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COVER. The reading and free viewing eye movement scan patterns were recorded on the HEL oculometer, Aberdeen Proving,Grounds, Maryland. The lines represent saccades while the angles (in circles) indicate fixations and their location. The larger the circle the greater the duration of fixation with a mean of approximately 240 msec. Thanks go to Dennis Fisher, Robert Karsh, Francis Breitenbach, and Dianne Barnett.

Children's Word Recognition in Prose Context

Susan F. Ehrlich

Research is reviewed in which children's processing of individual words is examined in prose context. This research includes studies of oral reading errors, word recognition experiments where context is artificially introduced, studies of the effects of repeated text manipulations, and observations of on-line effects of individual text manipulations. Taken together, these sources of data suggest that the reader's dependence on contextual constraint for individual word identification decreases with age, even though sensitivity to the constraints of context increases. This sensitivity may allow faster interpretation of individual words with respect to the emerging conceptual text structure. Some research is reviewed, however, which suggests that word identification may continue to be influenced by contextual constraint for older children and adults under certain circumstances.

In order to gather information from prose, the developing reader uses a variety of complex perceptual and cognitive processes. There is a great deal of variation in the demand put on the reader as he or she moves through the words on a page. The reader adjusts strategies to meet the level of difficulty of the text in terms of the clarity of the print, the familiarity of the words, the complexity of the syntax, and in terms of familiarity with the subject matter. In order to obtain a complete understanding of children's strategies for individual word recognition, visual analysis must be examined in conjunction with the simultaneous demands put on the child by each of these levels of processing. This paper will be concerned with various types of research on children's visual analysis of words in prose.

Probably the greatest challenge for this kind of research is to devise procedures which can isolate effects pertaining to particular words from the rest of the discourse. In general, global measures of reading time and comprehension cannot reveal such specific processing effects. Perhaps because of this difficulty, most of the research in word recognition has dealt with

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isolated words (Gibson and Levin, 1975; Barron, 1980). While such research effectively isolates processing applied to individual words, it also eliminates contextual variables that may alter visual analysis strategies in both positive and negative ways.

Comprehension requires that the reader develop a memory representation that establishes the relationships between the various concepts that are referred to in the text. This often requires that the reader draw inferences concerning concepts using other concepts that are not explicitly provided in the text (Schank, 1972; Haviland and Clark, 1974). In this sense, reading is an active building process. The comprehension process may have a positive effect on individual word recognition if context dictates that a concept with particular characteristics must be represented either explicitly or implicitly in the text structure. The greater the number of constraints for a particular concept in the emerging structure, the greater the potential that words in the lexicon that are consistent with those constraints may be primed (Morton, 1969). Priming may thus reduce the amount of visual processing required for identification. A number of researchers have suggested that the influence of constraint on word recognition is very strong (Goodman, 1965, 1967; Kolers, 1970; Levin and Kaplan, 1970). Others have argued the processing of contextual constraint is too slow to allow a strong influence on word recognition at least for adults whose perceptual analysis is comparatively fast (e.g., West and Stanovich, 1978). Evidence for the relative contributions of contextual and perceptual analysis for the developing reader will be reviewed below. A general conclusion will be drawn, consistent with statements by Perfetti and Roth (1980), that the reader's use of each of these sources of information is dependent on their relative availability. It will be emphasized that there is a tremendous flux in the amount and type of constraining information that is available to the reader as he moves through the text.

Note that the debate about the influence of contextual analysis has been clouded by a lack of clarity about what is meant by "recognition." There is a sense in which a word has been recognized if a representation for that word has been created within the reader's conceptual network, independent of whether or not the word on the page actually received visual analysis. This kind of recognition will be termed "word interpretation." Recognition may also mean access of a specific item in the lexicon, independent of the function of that word in the text structure. Clearly arguments about the importance of context for word recognition will differ depending on which of these two types of recognition are being referred to. This problem will be addressed below.

Some evidence will be presented which suggests that the analysis of contextual information may actually have a disruptive effect on visual analysis. If the structure building processes encounter difficulty, limited attentional capacity may be diverted away from perceptual analysis. This may be particularly disruptive when word decoding requires active attention as for beginning readers. Difficulties in conceptual analysis may also disrupt communication between perceptually driven analysis and the developing memory structure. A word might be identified via perceptual analysis but insertion of that word into the conceptual structure may be blocked due to the fact that the focus of the comprehension process is directed to some other aspect of the structure at that particular moment. Contextual disruption has received less attention than contextual enhancement in the literature.

The types of research which attempt to provide a discourse environment but also allow for measurement of processes that are influenced by or applied to individual words include (1) studies of reading errors, (2) measurements of various responses to individual words where context is artificially introduced, (3) observations of general effects of repeated text manipulations, and (4) observations of specific effects of individual text manipulations. Each of these types of research will be discussed in turn.

Observation of oral reading errors

A number of studies of reading errors have been reported which reveal various aspects of the interplay between visual analysis and higher level processing. One of the best known studies was done by Weber (1970) who observed the errors made by first graders as they read basal readers. She found that about 90% of the errors were grammatically consistent with context up to the location of the error. Weber reported that ungrammatical errors were more likely to be graphically consistent with the printed words than grammatical errors, suggesting that those ungrammatical errors were based on perceptual analysis that was independent of any interpretive processes, while the grammatical errors were primarily driven by the interpretive system. In her study, the graphic similarity of errors was measured by counting the number of letters common to both the substituted word and the printed word. Because this measure was averaged over letter location, no information about the relative salience of particular graphic cues was available. We have learned from other studies to be described that certain visual cues are particularly salient for young children and perhaps these cues were preserved in the error responses (see below). Results similar to those found by Weber are reported by Clay (1968).

In a related experiment, Biemiller (1970) observed a developmental change in the types of errors made by children even in the first grade. He observed that at a certain stage, children made a large number of non-responses (NR) which seemed to reveal that they were unwilling to make guesses even though they had trouble decoding the words in question. This stage occurred at different periods throughout the school year for different children. Biemiller hypothesized that the types of errors made before, during, and after this NR stage would differ. He found that before the NR stage, children made a large number of errors that were not graphically similar to the misread words (79%). During the NR stage, the relative number of graphically similar errors increased and this trend continued into the post-NR stage. Although errors were highly contextually constrained during the pre-NR stage (79%), such constraint lessened during the NR stage (66%) and increased again during the post NR stage (82%). Apparently, by the third stage, children were beginning to coordinate graphic and contextual cues in order to identify the words. Again we seem to have evidence of the relative independence of the contextually driven and the visually driven identification systems for the younger readers. In Biemiller's study, graphic similarity was assessed by simply noting whether the first letter of the misread word was the same as that of the word printed on the page. Studies using matching to sample tasks have shown that dependence on first letters becomes prevalent during the transition from kindergarten to the first grade (Marchbanks and Levin, 1965; Williams, Blumberg, and Williams, 1970; Rayner and Hagelberg, 1975), while dependence on more subtle graphic features at the ends of words appears to become more important as readers become more experienced (Rayner,1976). A dependence on first letters has also been reflected in the errors of 9- and 10-year-olds in reading isolated words, however (Shankweiler and Liberman, 1972).

It seems clear that a child's use of interpretive analysis vs. perceptual analysis should be dependent on the type of instruction received. Barr (1972) has presented some data showing differences between children who were taught with the sight word method and the phonics method. Errors made by children instructed with the sight word method tended to be limited to the words that had previously been learned, while children taught with the phonics method made fewer non-response errors and were likely to produce nonsense responses. Many more of the errors made by the phonics group included the first letters of the word printed on the page, perhaps because of the left-to-right "sounding out" strategies promoted by that method. Barr pointed out that the sequence of phases found in the Biemiller study may have reflected a transition from more global sight word recognition strategies to strategies that employed more structural analysis.

Although an instructional emphasis on dependence on context might result in some unwanted errors of identification, Goodman (1965) has suggested that such dependence actually increases identification accuracy overall. He found that more words were correctly identified in prose context than in isolation. Goodman has gone as far as to say that guessing word identities on the basis of contextual constraint is an important aspect of adult reading, so that instruction should provide the student with this skill (Goodman, 1967). Here guessing implies that identification of a word occurs prior to any use of visual input, presumably through the use of interpretive processes.

Juel (1980) observed reading errors in sentences that were specifically designed to control contextual constraint and word characteristics such as frequency and regularity of phonetic pattern. She found that fewer errors were made in sentence context than in isolation and that the more constraining the context in the sentences, the fewer the errors. The strength of the context effect decreased with reading ability for her second and third grade subjects, while the number of errors also generally decreased. This weakening influence of constraint with ability seems inconsistent with Goodman's strong hypothesis testing description of reading.

Studies with adults have shown that their reading errors also tend to be consistent with context. Stevens and Rumelhart (1975) found that 98 percent of substitution errors that were recognizable as words were grammatical, while Kolers (1970) reported that 70 percent of errors made while reading transformed text tended to be consistent with the part of speech of the misread word. Otto (1977) examined the relative contributions of syntactic, semantic, and graphic features to reading errors using low achieving college freshmen as subjects. She observed that a much higher proportion of the errors of the freshmen were highly graphically consistent (56% of the errors contained two "parts" of the printed word) than were highly semantically consistent with the text (16% of the errors maintained the meaning of the sentence), although these categories were not mutually exclusive. Twenty-five percent of the errors were grammatically consistent with the entire sentence. Otto interpreted these results as suggesting that these subjects were more dependent on graphic cues than on meaning for making decisions about word identity. These conclusions must be viewed with caution, however, because it is doubtful that the context in the prose provided sufficient constraint to allow selection of a word that would not alter the original meaning of the passage, in the absence of visual cues. Perhaps a better criteria would have been to observe whether errors were consistent with context up to the locations of the errors. This was the technique used by both

Weber and Biemiller. Otto presents an interesting analysis, however, of the freshman's self corrections. These corrections revealed that the readers had means of monitoring the degree to which their initial lexical choices were consistent with the memory representations of the meaning of the passage that they were developing. The more incongruous the errors with respect to the syntax, semantics, and graphics of the text, the higher the likelihood that they would be corrected. It is particularly interesting that when errors were highly graphically similar to the original word but semantically inconsistent, self corrections were less frequent, suggesting that these readers did not always attribute their confusion about meaning inconsistency to errors in visual analysis. Otto also found that subjects made fewer self corrections in more difficult text. This may be an indication that higher level comprehension difficulties may actually distract attention away from visual analysis. As in the studies of children's reading errors, only graphic similarity averaged over letter position was reported, providing no information about the relative importance of various visual cues for these readers.

It seems clear that there is more information to be gleaned from studies of reading errors through careful analysis of the graphic characteristics of the errors and also through analysis of the structure and content of the context in which they occur. Because the errors are produced under conditions where graphic features are not manipulated, these studies provide important information that is not available under experimental conditions where such manipulations are used and where guessing is encouraged.

Artificially introduced context

A general technique which has produced quite a bit of useful information is to provide subjects with context in advance of the individual words under study, and measure responses to those words as a function of the type of context used. The physical stimulus that is presented after the contextual material has differed from study to study. At one extreme are the studies using the "cloze" procedure in which no physical stimulus is given in the location of the critical word. With this technique, subjects are asked to guess which words belong in particular locations. In general, it has been found that the likelihood of selecting the exact words that have been omitted is a function of word class (Aborn, Rubenstein, and Sterling, 1959) and not too surprisingly a function of the size of the set of words that are consistent with context (Weaver, Kingston, and Dinnan, 1970-71). It has also been demonstrated that subjects' ability to select a word to fit into a moderately constraining context sentence that is presented aurally increases with reading ability (Perfetti and

Roth, 1980). These studies remind us that it is sometimes possible for subjects to guess words correctly in the absence of any visual information at all.

