonological information. However, Glushko (1979) has recently found results that are inconsistent with the assumption that nonwords are read only using GPCs. In fact it is argued that the same mechanisms are responsible for the pronunciation of both words and nonwords. Coltheart presents neuropsychological evidence that there is a double dissociation between words and nonwords, suggesting that each of two possible routes to phonology may be impaired while the other remains intact. Phonological dyslexics have a severe impairment in their ability to read nonwords aloud although their ability to read words aloud is intact, at least for single-morpheme content words. On the other hand, surface dyslexics have more difficulty in deriving phonology from print from words than nonwords, since they tend to "regularize" irregular words.

The implication is that in addition to a lexical phonological mechanism which can be used in pronouncing words correctly, there is a nonlexical phonological mechanism that can be used with nonwords and which has difficulty producing the correct pronunciation for irregular words. It should be emphasized that the term "nonlexical" here means *only* that the mechanism can be used to determine the pronunciation of letter strings which do not have lexical entries. In order to accommodate Glushko's findings, the possibility is left open that the nonlexical mechanism can make use of lexical information. How the mechanism may make use of lexical information but not in such a way as to be able to access the specific information that would allow it to produce the correct pronunciation for irregular words is not known, but it seems like a reasonable assumption that the mechanism should be able to produce the correct pronunciation for regular words as well as nonwords.

What is the role of the nonlexical phonological system in reading words?

If we accept the existence of the two mechanisms, then the phonological representation of unfamiliar nonwords must be provided by the nonlexical mechanism, the correct phonological representation of irregular words must be provided by the lexical mechanism, and either mechanism can provide the correct phonological representation for regular words. It seems as though both systems must operate smoothly in parallel since we do not experience much "changing of gears" as we read regular and irregular words and encounter letter strings for which we have no lexical entries (e. g., unfamiliar city names). Evidence that regular words are read aloud more rapidly than irregular words (e. g., Baron and Strawson, 1976) suggests that the nonlexical mechanism is not used only for unfamiliar nonwords, but also can participate in the reading of words. One view of how this participation might take place is in terms of a "race" between the lexical and nonlexical phonological mechanisms. However, since we rarely regularize irregular words when we read them aloud, it does not seem likely that the lexical phonological mechanism can ever lose the race when words are presented. Perhaps the output of the lexical mechanism is weighted more heavily than the output of the nonlexical mechanism (of course, the lexical mechanism will have little if any output when unfamiliar nonwords are presented), so that conflicts will almost always be adjudicated in favor of the lexical system when words are presented. When regular words are presented, the redundancy of the outputs of the two mechanisms will allow reading aloud to take place more rapidly.

Of course, the ideal way to study the importance of the nonlexical phonological mechanism would be to render this mechanism nonfunctional while leaving intact all other components associated with reading. From the evidence reviewed by Coltheart, it seems that we might come close to this situation with phonological dyslexics. Phonological dyslexics have great difficulty reading nonwords aloud although they can read single-morpheme content words correctly. They do, however, have difficulty reading some function words and tend to make derivational errors. Comprehension has been systematically studied in only one phonological dyslexic (Patterson, 1981). Although the patient's performance in the lexical decision task was good, as was his performance in other word comprehension tasks such as judging whether pairs of single words were synonymous and matching words to pictures, there seemed to be comprehension difficulties for certain function words and there were certain derivational errors in comprehension (the patient had difficulty in choosing which of two derived forms of the same root morpheme was the one that fitted correctly into a sentence frame).

There are two possible interpretations of these findings. It is possible that the nonlexical phonological mechanism plays some necessary role in reading words, particularly function and derived words. This finding is consistent with the rapidly growing literature which suggests that entries in the word recognition component or lexicon correspond not to words but to root morphemes (e.g., Taft and Forster, 1976; Taft, 1979). Of course, on the other hand, it may be that phonological dyslexia is too complex to be characterized simply in terms of an impaired nonlexical phonological mechanism.

Alternative routes to comprehension.
Work with surface dyslexics suggests that there are at least three ways of accessing the comprehension component of the reading system—one visual and two phonological. In surface dyslexia it appears that there is a failure of "visual reading" which forces the reader to access the comprehension component via one of the phonological mechanisms. For example, the word "none"

may be pronounced and comprehended as "nun" or it may be pronounced and comprehended as "known." In the former case, the interpretation is that phonology has been derived using the lexical mechanism, so that pronunciation is correct for the irregular word "none" even though there is confusion with homophones since only the phonological representation is used to access the comprehension component. In the latter case, phonology has been derived by the nonlexical mechanism, resulting in errors in both pronunciation and comprehension.