Some studies with adults have shown increased tachistoscopic word recognition accuracy when constraining context is available (Tulving and Gold, 1963; Morton, 1964). Note, however, that restricted visual analysis is forced on the subject because of the impoverished conditions of the stimulus words that are presented at short durations. A similar result has been shown for children using a different kind of task. Pearson and Studt (1975) asked children in first and third grade to guess the identity of words that followed sentence contexts. The sentences created high, moderate, or low constraint for the missing words. After each incorrect guess, the children were provided with a letter of the missing word. Pearson and Studt counted the number of letters required for a correct guess as a function of the level of contextual constraint. In the high constraint conditions, far fewer letters were required for correct identification for both grades. It was also found that far more guesses were needed for high vs. low frequency words. The advantage of context was much less pronounced for the low frequency words, although the constraint of the sentences may not have been as strong for those words. This study provides evidence that young children, like adults, can use context to reduce the amount of visual analysis needed for correct identification. Keep in mind, however, that guessing is encouraged in these tasks. It is suggested here that visual analysis may well proceed independently from the interpretive analysis that is used as the basis for making such guesses.

Perhaps consistent with the theory that context allows a reduction in the amount of visual analysis applied to words, is a suggestion made by a number of researchers that context facilitates word recognition by increasing the amount of information that can be extracted from a single fixation. If less visual analysis is required for each word, more words may be analyzed during a fixation.

In a study by Marcel (1974), fast and slow eleven-year-old readers and adults were presented with two slides. The subjects read a sequence of words from the first slide and then read the last word aloud to trigger display of the second slide which continued the sequence on the first slide. The second slide was displayed for 200 msec for the children. The level of contextual constraint was manipulated by varying the degree to which the word sequences given on the two slides approximated English (Miller and Selfridge, 1950). Marcel found that the number of words correctly identified from the second slide increased with the level of approximation to English, although this effect was not as strong for the better readers. The reading errors tended to be less consistent with the visual characteristics of the words on the slide as the constraint increased, suggesting a trade-off between visual and contextual sources of information. The overall number of erroneous words was greater for the stronger constraint condition. The increase in the number of words correctly extracted from a single fixation may well have reflected an increased ability to remember letters and visual features that are consistent with words that are constrained by context. Marcel used the same index of graphic similarity used by Weber (1970), so again, there is no way to determine which of the visual characteristics were most salient. (A similar study using sentence contexts and adult subjects has been reported by Frederiksen [1977]).

As in the word selection and tachistoscopic tasks, there was no penalty for guessing in the Marcel study; in fact, guessing was encouraged. Again, under natural conditions, direct visual analysis may be more efficient than guessing at words on the basis of context, particularly as readers become more familiar with the visual features of words and as recognition becomes more automatic (LaBerge and Samuels, 1974).

There is some evidence for increased dependence on visual analysis for older readers. Studies with adults have shown that subjects' ability to decide whether a string of letters is a word or not is enhanced by the availability of constraining context (e.g., Meyer, Schvaneveldt and Ruddy, 1975; Schuberth and Eimas, 1977) and inhibited by the availability of inconsistent context (Schuberth and Eimas, 1977; Stanovich and West, 1979). Schvaneveldt, Ackerman, and Semlear (1977) examined the advantage of contextual constraint for second and fourth graders. In their task two consecutive strings were sometimes highly related words (king-queen) and in some trials they were unrelated (king-butter). There was a significant advantage for decision times for both grades for the highly related pairs. However, the size of the advantage decreased with age (94 msec for second grade and 49 msec for fourth grade). Schvaneveldt et al. also found a much higher error rate for the second graders and reaction times were faster in general for the older children. They suggest that older readers may be more sensitive to the constraints of context, particularly when more complex contexts are used. Nevertheless, it appears that direct visual analysis may be more efficient than depending on context for the older readers.

Some evidence which is consistent with the conclusion that dependence on context decreases with age is presented by West and Stanovich (1978). They measured word naming times under three different contextual conditions. An advantage for congruous context and a disadvantage for incongruous context was found in relation to conditions where no context was presented prior to the word. These effects were found for fourth and sixth graders. However, the advantage of congruous context was not found for adults. In an interesting variant of the task, West and Stanovich asked subjects to name the color of the ink of the words presented under the same three contextual conditions. The color naming latencies were higher for the sentence contexts for the fourth and sixth graders but not for the adults. West and Stanovich suggest that for the children, automatic contextual processing causes this disadvantage. They explain the lack of contextual effects for the adults in terms of the relative speed of visual analysis vs. contextual analysis. Context interferes more in the color naming task and helps more in the word naming task for the younger readers because processes constraining the set of possible words occurs faster than direct visual analysis. Visual analysis is much faster for adults, on the other hand, so identification occurs before contextual processing can have an effect. West and Stanovich cite as support for this position, a number of studies showing that the advantage of contextual constraint for adults is greater when the visual stimuli are degraded with visual noise (Meyer, Schvaneveldt, and Ruddy, 1975; Stanovich and Pachella, 1977) or by reduction of intensity (Becker and Killion, 1977).

The advantage of constraining context was also greater for less skilled fifth grade readers as compared to more skilled fifth grade readers in a word naming study conducted by Perfetti, Goldman, and Hogaboam (1979). In their experiment, context was presented in both the visual and auditory modes and both types of context produced the same effect. These researchers suggest that reading difficulty is more likely to be attributable to word level analysis problems than to an inability to take advantage of context. In a similar study reported by Perfetti and Roth (1980), response latency to identify a word on a screen was influenced by the type of context presented, with highly constraining context producing the fastest latencies and anomalous context producing the slowest latencies. Less skilled readers were more negatively affected by the anomalous context than more skilled readers. In another set of experiments reported by Perfetti and Roth (1980), the target words were degraded by randomly deleting dots from the computer-printed letters. For high levels of letter degradation, more skilled readers began to look like less skilled readers reading undegraded words. That is, the availability of constraining context became important for the skilled readers, having a strong influence on word recognition accuracy.

In general, the studies in which constraining context is made available show a benefit of such constraint both for naming and lexical decisions, although this advantage seems to diminish with age (Schvaneveldt, Ackerman, and Semlear, 1977; West and Stanovich, 1978) and with reading ability (see Stanovich, 1980, for a more complete review). The nature of this advantage has been discussed in terms of priming of the representations of words in the lexicon (Morton, 1969; Meyer, Schvaneveldt, and Ruddy, 1975), but the implications of such priming effects for a description of the visual analysis procedures are still somewhat cloudy. Goodman (1965), Levin and Kaplan (1970), and Kolers (1970) have suggested that visual analysis is restricted under high constraint conditions. In the next section, some studies will be reviewed which show that certain visual characteristics of words in prose are particularly salient. These cues may receive consistent analysis while other less salient cues may be left unanalyzed, under high constraint conditions.

The inhibiting effect of inconsistent context in the lexical decision task (West and Stanovich, 1978; Stanovich and West, 1979) and the naming task (Perfetti and Roth, 1980) provides evidence that expectancies from context can interfere with recognition although the potency of this interference also seems to be weaker for adults whose visual processing is presumably more automatic.

Repeated text manipulations

One way to examine the importance of various types of visual features of words in prose is to systematically alter those features throughout the text and observe overall effects on reading time and comprehension. Such global measures can provide useful information under these circumstances because the effects of the mutilations accumulate as the reader moves through the text. Fisher and Lefton (1976), for example, have demonstrated the importance of spacing and overall shape in text. They presented third, fourth, and sixth grade children and adults with paragraphs in which spacing between words was either normal, filled with crosses or entirely deleted. These conditions were crossed with another variable in which the case of the letters was manipulated. The words were printed in either normal case, all uppercase, or alternating uppercase and lowercase. Fisher and Lefton found that reading times and level of comprehension was negatively affected for all grades by the spacing manipulations, with absence of spacing producing the worst results. Case manipulations also affected reading times and comprehension with alternating case producing the worst disruption. Fisher and Lefton suggest that case changes and spacing manipulations eliminate the important cues of word shape and word boundaries. They suggest that such cues may be particularly important sources of information in peripheral vision, allowing the reader to program eye movements appropriately.

Other types of specific text manipulations have been made by Rayner and Kaiser (1975) and Strange (1979). In both of these studies text was mutilated by substituting letters in either the beginning, middle, or end of a certain percentage of the words. In the Rayner and Kaiser study it was found that sixth graders' oral reading times for paragraphs with substitutions in the first letter positions were longer than for paragraphs with middle and end letter substitutions. The letter substitutions used by Rayner and Kaiser either maintained the overall shape of the word or changed it. This variable was found to be an important factor, with faster reading times for same shape letter substitutions.

The results of the study by Strange (1979) seem to contradict the Rayner and Kaiser results on a number of points. In the Strange study fifth and sixth grade children read altered text, and it was found that for both grades substitutions in the beginning and middle of the words were equally disruptive and more disruptive than substitutions to the ends of the words. This difference between the two studies might be accounted for by the fact that fewer mutilations were included in the Strange paragraphs (about one in ten words as opposed to 18% of the letters in the Rayner and Kaiser study). Perhaps in the Strange study the children were more able to depend on context, possibly decreasing the relative disruptive influence of mutilations of the first letter over substitutions occurring in the middle of the words.

Another major difference between the two studies was that Strange found no effect of the severity of the letter substitution on reading times. However, in that study, "major" letter substitutions included both letters that changed the overall shapes of the words and substitutions of consonants for vowels. It is unclear why such consonant substitutions should be considered major alterations. Perhaps inclusion of this type of alteration masked the relative importance of the shape-disrupting substitutions.

The importance of beginning parts of words for the older children studied in these experiments is in general consistent with evidence from other paradigms such as the matching to sample technique (Marchbanks and Levin, 1965; Rayner and Hagelberg, 1975; Rayner, 1976). Older subjects tend also to rely on more subtle visual similarities that contributed to overall shape in order to make similarity judgements. Attention to beginning letters is encouraged by instruction which requires children to sound out words. More importantly, dependence on beginning letters is consistent with the saliency of beginning phonemes in auditory speech comprehension. Spoken words form the basis for the organization of the lexicon for the developing reader and they are produced over time. Research in the area of speech comprehension suggests that beginning sounds function to restrict the identity of lexical items that are heard in context (Marslen-Wilson and Welsh, 1978; Cole and Perfetti, 1980).

While first letters continue to be salient, the developing reader becomes increasingly sensitive to the subtleties of orthographic patterns. Barron (1980) reviews research in which children are shown to increase in their ability to classify pseudo-words as being more or less word-like.

While repeated text manipulations reveal the importance of various features under conditions of competing demand from higher level processing, such studies are not likely to provide much opportunity for examining the independent contributions of the various components of the comprehension process as they affect visual analysis. By using measures of processing at specific text locations, the interactions of specific types of context with analysis of specific types of words can be examined.

On-line analysis of word recognition processes in prose

Perhaps the most fruitful way of studying on-line analysis during reading is with the use of eye movement data. Fixation durations have been found to be influenced by various higher level processing factors. A number of studies reveal increased durations when words are difficult to integrate into the structure that has been created in memory of the content of the passage. For example, fixations are longer on words that are related to information occurring less recently in a passage (Carpenter and Just, 1977). Fixation durations have also been found to be longer on words that reveal unexpected syntactic structures (Wanat, 1971; Frazier and Rayner, 1981). Such effects may result from integration processes that follow lexical identification, although expectations about syntactic function may actually interfere with recognition of inconsistent words. Eye movement data has also provided information about the importance of particular graphic features, especially in peripheral vision (Rayner, 1978). Recently eye movement data has been collected revealing the salience of particular features in words in which letter substitutions have been introduced (Ehrlich and Rayner, 1981).

Unfortunately, few eye movement studies have been done with children and those that have been done have provided only general information about number of fixations (Buswell, 1922; Taylor, 1965; Spragins, Lefton, and Fisher, 1976) or information about visual analysis of large stimulus materials (e.g., Nodine and Steurle, 1973). Eye movement data concerning specific locations in a page of text is restricted for children due to the necessity of constraining the head movements of subjects. The more precise studies of eye movements with adults employ a bite bar which may be overly restrictive for young children. There are, however, a few studies which have attempted to measure processing of individual words in the absence of eye monitoring equipment. In these studies word substitutions are made in various kinds of contexts and recognition accuracy is measured. When substituted words are inconsistent with the semantic or syntactic constraints, disruption is evidenced. Siler (1973-74) presented sentences with word substitutions to second and fourth grade children. Three types of substitutions were used. Semantically violated sentences contained words that were incongruous with context. In the syntactically violated sentences, an inappropriate word order was used. In the third case both of these manipulations were used.

Control:	I like cold *milk* with my cake.
Semantic violation:	I like cold *silk* with my cake.
Syntactic violation:	I like cold with *milk* my cake.
Combination:	I like cold with *silk* my cake.

Reading times increased in the same order that the sentences are listed above, with the exception that the last two types did not significantly differ from each other. Siler concluded that syntax has a greater effect than semantics on oral reading performance. One problem with this general conclusion is that the design of the study tacitly assumes that substitution of incongruous words creates the same degree of violation as interchanging two words. It is unclear whether such a direct comparison is appropriate. Nevertheless, the results of this study are of interest in that they demonstrate the strength of word order violations for both the second and fourth grade readers. It is particularly interesting, in regard to our inquiry into the interaction between visual analysis and higher level processing that those sentences which contained word order violations produced a larger number of reading errors than either sentences with incongruous substitutions or controls. The word order changes may have violated expectancies about the function of the words, also interfering with the childrens' ability to parse the sentences into their appropriate constituents. This disruption apparently had the effect of reducing the accuracy of individual word recognition. A smaller but significant number of errors for the incongruous substitutions suggests that this type of violation can also disrupt accurate word identification, possibly because the reader must focus attention on integrating an inconsistent word into an overall memory structure. The fact that the combined condition did not differ from the syntactic violation condition either in terms of reading time or errors suggests that the syntactic violation was enough to disrupt semantic assimilation of concepts into a memory structure and that the semantic consistency no longer played a useful function in that assimilation.

Isakson and Miller (1976) used a different set of manipulations to examine the distinction between syntactic and semantic processing. In their study, substitutions were made in the position of the verb in transitive sentences. Verb substitutions either violated the semantic constraints of the sentences or both the semantic and syntactic constraints of the sentences. The syntactic violation was made by using an intransitive verb in a transitive sentence.

Control:	The old farmer *planted* the bean seeds in the rich, brown soil.
Semantic violation:	The old farmer *paid* the bean seeds in the rich, brown soil.
Combination:	The old farmer *went* the bean seeds in the rich, brown soil.

Isakson and Miller counted the number of errors made by the subjects at the positions of the verbs. The subjects were fourth graders that were good vs. poor comprehenders. A significant interaction between level of comprehension of the subjects and type of substitution was found. In general, good comprehenders made far fewer errors than poor comprehenders at the position of the verb. However, the number of errors on the combined condition was equal for the two groups, suggesting that the syntactic violation was equally disruptive for the two sets of subjects. The number of errors for the low comprehenders did not differ across conditions. Of interest is the fact that the semantic violations used in this study did not differ significantly from the control condition for either group.

Isakson and Miller suggest that the poorer comprehenders were generally less sensitive to the constraints of language because the relative disruption caused by the combined condition was less for these subjects. The poorer readers' relative insensitivity to the context is understandable considering that the constraint on the appropriateness of the word actually followed the verb. It appears that at least under some circumstances, complete identification of the verb was left until words following the verb were identified. It is even possible that the children may have changed their interpretation of a word after reading following context silently. These data may, then, provide evidence of feedback from higher level interpretive processing following initial perceptually driven identification. The self correction data reported by Otto (1977) also seem to show evidence for such a feedback system.

In a study by the author (Ehrlich, 1979) an attempt was made to investigate the influence of contextual processing on visual analysis by substituting words that were visually confusable in paragraphs that were either highly constraining or neutral with respect to the original words. Sensitivity to the substituted words was measured as a function of the level of contextual constraint. The substituted words were identical to the original words except for one letter which occurred either at the beginning, middle, or end of the word. The letter substitutions either maintained the overall shape of the words (house-horse) or changed the overall shape of the words (cakes-cares). Separate paragraphs (high and neutral constraint) were developed for second, fourth, and sixth grade children and the degree of constraint of the paragraphs was independently evaluated by presenting the paragraphs to sets of children with the location of the critical word as well as the following context deleted. These children were asked to judge which word fit best in each paragraph. Some of the paragraphs did not reach the criterion set for the number of target responses and they were rewritten and retested. This procedure revealed some interesting trends which bear on the nature of the development of competing higher level demands during reading. The following paragraph was initially written for fourth grade subjects.

> Ellen arrived at the wedding party and looked around the room. She saw her favorite uncle sitting at a table. She went over and he smiled and said, "Pull up a ________."

The fourth graders' responses to this context included the words "steak," "knife," "shade," and only an infrequent "chair" – the intended response. However, in a similar paragraph for sixth graders "chair" was the unanimous choice. Apparently by the sixth grade the children had become more familiar with this constraining idiom. Other trends were observed showing increasing knowledge of word associations and increasing knowledge of real world constraints that are reflected in language.

The final paragraphs were typed with and without the substituted words and presented to new sets of subjects. Examples of the sixth grade paragraphs:

> *High Constraint*
> The cattleman stormed through the gate and toward the barn. He was out for blood and he would ride all night to catch the outlaw. He grabbed his saddle from its peg, threw it on his house, and rode toward the northern mountain pass. The trail of the outlaw was still warm.

> *Low Constraint*
> Ed Walker got into the photography business by a lucky break. A New York magazine was looking for someone to do a series of animal shots. He sent them some samples of his work including a terrific shot of the eyes of a house that was standing under a branch. That was the shot that caught the attention of the editor.

The design of this experiment is somewhat unusual in that the subjects were led to make errors by both the context and the visual characteristics of the words. Also, specific kinds of graphic manipulations were used to determine which of the visual features were most salient for the subjects under the different contextual conditions. Three measures were taken from the children's oral reading of the paragraph. The first measure was whether or not the children misread the substituted word, producing the word that was consistent with context. This measure has also been used in a study reported by Allington and Strange (1977). Incompletions were also counted. These were cases where the children initiated pronunciation but stopped in the middle of the word and returned to words earlier in the text or began pronunciation of the same word again. The third measure was a count of the number of times readers made unusually long pauses before pronunciation of the critical word.

The error frequency results are illustrated in Figure 1. For all three grades fewer misreadings were made when the substituted letter occurred in the first letter position, although this effect was only found for same shape substitutions. Different shape substitutions showed no effect of letter position, and these conditions produced very few misreadings overall, showing high sensitivity to overall shape for all three grades. The effect of the constraint of the context was significant for the sixth and second grades, and this effect interacted with letter position, again because words with substitutions in the first letter position produced very few errors. Far more misreadings occurred for the highly constraining context. The fourth grade data produced inconsistent results. The constraint effect did not reach significance although differences in frequency were fairly large and in the predicted direction for words with substitutions in the last letter position. The main inconsistency in the fourth grade data resulted from the fact that more errors were made for the low constraint paragraphs than for the high constraint paragraphs for the middle letter position substitutions. The errors in the low constraint/middle letter condition were all generated by the same paragraph. This paragraph did produce a wide variety of responses in the cloze procedure but it may have been more constraining than intended, particularly in conjunction with visual analysis of the first letter (Pearson and Studt, 1975). The lack of errors for first letter substitutions supports the idea that first letters are very salient for all three grades.

Occurrences of pauses and incompletions were fairly frequent. Percentages for each type of behavior (undisrupted reading, pause, incompletion, misreading) are shown for high and low constraint paragraphs in Figure 2. Only the fourth and sixth grade percentages are given because it was not possible to develop a consistent criterion for pauses for the second graders. In general, the incompletion pattern for the second graders was quite similar to that of the other two grades, although this type of response was slightly less frequent for the youngest subjects.

The frequencies of each type of response for each of the three letter positions in high constraint paragraphs are given in Figure 3. Of particular interest is the trading relationship between incompletions and pauses for both the

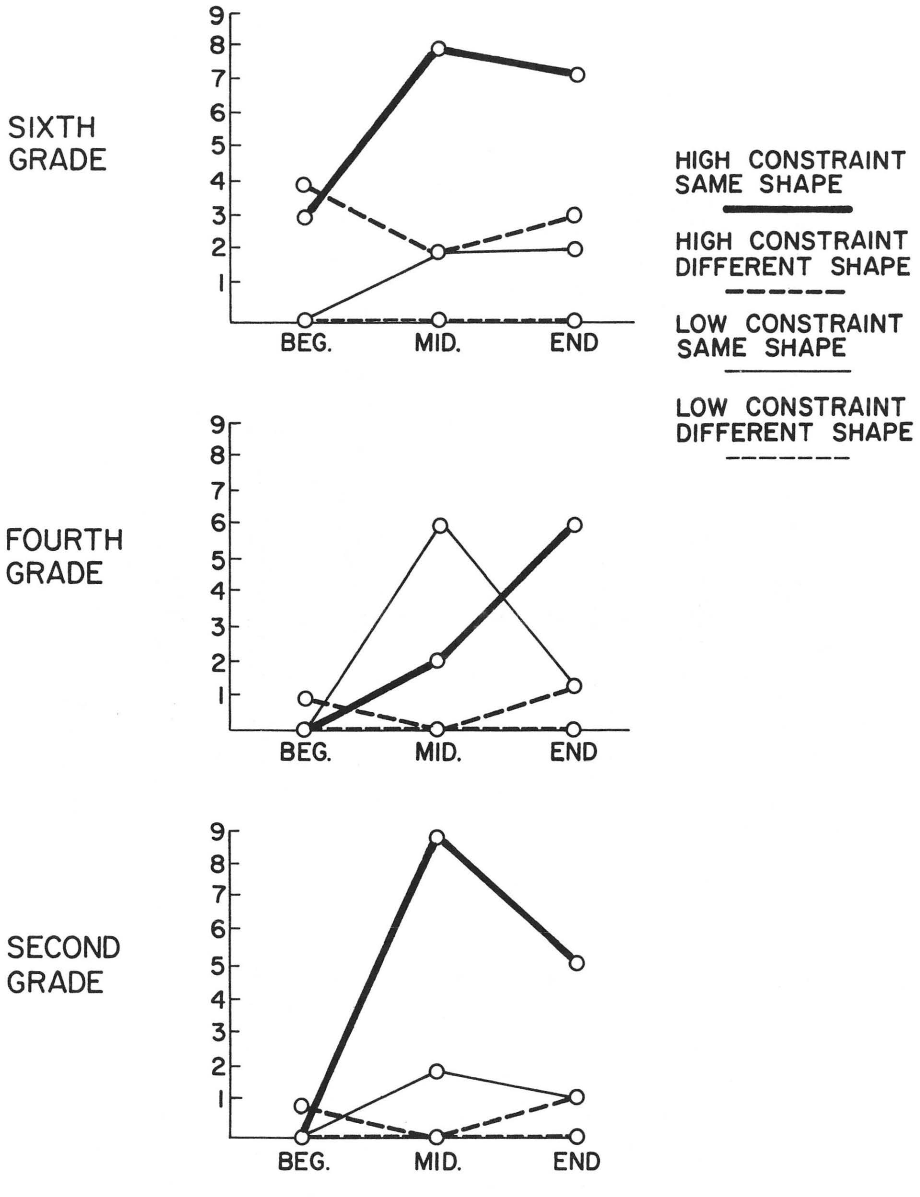

Figure 1. Frequencies of misreadings. Each point represents number of misreadings out of a possible 16 (from Ehrlich, 1979).