We do not have space here to discuss some of the other interesting findings reviewed by Coltheart (e.g., the "number sparing" observed in word-form dyslexics which suggests that different systems are used for numbers than for linguistic stimuli; the finding that the patient with the "unnamed dyslexia" could read irregular words aloud correctly with no understanding, indicating again that stored information about pronunciation can be accessed without the access of meaning). We do, however, strongly believe that this body of literature provides useful information for the study of normal reading. As mentioned earlier, models of reading consist of separate components. Work of the sort reviewed by Coltheart helps us understand what these components might be and to what extent they may operate independently of one another. The fact that most of the disorders reviewed here can be explained economically in terms of the model presented in Coltheart's Figure 1 (the glaring exception being deep dyslexia) increases our confidence in this kind of model. In addition, the importance of certain issues (e.g., the role of the nonlexical phonological system in reading aloud and understanding function words and derived words, and the related question of whether entries in the word recognition component consist of root morphemes) is emphasized for future research with both dyslexics and normal readers.

Summary

The articles contained in this issue address a variety of topics but are primarily concerned with the perceptual aspects of reading. In our attempt to integrate some of this information, we have emphasized a number of points.

We believe that the lower-level perceptual aspects of reading can be studied in a meaningful fashion without addressing higher-level linguistic variables in detail. While there is a temptation to invoke complex top-down or interactive models, the nature of the interactions in heterarchical accounts of reading is difficult to analyze and understand. We see little value in models that can explain almost any possible result that could be obtained. Brady has shown that findings from the reading of transformed text can be accounted for without postulating complex interactions between early perceptual processes and downflowing conceptual information; moreover, Ehrlich has reviewed evidence suggesting that the visually driven and the contextually driven word identification systems are relatively independent in younger readers and that readers' dependence on contextual constraint for individual word identification decreases with age and level of skill. While contextual information can operate to reduce dependence on visual processing, it is not necessarily the case that such information alters the activities of lower-level processes.

One of the most important recent developments in the study of reading has been the increase in knowledge about what information is available from the parafovea in reading. Much of this information has been made available by the moving window procedure, although Brady reviews a number of important theoretical developments. Considerable progress has been made in learning from where in the visual field word boundary and letter information can be extracted during reading, and a good deal of work currently in progress is aimed at determining the time course of the extraction and processing of this information. One extremely important issue that we do not think is understood very well is how information is integrated across saccades. With regard to this issue, it seems that reading may differ from other kinds of visual activities in that integration does not seem to occur via any mechanism that might be termed an integrative visual buffer. Rather, integration in reading seems to depend on some more abstract representation.

According to our view of reading, words are identified through information about letters. Haber and Haber review in some detail the difficulties encountered in characterizing the information about letters that is used in reading. Brady, Ehrlich, and Morrison and Inhoff all indicate that information from the extremities of words may be particularly important in reading. Considerable evidence is adduced that the beginning parts of words are particularly important for both children and adults. Coltheart makes a strong case that an abstract letter identity code which is not the same thing as the name of the letter and which contains no visual information exists and plays an important role in reading. Haber and Haber consider the possibility that information about the overall configuration of the word, over and above the information about letters, is important. We believe the evidence that word shape information is used in reading is weak and, moreover, that there is a high degree of confounding between word shape and letter shape.

Both the developmental work reviewed by Ehrlich and the work with reading disorders reviewed by Coltheart provide evidence which suggests that the system used in reading consists of components that have a certain degree of independence of operation. We find, for instance, that the work with surface dyslexics and phonological dyslexics seems to have established that there are both "lexical" and "nonlexical" routes to phonology, although how the nonlexical mechanism functions and what role it plays in the reading of words is still poorly understood. We feel strongly that the work with reading disorders will provide information useful for the generating and testing of models for reading and will lead to certain questions that will stimulate research with both dyslexics and normal readers.

Haber and Haber, Morrison and Inhoff, and Brady all deal with issues relating to typography. While many issues are raised, a number of typographical effects can be explained in terms of the use of parafoveal information. We also think that the legibility of type will largely be determined by the ease of identification of individual letters, since word shape is probably relatively unimportant.

1. Although the perceptual span experiments employing the moving window procedure have confounded number of characters with visual angle (there generally being either three or four characters per degree of visual angle), recent work reported by Morrison (1982) and O'Regan (1982) seems to establish conclusively that the appropriate metric is number of characters.

It should also be noted here that the perceptual span is defined as the area around the point of fixation from which information useful in reading can be extracted. Operationally, the perceptual span is defined in terms of how close to the point of fixation a mask or mutilated text can encroach before reading performance is affected. If the momentary perceptual span varies from fixation to fixation or varies within a fixation, the moving window procedure will provide an estimate of the "maximum" span; namely, the area around fixation from which information may be extracted at least some of the time during reading. The nature of this measure may complicate the interpretation of developmental studies in which *average* saccade length increases with age but (maximum) perceptual span does not.

2. McConkie (1982) has recently reported a number of experiments that provide even stronger evidence against the notion of an integrative visual buffer. For example, readers do not notice when the uneven spacing between words is altered during a saccade.

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