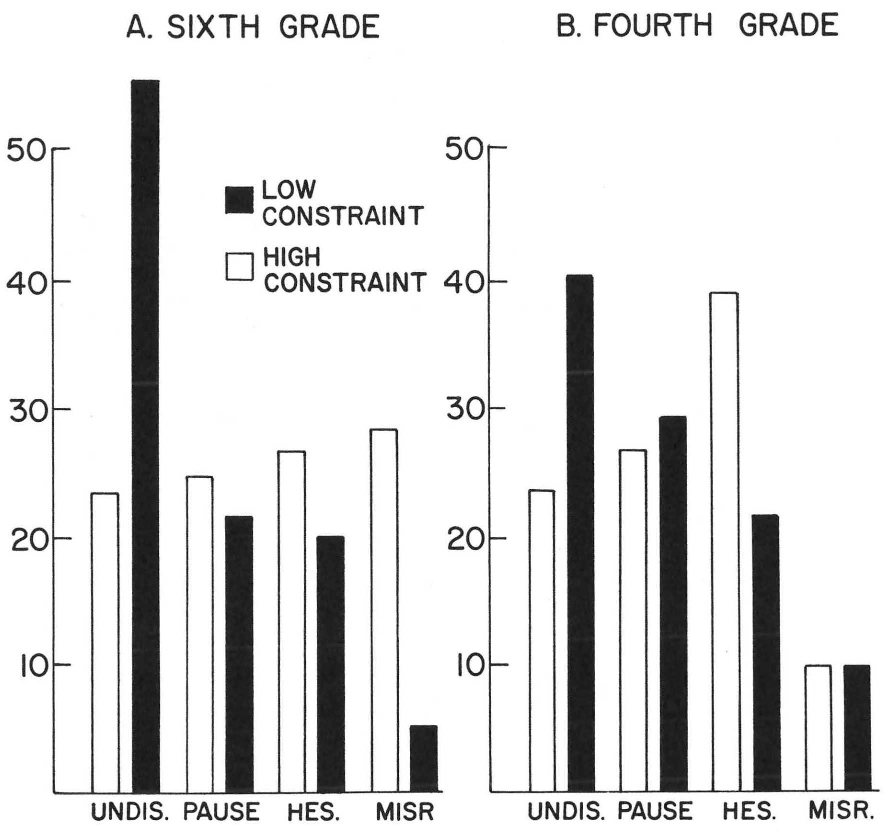

Figure 2. Percentages of each category of reading behavior for high and low constraint paragraphs (from Ehrlich, 1979).

fourth and sixth graders. Incompletions were more frequent when substitutions occurred in the middle or end of the words. On the other hand, pauses were more frequent when substitutions occurred in the beginning of the words. This trade-off suggests that the children sometimes began pronunciation of the constrained word on the basis of the first letter (when it was consistent with the word constrained by context) but sometimes interrupted pronunciation presumably because they encountered an inconsistent letter later on in the word, possibly during a subsequent fixation. However, when the first letter was inconsistent with the word constrained by context, the subjects were more likely to pause before pronunciation. The pattern of responses was strikingly similar for the fourth and sixth grade children except that the fourth graders seemed to be more prone to making incompletion responses than actual misreadings.

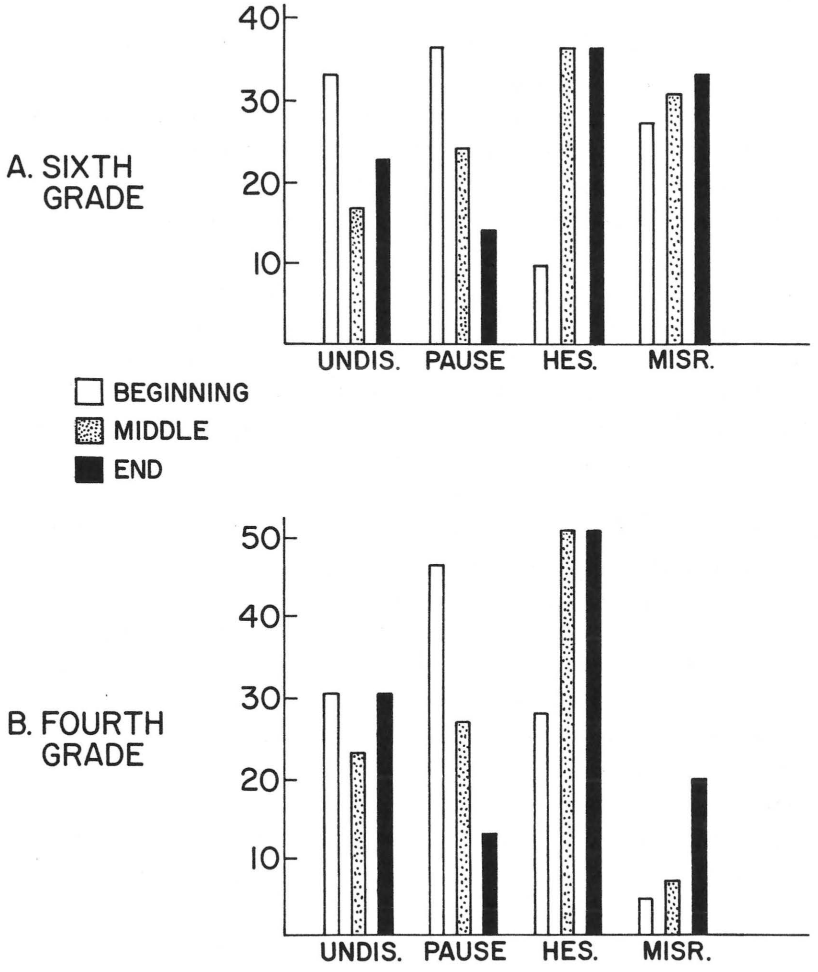

Figure 3. Percentages of each category of reading behavior for words with beginning, middle or end letter substitutions in high constraint paragraphs (from Ehrlich, 1979).

The results of this experiment were interpreted as providing further support for the theory that contextual constraint facilitates word recognition and functions to restrict the amount of visual analysis applied to words for a wide age range. This reduction in sensitivity occurred in a natural reading situation where guessing was not artificially encouraged and where the visual input to the subjects was not degraded in any way.

Summary of the developmental literature

The research reviewed in this paper clearly reveals that the child's comprehension goals play an important role in individual word recognition. The influence of these comprehension goals is seen for even the youngest readers who are struggling to integrate new visual analysis skills with the comprehension procedures learned for spoken language. The reading errors of first graders are constrained by context at least with certain methods of instruction. With experience, errors tend to become more constrained by visual features, particularly the beginning letters of words. Through the elementary school years, word knowledge develops as does the speed of visual analysis. At the same time the advantage of contextual priming seems to decrease to some extent, although children's sensitivity to violations of constraint remains strong. West and Stanovich (1978) have explained the decrease in the advantage of constraint for older children in terms of the relative speed of visual analysis. When visual analysis procedures are slow, context can help to delimit the set of appropriate words for a particular location before analysis is complete (Morton, 1969; Meyer, Schvaneveldt, and Ruddy, 1975), while faster analysis may allow lexical selection before context produces its priming effect. Note again, however, that fast access of words in the lexicon does not insure appropriate interpretation of those words in terms of the reader's memory structure for the content of the prose.

For younger readers, attempts at careful visual analysis may cease once the identity of a word is singled out. This may account in part for beginning readers' relative insensitivity to features at the ends of words. For older readers, however, visual analysis of familiar words may be automatic, requiring little or no conscious attention (LeBerge and Samuels, 1974). Thus, features internal to words and features contributing to overall shape may be likely to influence lexical selection even under conditions of high contextual constraint.

But in the study by Ehrlich (1979) even the sixth grade readers were prone to misread constrained words that were highly familiar to them and relative insensitivity to end letters for sixth graders was found in both the Rayner and Kaiser (1975) and Strange (1979) studies with repeated text manipulations. These results are not necessarily inconsistent with a theory of automatic perceptual analysis. Misread words may not have been directly fixated in the Ehrlich study because the identities of the words were determined in advance. In that study the converging constraints on the critical words were introduced early in the paragraphs so that identification in the absence of visual analysis would have been possible. These sixth graders' consistent sensitivity to violations of first letters and overall shape may reflect sensitivity to features of words that are viewed in peripheral vision. Peripheral sensitivity to these features has been documented for adults (Rayner, 1978), and Forgays (1953) has demonstrated that children's ability to identify words in peripheral vision increases with age. It has also been demonstrated that the number of fixations made in text decreases with age (Buswell, 1922; Taylor, 1965). It will be of interest to determine whether older children are actually capable of misreading highly familiar words that are directly fixated. If they are not, then there would be good evidence for automatic visual analysis en route to lexical access. Even if good readers were found to misread words that were directly fixated, a theory of automatic perceptual analysis could not be ruled out. Such misreadings might reflect a block in communication between the visual analysis system and the interpretive system as suggested above.

Data relevant to these issues have been collected with adult subjects in a study by Ehrlich and Rayner (1981; see also Zola, 1979). In this study high and low constraint paragraphs similar to those in the Ehrlich (1979) study were used. Fixation locations and fixation durations were recorded as the subjects read the paragraphs silently. Averaging across words with various types of letter substitutions, the readers were more likely to make initial forward fixations on the low constraint words (79%) than the high constraint words (56%). The probability that the subjects reported seeing anomalous words during the debriefing session was 86% for the low constraint words and 64% for the high constraint words. It appeared that for the large majority of cases, misread words were not directly fixated. When direct fixations occurred, durations were substantially longer than fixations on control words containing no letter substitutions. The fixation duration data suggested that the adults were immediately sensitive to the degree to which the critical words were consistent with context, with anomalous words receiving the longest fixations and the highly constrained control words receiving the shortest fixations.

The high degree of sensitivity to substitutions viewed in central vision is consistent with the notion that visual analysis becomes automatic with experience. Adults do apparently learn to increase efficiency, however, by skipping direct fixation of a subset of the words in the text.

Both children and adults seem to be simultaneously sensitive to graphic, semantic, and syntactic sources of information. The cognitive system is flexible in that word identification can be influenced more or less by these three sources of information depending on their relative informativeness and on the relative ease of processing. This interactive nature of word recognition has been stressed recently (Perfetti and Roth, 1980; Stanovich, 1980; Wildman and Kling, 1978-1979). Rumelhart (1977) has proposed that syntactic, semantic, and graphic information are analysed by separate components and that hypotheses about lexical identity are generated and output to a central message center. This model allows each component to operate relatively independently, with the most informative source of information having the greatest impact on the final lexical choice. With increasing experience with visual analysis, children's word identification appears to become more and more dependent on that analysis, reflecting the increased efficiency of the visual component and the greater informativeness of the words on the page as compared to the less specific constraint of context.

In recent discussions of interactive processes in reading relatively little attention has been paid to the problem of the nature of the relationship between the construction of a conceptual network and the priming of words in the lexicon. It will be suggested here that identification of a word is not really complete until the function of that word in the discourse is established. Many discussions of interactive recognition imply that the goal of reading is identification of single words within the lexicon rather than their interpretation. This focus seems to have influenced the importance ascribed to the various processing components. For example, it has been argued (e.g., McConkie and Rayner, 1976) that Goodman's hypothesis testing model (1965, 1967) which stresses the importance of contextual analysis is implausible because there isn't enough time during a fixation for the reader to generate specific hypotheses concerning subsequent words, and that direct perceptual analysis seems more likely to influence identification. If access of individual words in the lexicon is the goal in reading, then perceptual analysis is probably the most direct route for experienced readers. However, if interpretation of a word is the goal of recognition, then contextual analysis seems to carry more importance. While the extreme position of word by word hypothesis testing seems unrealistic, interpretation of text often requires the creation of memory nodes representing information that is not explicitly represented in the text. Such structure building processes may indeed allow generation of "hypotheses" about concepts that must be represented in the text structure, and on occasion, the output of the automatic perceptual component may simply fill in the lexical form of the anticipated concept. In this way, contextual analysis may precede and dominate perceptual analysis, and on occasion influence fixation location as in the study by Ehrlich and Rayner (1981). The time course of such structure building procedures that delimit a concept and thereby reduce the amount of visual information required for accurate identification should not be constrained to occur during the fixation immediately preceding the relevant word, but such constraint should instead develop over time as the set of concepts in the text is interpreted and integrated.

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Disorders of Reading and Their Implications for Models of Normal Reading

Max Coltheart

Many investigators concerned with developing theoretical models of reading start from the assumption that the information-processing system used to accomplish the task of reading consists of a number of subcomponents, each responsible for performing a specific information-processing job. If this assumption is correct and if in addition the subcomponents of the system are anatomically as well as functionally separate, then one can test a multicomponent model of reading by observing the different forms which acquired reading disorder takes as a consequence of different patterns of damage to the brain. One can also use such a model to provide economical interpretations of various forms of acquired reading disorder. These possibilities are illustrated with reference to five different forms of acquired reading disorder (letter-by-letter reading, phonological dyslexia, an unnamed dyslexia, surface dyslexia, and deep dyslexia). The symptoms of each disorder are described and an assessment is made of the success with which each disorder can be explained within the theoretical framework provided by one multicomponent model of reading, a version of Morton's logogen model.

Many cognitive psychologists are currently engaged in efforts at modelling the process of reading. In some cases, their intention is to produce a detailed model of one particular aspect of reading – the identification of letters within a word, for example, or the conversion of printed letter-strings to phoneme sequences. In other cases, attempts are being made to produce a general model of the entire reading system.

Many of these investigators adopt the assumption that reading is accomplished by the use of a complex information-processing system consisting of a number of subcomponents, each responsible for performing a specific job. If one makes that assumption, then one's attempts at modelling the reading system consist of statements about what the subcomponents of this system are, and about how they are interrelated.

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After a model of the reading system has been proposed in this way, the next step is to investigate its appropriateness by experiment. There are various ways of doing this. If one's model consists of a unidimensional sequence of information-processing stages, with a unidimensional flow of information, one might devise tests of the model based upon the additive-factors technique developed by Sternberg (1969). Numerous other techniques for testing multicomponent models have been devised: for example, selective interference (Brooks, 1968) or the study of stimulus confusability effects (Conrad, 1964).

These techniques rely upon the use of experimental manipulations to try to produce predicted effects in experiments with normal readers. A completely different approach to the assessment of models of reading is to investigate abnormal readers. Studies of impaired reading can provide tests of predictions from models of the normal reading process, and models of the normal reading process are able to offer natural and economical interpretations of the various forms of abnormal reading.

Any method for testing models of reading makes its own set of assumptions – for example, use of the Sternberg additive-factors method assumes unidimensionality and unidirectionality of the sequence of information-processing stages – and the neuropsychological method is no exception. Any user of this method has to hope that any two components of the reading system which are *ex hypothesi* functionally independent are also anatomically independent in the sense that it is possible for the brain to be so damaged that either of these components can be impaired or abolished whilst the other continues to function normally. An advantage of the neuropsychological approach, however, is that if this assumption is false (e.g., if the neural mechanisms subserving functionally separate components are anatomically intertwined and so cannot be independently impaired by brain damage), the data one collects from people with reading disorders are likely to be uninterpretable within the context of one's model of reading, rather than actually misleading. In the limit, where no subcomponent can be damaged whilst any other is intact, brain damage will have a merely quantitative effect on reading, and one will not discover qualitatively different forms of acquired dyslexia. This would make it clear that the neuropsychological approach to testing multicomponent models of reading is futile.

Competent readers can perform a number of different tasks when confronted with a string of letters. Although there is no reason why these various tasks should map one-to-one on to the various subcomponents of the reading system (for example, some tasks might be performable by more than one component, and some components might be used for performing more than one task), it must be that the system as a whole is capable of performing all the tasks that we know readers can perform; if any of these tasks are beyond the capabilities of a postulated system, then the model of reading embodied in this system is at best incomplete. I begin, then, by describing what I take to be the important kinds of tasks which readers are capable of when presented with a single string of letters.

SOME READING TASKS

Abstract letter identification

One task performed with ease by the skilled reader is the identification of a letter regardless of its particular form. We all know that a, A, *A*, and a are examples of the letter A. Absence of the ability to achieve such identifications would prevent a reader from being able to read anything printed in a typeface which he has not seen before. Since unfamiliar typefaces can be read without difficulty by the skilled reader, it follows that the reading system employed by such a reader must include a component whose job it is to identify letters even when their particular visual forms have not been encountered before. I propose to call this component Letter Identification, and I suggest that what the component actually does is to assign to seen letters their appropriate Abstract Letter Identities (ALIs).

By way of illustrating what I mean by ALIs, consider an experimental task used very widely in the past fifteen years: visual same-different matching. If a subject judges that the words GARDEN and GARDEN are the same whilst the words GARDEN and DANGER are different, what account might we give of how this is achieved? We assume that each of the two stimuli are encoded, and that the decision as to the sameness or differentness of the two stimuli is made by comparing the two encodings; but what is the nature of the code employed? In the example I have just given, three possibilities often considered are:

(a) Semantic code: the response "Same" is made when the two stimuli have the same *meaning*.

(b) Phonological code: the response "Same" is made when the two stimuli have the same *pronunciation*.

(c) Visual code: the response "Same" is made when the two stimuli are *visually identical*.

Judgments that GARDEN/GARDEN requires a "Same" response and GARDEN/DANGER requires a "Different" response could thus be accomplished perfectly by using any one of these three kinds of code. Therefore, if one wishes to explore the uses of the various types of code, one needs to design stimuli in such a way that not all of the codes are usable; and this avenue of research has been extensively explored.

One can render the use of semantic codes irrelevant by using stimuli which do not possess semantic codes – namely, nonwords. Judgments concerning DENGAR/DENGAR and DENGAR/NADGER cannot use comparisons of semantic codes, and so here the experimenter has compelled the subject to use either a phonological code or a visual code.

One can then eliminate the use of a visual code by varying case. Since DENGAR and dengar are visually different, one cannot judge them to be the same by comparing their visual codes.[1]

This leaves only one code remaining: the phonological code. Thus by using nonword stimuli differing in case one has reduced the number of possible codes in the visual same/different task from three to one, the phonological code.

If one wished to restrict subjects to the use of semantic codes only, one could eliminate visual codes by using different cases, and one could eliminate phonological codes by using pairs of homophones for all the "Different" stimuli: thus responding "Same" to PHRASE/phrase and "Different" to PHRASE/frays obliges the subject to use semantic codes. Similarly, if one wishes to restrict subjects to the use of visual codes, one instructs them to respond "Same" only when stimuli are visually identical, and one uses as "Different" stimuli item pairs which differ *only* in case. Responding "Same" to GARDEN/GARDEN and "Different" to GARDEN/garden requires the use of visual codes, since for every item pair (including all the "Different" pairs) the two items have the same semantic code, and the same phonological code.

This theoretical rationale for the analysis of the codes used in visual same-different matching tasks has served as the basis for a great deal of research in the past fifteen years, beginning with the studies of visual and name codes by Posner and his associates (Posner, Boies, Eichelman, and Taylor, 1969)[2]. The rationale depends crucially on the assumption that the list of potentially usable codes I gave earlier is *exhaustive* – that is, that there are only three possible codes, so that if one eliminates two by appropriate choice of stimuli one knows exactly what form of code the subject must be employing. Studies of reading disorders, however, reveal that this assumption of exhaustiveness is false. Two examples will be given: one in connection with conduction aphasia, and the other in connection with deep dyslexia.

In conduction aphasia, the patient's speech comprehension will be at worst mildly impaired, and at best intact, and speech production will also be relatively good; in contrast there is a gross impairment in the ability to repeat stimuli which are spoken to the patient. The syndrome is reviewed by Green and Howes (1977) and by Benson, Sheremata, Bouchard, Segarra, Price, and Geschwind (1973).

The patient to whom I refer here, K. C., (see Coltheart, Wyke, and Henson, submitted) had intact speech comprehension, and intact speech production except for some word-finding difficulties; but when asked to repeat even a single short spoken common concrete noun, he sometimes was unable to do so correctly. Thus his repetition deficit was severe.

Although reading aloud of common concrete nouns was poor (15 correct out of 25), matching these to pictures was perfect. Various other tests of comprehension of single printed words were tried, and performance was uniformly error-free. Consequently, ability to access semantics from print was unimpaired, at least for the classes of words we used, whilst ability to derive articulation from print was considerably impaired (since reading aloud was defective).

A failure to read aloud could be due either to a failure to derive phonology from print, or to a failure to derive articulation from phonology. One can adjudicate between these two possibilities by using tasks which do not require articulation, but which do require the derivation of phonology from print. One such task is homophone matching: the patient is given pairs of words, and asked to judge whether the two words in a pair have identical pronunciations or not. For example, the patient should classify SO/SEW as "Same" and NO/NEW as "Different".[3] Our patient was given 50 word pairs, 25 of which were homophonic and 25 not, and asked to sort the 50 pairs into two categories (homophonic versus non-homophonic). He was correct with 16 of the 25 homophones and 16 of the 25 non-homophones; this performance (64% correct) is very poor and in fact is barely above chance ($\chi^2 = 3.92$, $\chi^2_{[.05]} = 3.84$). Thus even when overt articulation is not required, this patient's phonological processing of print is severely impaired.

Suppose one now asked him to do same/different matching of nonwords with the two items in a pair differing in case. Since these two are nonwords, semantic coding cannot be used; since their case varies, visual coding cannot be used; and since the patient's ability to match stimuli using phonological codes (homophone matching) is grossly impaired, matching using phonological coding will be almost impossible. Therefore, if these are the only three codes which are in principle usable, this patient should be near chance at same-different matching of nonwords differing in case. In fact, however, the patient performed this task with ease and entirely without error: he could respond "Same" to stimuli such as ANER/aner and "Different" to stimuli such as ANER/aneg with no difficulty.[4]

This means that the list of three codes given earlier is not exhaustive, since it is possible to respond "Same" to ANER/aner without using a phonological code. There must be at least one additional possible code. I suggest that this fourth kind of code uses the identities of the letters – *abstract* identities in the sense that neither the phonological representations nor the visual forms of the letters are being used.

If it is conceded that one can judge that A and a are the same without using name codes (using ALIs instead), this has certain consequences for the interpretation of the past decade's work on visual same-different matching. For example, it has been found that Aa matching is faster in the left hemisphere than the right, whilst AA matching is faster in the right hemisphere than in the left (Geffen, Bradshaw, and Nettleton, 1972), and it has been argued that this is evidence for the superiority of the left hemisphere at phonological processing; but this inference is not legitimate if Aa matching is possible using a code which is *not* phonological (namely, the ALI code). More generally, one cannot assume that one is studying the name code in experiments involving matching of nonwords or letters differing in case.

The performance of this conduction aphasic patient in matching nonwords differing in case provides evidence for the concept of ALIs. Evidence for this concept is also provided by the performance of patients suffering from deep dyslexia (Marshall and Newcombe, 1966, 1973; Coltheart, Patterson, and Marshall, 1980). This syndrome is described in more detail later in this paper. For these patients, reading nonwords aloud is virtually impossible, and so is judging whether or not printed nonwords rhyme; however, they can read a considerable number of words aloud, especially concrete nouns, and can comprehend an even greater number. Since deep dyslexics cannot encode letter-strings phonologically prior to lexical access, their reading (silent or oral) must depend on visual coding of words. Of course, the term "visual coding" is extremely vague in this context, but one thing it might mean is the treating of words as overall visual forms, as wholistic configurations. If this is what visual coding of words means, then disrupting the visual form of a word should make reading aloud very difficult for the deep dyslexic. A powerful way of doing this is to alternate case within a word: the visual form of TrEe is entirely novel, and certainly quite unlike the visual form of TREE or tree. However, as Saffran (1980) has shown, the ability of deep dyslexics to read words aloud is not significantly reduced by presenting words in alternating case. It follows that the visual code they use is not a wholistic visual configuration; Saffran (1980) proposed that the nonphonological method of reading relies on abstract letter identities instead.

Studies of the characteristics of reading in two neuropsychological disorders – conduction aphasia and deep dyslexia – thus provide evidence for the validity of the concept of abstract letter identities. Further evidence of various kinds is provided from studies of normal skilled reading.

Scarborough, Cortese, and Scarborough (1977) showed that the "No" response to a nonword in a lexical decision task was faster if the same nonword had been presented on an earlier trial, and that this was so even if the two presentations of the nonword were in different cases. What is it that is being repeated to produce this repetition effect? It cannot be a semantic code (since the items are nonwords) nor a visual code (since the item is repeated in a visually different form); perhaps it is a phonological code. If so, nonword homophones should show a facilitation effect: the "No" response to FLANE should be facilitated by prior presentation of PHLAIN. Davelaar (unpublished experiments, University of Reading), however, has shown that no facilitation is obtained in this situation. This suggests that the crucial factor is the repetition of a particular sequence of ALIs, since neither semantic nor visual nor phonological repetition is sufficient to explain the effect.

Rayner, McConkie, and Zola (1980) presented single target words in parafoveal vision, and requested subjects to make a saccadic eye movement to the target word and then to read the word aloud. Changing the case of the target word during the eye movement had no effect on naming latency, whereas replacing the word with a different word slowed the naming response. These results are compatible with the view that information about ALIs is collected prior to the initiation of the saccade, and that if this information remains pertinent (i. e., if the *identities* of the letters in the target word are not changed during the saccade) this facilitates processing of the target word after the saccade.

Evett and Humphreys (in press) showed that tachistoscopic report of single words was facilitated by prior presentation of nonwords sharing letters in the same position, even though the nonwords were in lowercase and the words were in uppercase (e. g., the report of the word WHITE was better when it was preceded by whibe than when it was preceded by sornd). They proposed that this result should be explained in terms of priming of ALIs: assigning an ALI to the first letter in WHITE is facilitated by prior presentation of a letter string in which the first letter has the same ALI.

Although the various lines of evidence just cited provide a variety of forms of support for the ALI concept, the precise role played by ALIs in the processing of words is by no means clear. The simplest proposal is that the first stage in word processing is the assignment of ALIs to each of the letters in the word, and that subsequent stages use these ALIs as data. This proposal is contradicted by several findings. Firstly, it is not evident why, if this proposal were correct, tachistoscopic report should be worse for case-alternated words like GaRdEnEr than for GARDENER or gardener; this impairment is small, but it exists (Coltheart and Freeman, 1974). Why should the assignment of ALIs be more difficult for case-alternated stimuli? But if it is not, then no effect of case alternation could occur, since once ALIs are assigned lettercase is irrelevant. Secondly, Henderson and Chard (1976) have shown that, in same-different matching, the "word"-superiority effect enjoyed by acronyms such as FBI in comparison with control stimuli such as BFI does not occur when the acronym is presented in the wrong case; and Besner (1980) has shown that precisely the same is true when the task is tachistoscopic report. Thirdly, McClelland (1977) showed that subjects taught arbitrary meanings for nonwords presented in uppercase were slower at subsequently accessing these meanings when the nonwords were presented in script, and vice versa (although this difference disappeared with practice).

These results are, of course, not *inconsistent* with the concept of ALIs. They simply require one to suppose that ALI coding is not the only way in which print is represented at the early stages of the reading system. The fact that semantic information necessary for reading comprehension sometimes depends upon case or some other aspect of typography is sufficient to indicate that specific visual information is preserved during reading rather than being discarded at the first stage.

It is thus evident that at present we are unable to give a complete account of the role played by ALIs in reading. Nevertheless, the evidence cited above does indicate that readers are *capable* of abstract letter identification and do perform this task during reading. Therefore one must attempt to include in one's model of reading a subcomponent capable of performing the task.

Word recognition

What I mean by "word recognition" is determining that a particular sequence of letters is a word which one has seen previously and which one is seeing again (re-cognising) now. One studies this process of word recognition by presenting a subject with strings of letters, some of which are words and some nonwords, and requiring him to decide which are words and which are not: this is known as the lexical decision task.

Lexical decisions can be performed with remarkable speed. Typical mean latencies for deciding that a letter string is a word are around 500 msec. Since a portion of this time is attributable to peripheral input and output processes, it is evident that the time needed to consult one's stored knowledge about words and to decide that a letter string is a word is at most only a few hundred milliseconds.

An important point here concerns the nature of the nonwords in lexical decision tasks. If the nonwords are all inconsistent with the orthographic constraints of English if they are sequences such as QVBLO or SKRPJ – it is in principle possible to make accurate "Yes" and "No" decisions simply by determining whether a letter string is orthographically regular or not. In this case, the lexical decision task does not require the subject to consult an internal lexicon. However, if (as is usually the case) all nonwords are orthographically regular sequences such as LEAT or MAINTINESS, the subject is forced to consult his internal store of words. How else could he determine that such items as these are not actually words?

It follows that the normal reading system must include a subcomponent which is capable of interrogating the reader's knowledge of all the words in his vocabulary so as to determine whether any of these words matches the stimulus letter string; and that such interrogations can be completed extremely rapidly.

Word comprehension

Words have meanings, and readers can discover these. Thus the reading system is capable of accessing, from a printed representation, a semantic representation which is the meaning of the word the reader is looking at; and hence the system must possess a subcomponent which accomplishes such access.

Word pronunciation

It is also possible for readers to read words aloud, and hence they are able to access a phonological representation from a printed word. The reading system must therefore contain a subcomponent capable of this task.

Nonword pronunciation

Reading aloud can be achieved successfully with letter strings even when they are not words. As will be discussed later, in some forms of reading disorder nonword reading is much more seriously impaired than word reading, which suggests that we should be prepared to regard these two tasks as different ones. Furthermore, as is also discussed later, many models of normal reading postulate that there are two different ways of reading aloud: one of these ways is available only when the letter string is a word, and the other way is usable for all nonwords but not for certain types of words.

The concept of two routes to pronunciation may turn out to be wrong, and it may be the case that the same mechanism is used for reading words and nonwords aloud; but it is clearly necessary at present to distinguish the two tasks (reading words aloud and reading nonwords aloud), and to require any postulated reading system to include a subcomponent capable of reading nonwords aloud as well as a subcomponent capable of reading words aloud. At the same time, one must keep in mind the question of whether it is the same subcomponent which performs these two tasks, or whether there are two different subcomponents involved.

Implications for models of reading

I have just described a number of tasks which the normal reader can perform when confronted with a letter-string. He can assign abstract letter identities to the letters; he can recognise whether the letter-string is a word of English or not; if the letter string is a word, he can understand what it means; and whether it is a word or not, he can read it aloud. Thus, whatever the cognitive system which subserves reading is, it must be capable of performing all of these tasks, and so any model of the system which aspires to completeness must provide explanations concerning how each of these tasks is performed.

The aim of this paper is to illustrate how such models can offer interpretations of, and in turn be tested by, reading data collected from patients suffering from acquired dyslexia, data gathered by requiring such patients to perform the various reading tasks just described. The next step, then, is to outline one such model; then various forms of acquired dyslexia will be described; and finally I will consider how each of these acquired dyslexias might be interpreted within the theoretical framework offered by the model.

THE READING SYSTEM: A THEORETICAL FRAMEWORK

A model for the reading aloud and the comprehension of single words is depicted in Figure 1. It is an extension of, but otherwise differs only in minor ways from, the current version of the logogen model (see e.g., Morton, 1979; Morton and Patterson, 1980). According to this diagram, the initial stage in reading is the assignment of abstract identities to the letters in the word the reader is inspecting. The output of this stage has three different uses: it serves as input to a word recognition component, to a non-lexical procedure for converting print to phonology, and to a letter-naming component. One can assess the integrity of the ALI component in a dyslexic reader by using the nonword cross-case matching task described earlier, the assumption being that the ability to judge the identity of A and a requires the correct functioning of a system which assigns abstract identities to these two letters.[5]

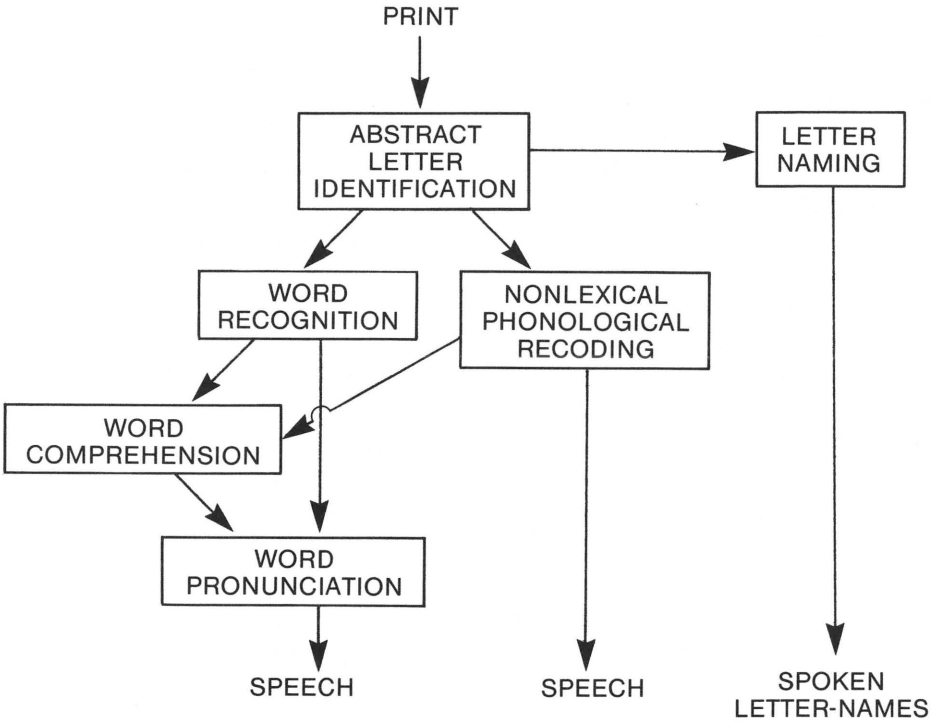

Figure 1.

The word recognition component in the diagram corresponds to the visual input logogen system in the logogen model. It contains "word detectors," one for each of the words in a person's reading vocabulary. This component responds when a word is presented, but not when a nonword is presented, and I assume that it is this differential response which permits readers to make lexical decisions.[6] If this assumption is correct, then integrity of this component may be tested by using the lexical decision task with dyslexic patients.

The comprehension component in the diagram is the system required for understanding the meanings of printed words, and its correct functioning can be assessed by having dyslexic patients perform tasks requiring such understanding: judging whether word pairs are synonymous, for example, or obeying printed instructions, or matching words to pictures.

The component labelled "word pronunciation" and the component labelled "nonlexical phonological recoding" serve the same function – they enable the reader to read aloud. Why does the model provide two different ways of performing this one task?

If the only route from print to speech were via word pronunciation, we could not read nonwords aloud, because this route proceeds via the word recognition component, and this component cannot respond to nonwords. Since we can read nonwords aloud, the model must incorporate a method for doing so.

If the only route from print to speech were via nonlexical phonological recording, it would be necessary to explain how this nonlexical process could deal correctly with the vagaries of English grapheme-phoneme relationships. This point can be elucidated only by being more precise concerning the way in which such nonlexical phonological recoding occurs. A popular proposal has been that this conversion is accomplished by grapheme-phoneme correspondence rules (GPCs): a detailed exposition of what is involved in such a proposal has been given elsewhere (Coltheart, 1978). Consider the word *down*. This contains the graphemes *d, ow,* and *n.* The most common pronunciations of these three graphemes are /d/, /aω/ and /n/. Thus if the assignments of phonemes to graphemes which are used by the GPC procedure are those which are the most common, the GPC procedure will yield *down* → /daωn/, which is correct. Most words containing the grapheme *ow* will be dealt with correctly, in fact; but not all, since *mown* → /maωn/ is incorrect. For this reason, words like *mown* have been known as irregular or exception words, and the view has been taken that nonlexical conversion of print to phonology, if it uses GPCs, will only function correctly for regular words (and nonwords). As we will see, there is neuropsychological support for the distinction between regular and irregular words: in the syndrome known as surface dyslexia, described below, reading aloud is much more frequently correct for regular words than for matched irregular words, and, what is more, many incorrect readings for irregular words take the form of applying GPCs to these: for example, *pint* is read as /pɩnt/, *quay* as /kweɩ/ and *bury* as /bjuri/. On this view of the nature of nonlexical conversion from print to phonology, such conversion will not work for irregular words; since *lexical* conversion of print to phonology does not work for nonwords, we therefore need to postulate two different pathways from print to speech because we are able to read nonwords and irregular words.

However, data provided by Glushko (1979) make it difficult to retain the view that nonlexical conversion of print to phonology operates by using GPCs. There are two important results in Glushko's work. Firstly, he showed that regular words like WAVE (for which there exists an "orthographic neighbour," HAVE, in which the segment -AVE has a different pronunciation) are named with longer latencies than regular words like WADE (for which there are no orthographic neighbours containing segments with conflicting pronunciations). In fact, naming latency for regular words with inconsistent neighbours (words like WAVE) was as slow as for frankly irregular words like HAVE. A GPC-based account cannot explain why WAVE should be dealt with differently from WADE. Glushko's second important finding concerned naming latencies for nonwords; he found that nonwords with inconsistent word neighbours (e.g., BINT – cf. MINT, PINT) produced longer naming latencies than those with only consistent neighbours (e.g., BINK). This result is especially damaging to GPC theory since on that theory all nonwords are dealt with in the same way (by GPCs) and no reference at all is made to the pronunciations of any real words when nonwords are being read aloud.

If the reading aloud of nonwords is not accomplished by the application of GPCs, then how is it done? Glushko (1979, p. 686) proposed: "A letter string is not read aloud by retrieving a single pronunciation from memory or by employing abstract spelling-to-sound rules. Instead, it appears that words and pseudowords are pronounced using similar kinds of knowledge: the pronunciations of words that resemble them and specific spelling-to-sound rules for multiletter spelling patterns."

There are a number of difficulties with this proposal. Firstly, English contains a good number of words – *sew, yacht,* and *colonel* are examples – which contain multiletter sequences whose spelling-to-sound relationships are unique. The pronunciation of *ew* as /soω/ is unique to *sew* and its derived forms; therefore, knowledge of the pronunciations of words which resemble *sew* orthographically simply could not be used as part of a process which determines how *sew* is to be pronounced. Surely the only way in which such a word could be read aloud correctly is in fact by retrieving a single pronunciation from memory. Secondly, it is not difficult to produce pronounceable *nonwords* which have no words resembling them; indeed, Table III of Coltheart, Besner, Jonasson, and Davelaar (1979) contains a list of such nonwords. These nonwords were all of the structure CVVC, and they were selected so that no English word began or ended with the initial CVV- component of any nonword, and no English word began or ended with the terminal -VVC component of any word. An example is *joov.* When subjects were asked to read this aloud, the response /dʒuv/ was produced by 93.1% of these subjects; but since no English word begins or ends with *joo,* and no English word begins or ends with *oov,* how could the reading aloud of this nonword make use of the pronunciations of words which resemble it, or make use of multiletter spelling patterns where "multiletter" means "more than one grapheme"? Surely the only way in which such nonwords could be read aloud is by employing abstract spelling-to-sound rules at the level of single graphemes and phonemes?

Thus words like *sew,* on the one hand, and nonwords like *joov,* on the other, represent examples which conflict with Glushko's claim that a letter string "is not read aloud by retrieving a single pronunciation from memory or by employing abstract spelling-to-sound rules." The former method of reading aloud is required for words like *sew,* and the latter method is required for nonwords like *joov.*

A further difficulty arises in connection with Glushko's view that words and nonwords are read aloud by the same procedure. In the syndrome known as phonological dyslexia (discussed below), the reading aloud of nonwords is severely impaired, whilst the reading aloud of words (at least in the case of single-morpheme content words) is virtually intact. How could such a dissociation arise if the same mechanism is used for reading aloud both words and nonwords? One could reply to this objection by arguing that nonwords are intrinsically more difficult to read aloud than words (although it is by no means clear whether such a claim could itself be consistent with Glushko's view), and that when the reading system is stressed by brain damage, it is the more difficult tasks which are the most impaired. The problem with this objection is that in another form of acquired dyslexia, namely surface dyslexia (also discussed below) it appears possible to argue that the reading aloud of at least certain kinds of words (irregular words) is more impaired than the reading aloud of nonwords: certainly, surface dyslexics are better at judging whether two printed nonwords are homophones (e.g., *afe/aif* versus *afe/auf*) than at judging whether printed irregular words are homophones (*hear/here* versus *wear/were*). Consequently there are circumstances in which deriving phonology from print may be worse for words than for nonwords (surface dyslexia) and also circumstances where it is worse for nonwords than words (phonological dyslexia); this "double dissociation" between words and nonwords is difficult to reconcile with the view that reading aloud of the two types of stimuli uses a single mechanism.

A final problem relevant here is that it is unclear what the nature of the single mechanism postulated by Glushko for reading words and nonwords actually is; it appears that two rather different views are advanced at different points in Glushko's paper.

On one view, subjects map multiletter sequences onto multiphoneme sequences, so that the essential knowledge used for reading aloud is a system of multiletter spelling-to-sound correspondences. This is what appears to be argued when it is proposed that nonwords "might be parsed into smaller units to activate analogies or specific spelling-to-sound correspondences"

(p. 678) and that "words are generally pronounced using larger units (up to the entire letter string)" (p. 675).

An alternative view proposed by Glushko is that letter sequences are *not* divided up into smaller (subword) units: instead, a letter sequence activates the internal representations of all "orthographic neighbours," and this family of activated words is then subjected to some kind of segmentation and synthesis operation. For example, a nonword like FENT might activate a family of words ending in -ENT and a family of words beginning F-; by appropriate segmentation and synthesis operations upon these sets of words the pronunciation /fent/ is computed. This alternative view is advanced (p.683), at the expense of the multiletter correspondence view: "Readers might pronounce the novel word BINT using a generalization about -INT. Perhaps such independent representations of orthographic structure do not exist at all: the -INT rule might exist only implicitly in the integrated activation of words like HINT, MINT, and TINT."

These two accounts of the procedure used for reading aloud are clearly rather different: for example, the second one uses knowledge about the pronunciations of specific words to read nonwords aloud, whilst the first does not. It is not at all clear whether either procedure is consistent with the data on reading nonwords and words aloud. If words can be read aloud using the whole word as a unit, why do words with subunits having inconsistent pronunciations (e.g., *wave*) take longer to initiate in reading aloud than words without such inconsistency (e.g., *wade*)? On the other hand, if a word activates a family of orthographic neighbours, it is unclear how the ultimate pronunciation is chosen: for example, if *tomb* activates *comb, tomb, bomb, womb,* and *aplomb,* how does the reader choose to pronounce *o* as /u/ and not /α/ or /oω/?

If each procedure fails in certain circumstances, perhaps this is why Glushko (1979, p. 686) at one point proposes that both procedures are used: but this makes matters even more complicated, since there is nothing said about what determines when one procedure is responsible for reading aloud and when the other is.

I conclude from this analysis of Glushko's work not only that his results are inconsistent with a theory of reading aloud in which nonwords are read aloud solely via GPC's, but also that the alternative theoretical framework for reading aloud which he proposes is no more satisfactory.

We are left, therefore, without a viable theory concerning how people read words and nonwords aloud.

An attempt has been made to deal with some of these problems by Marcel (1980). His view is that the mapping of letters to sounds in reading aloud occurs at the grapheme-phoneme level and at various higher levels simultaneously, up to the highest possible level at which letter sequences are recognized. For words, this highest level is the whole letter string; for nonwords, since they are unfamiliar letter sequences, the highest level of recognizable letter sequence is smaller than the whole letter string. The ultimate decision as to pronunciation relies upon an overriding mechanism according to which the highest level (largest letter-sequence unit) achieved is the one subsequently used. However, lower levels do affect the time taken to decide upon pronunciation: this must be so, or else the inconsistent phonological representations generated by the final three letter sequence in the word *have* would not affect naming latency for this word. This theoretical approach has not yet been worked out at a level of detail which would allow a satisfactory assessment of its success in accounting for reading aloud: for example, nothing is said about how letter-sound relationships below the level of the entire letter string affect the derivation of a phonological representation of the letter string as a whole. This is true for both *words* (where the problem is why the reader does not rely simply on the mapping using the whole word) and *nonwords* (where the problem is how the reader decides upon a pronunciation for, e.g., *tave,* given the pronunciations of all the words orthographically similar to this nonword, including *have* and *wave*).

A recapitulation may be in order here. This discussion of the work of Glushko (1979) was prompted by considering whether one needs to postulate two separate mechanisms for reading aloud. If one assumes that nonwords are read aloud using GPCs, then one does need to postulate two such mechanisms; but Glushko's results are inconsistent with the assumption that nonwords are read via GPCs. Glushko argues instead that there is one mechanism which accompanies reading aloud both for words and nonwords; here it is claimed that the mechanism he proposes is an unworkable one, and furthermore that there is some neuropsychological evidence for the view that two different mechanisms for reading aloud do exist.

Precisely what these mechanisms are is unknown, if one must abandon the concept of nonlexical phonological recoding using GPCs. I will refer to the two mechanisms as "word pronunciation" and "nonlexical phonological recoding" and, without being able to offer ideas as to how each actually works, will simply define them as follows. The *nonlexical mechanism* is so termed because it can be used to read aloud letter strings which have not previously been seen and hence which do not have lexical entries (i.e., nonwords); the term "nonlexical" should not be taken to mean that this mechanism makes no use of lexical information when determining the pronunciations of such stimuli. Word pronunciation is a *lexical* mechanism in the sense that it can only be used for letter strings which have been seen before and about which the reader has previously stored information concerning pronunciation (pronunciation of the string as a whole, that is).

If a reader had never seen the words *new* and *sew* before, and so had to use the nonlexical mechanism to read them aloud, he could not pronounce both correctly. Studies of nonword reading indicate that the pronunciation given to the grapheme *-ew* here would probably be /u/ because this is how terminal *ew* is pronounced in most English words, and information about the usual pronunciation of a grapheme is what determines how it is pronounced when it is part of a grapheme sequence whose pronunciation as a whole has not previously been learned by the reader. It follows from this that one may deduce that the nonlexical mechanism is being used to read words aloud if one observes that errors in reading aloud are more common with irregular words like *sew* than with regular words like *new.* Furthermore, not only should *sew* be read wrongly: it should be read as /su/ if it is being read by the nonlexical mechanism. This kind of error may be termed a "regularisation"; and, as I have already mentioned, such errors are characteristic of one form of acquired dyslexia, surface dyslexia.

If a reader is using the *non*lexical mechanism to read *words* aloud, then there must be an impairment of the lexical mechanism, since it would normally be used for reading words. The opposite impairment – an impairment of the nonlexical mechanism – would be revealed by poor reading aloud of nonwords with good reading aloud of words; and, as has also already been mentioned, this pattern is characteristic of phonological dyslexia.

It is the model described in Figure 1, then, which I will use to interpret the patterns of deficits and preservations of reading abilities displayed in the various forms of acquired dyslexia which I am about to describe. The general approach here is to propose, for each acquired dyslexia, that some of the components of the model are impaired, whilst the remainder are intact. Different acquired dyslexias will correspond to impairments of different components or sets of components. One then needs to show that impairment of a particular component or set of components would cause the system as a whole to read in the way that sufferers from the relevant form of acquired dyslexia do.

A successful demonstration that a particular selective impairment of the model would produce reading symptoms which parallel those of a particular acquired dyslexia achieves two things. The first is that an economical description of the disorder, in information-processing terms, has been obtained: a constellation of symptoms has been reduced to one or a few basic impairments. The second is that one's confidence in the usefulness of the model must be increased each time it deals in a plausible way with an acquired dyslexia.

Furthermore, one can test one's hypotheses as to which components are intact and which are impaired because tests can be devised which are specific to each component: these have already been mentioned. A patient who succeeds at cross-case matching with nonword stimuli has an intact ALI component. Success at lexical decision indicates an intact word recognition component. Success at judging whether or not words are synonyms, at obeying printed commands, or at matching words to pictures indicates an intact word comprehension component. Because irregular words can be read aloud only by using the word pronunciation component, intactness of this component is indicated by competent reading aloud of irregular words; and because nonwords can be read aloud only by using nonlexical phonological recoding, this component must be intact if nonwords can be read aloud.

Five varieties of acquired dyslexia will now be described, and attempts will be made to interpret each one within the theoretical framework offered by Figure 1. In this kind of enterprise, it is important that the descriptions of the acquired dyslexias be as atheoretical as possible: one needs to preserve a proper distance between, on the one hand, the data characterising the syndrome, and, on the other hand, the theoretical framework being offered to explain these data. Only in this way can the data survive when the theory expires. Consequently, it is hoped that even if evidence emerges (from studies of normal readers, for example) which compels one to reject or radically to modify the model described earlier in this section of the paper, the characterisations of acquired dyslexias presented in the following section of the paper will retain their validity, and will therefore be of use in future attempts at building models of reading.

VARIETIES OF ACQUIRED DYSLEXIA

Damage to the brain can impair reading in a number of different ways. Some patients, for example, show no impairments in dealing with single words, whilst showing reduced ability to comprehend continuous text; at the other extreme, patients may be entirely unable to comprehend or read aloud single words. It is difficult to study the former kind of patient, because so little is known about the comprehension of continuous text and how it may be measured, and it is difficult to study the latter kind of patient because of limitations on the amount of data which can be collected from someone with so severe an impairment. For these reasons progress in studying acquired dyslexias has been achieved mainly with patients who have both impairments and preservations at the single word level: patients who can perform some tasks with single words but not others. All of the varieties of acquired dyslexia described here are of this type.

Letter-by-letter reading

A symptom observed only in this form of acquired dyslexia is that the patient often or always can only read a word aloud if he first *names* each of the letters in the word: thus city – "/si/ . . . /aɩ/ . . . /ti/ . . . /waɩ/ . . . /sɩti/." These patients use letter *names*, not letter *sounds*, when they read letter-by-letter.

This disorder is referred to as "word-form dyslexia" by Warrington and Shallice (1980); also, since writing is usually intact in letter-by-letter readers, it seems highly likely that the traditional terms "pure alexia" and "alexia without agraphia" are synonymous with "letter-by-letter reading."

Some letter-by-letter readers have intact letter naming (e.g., case R. A. V. of Warrington and Shallice, 1980) and so their reading aloud, though extremely slow, is accurate. Other letter-by-letter readers make errors in letter naming (e.g., case C. H. of Patterson and Kay, 1980) and so their reading is not only slow but also inaccurate.

It is common in these patients that Arabic numerals are read aloud with greater ease than letters. This "number sparing" could, of course, be an effect of meaningfulness, but this appears not to be so: case B. W. (Coltheart, Bailey, and Masterson, unpublished observations) responded more promptly and more easily to four-digit numbers which he was asked to read as dates (e.g., 1911 → "nineteen eleven") than to single numbers written alphabetically (*nine* → "nine"); and he was faster at sorting single numbers into "odd" and "even" piles when they were written as Arabic digits than when they were written alphabetically.

In this syndrome nonwords can be read aloud, but (like words) they must be read letter-by-letter before the whole nonword can be uttered.

One possible theoretical interpretation of this syndrome in terms of Figure 1 is that it arises because of a disturbance in the transmission of information from the ALI system to the word recognition component; but if this were the only difficulty, the patients would not read *nonwords* letter-by-letter. The difficulty would thus appear to arise at all outputs from the ALI system: in particular, there is impaired or abolished output from this system both to the word recognition system and also to the nonlexical phonological recoding system.

Some subjects have intact output from the ALI system to the letter-name system; others, those who make errors even in naming single letters, may have a defect in the letter identification process itself, in addition to impaired or abolished communication between the ALI system and the word recognition and nonlexical phonological recoding components.

For these patients, then, there is a barrier at a very early stage of the reading system, preventing information from print reaching higher stages of the system in the normal way. The only way to circumvent this barrier is to name the letters in a printed stimulus. The ability to comprehend and to utter a word after hearing it spelled aloud is a normal linguistic ability, and this ability is intact in the letter-by-letter reader, since it does not require there to be any communication between the ALI sytem and the word recognition or nonlexical phonological recoding systems: thus an impairment of this kind of communication would not prevent a reader from being able to identify a word from hearing it being spelled, and hence spelling of individual letters is a strategem which the letter-by-letter reader can use to gain access to semantics or phonology from print.

Number sparing is of interest here. The fact that a patient may read 9 promptly, whilst only being able to read *nine* by first spelling the letters, could be explained by supposing that the route from ALIs to letter names includes links from number identities to number names. However this does not seem to be the explanation of number sparing, because patient B. W. could read arbitrary two-digit numbers (17 → "seventeen") rapidly and accurately whereas he was slow and inaccurate at reading single letters when prevented from tracing them with his finger (37/52 correct). This suggests that the system described in Figure 1 is specifically for the processing of *letters* – that is, this system is required when alphabetically-written material is to be processed, whereas there is some other system which can be used for processing ideographically-printed material. Besner and Coltheart (1979) provide evidence from normal readers of English that different mechanisms are involved in the reading of alphabetic and ideographic material.

A further interesting aspect of the behaviour of patient B. W. is that he did not make errors in letter naming if allowed to trace the letters with his finger. The accuracy of his tracing indicates that his difficulty in naming letters was not a low-level perceptual difficulty: if there had been such a defect, visual representations of letters would not have been of sufficient quality to allow correct tracing (B. W. did not trace over letters, but made tracing movements some distance away from them).

Phonlogical dyslexia

The essence of this syndrome is a severe impairment of the ability to read *nonwords* aloud, coupled with preservation of the ability to read *words* aloud – at least when these words are single-morpheme content words. The syndrome was first described by Beauvois and Dérouesné (1979) and Dérouesné and Beauvois (1979) who discuss four cases, one (R. G.) in considerable detail; there are three other published cases (Shallice and Warrington, 1980, cases G. R. N. and B. T. T.; Patterson, in press, case A. M.). Some of the information given here about these patients was provided by personal communications from these authors.

Because of the small number of cases, this syndrome is not yet clearly defined, and we cannot yet evaluate the significance of some differences between the patients. For example, R. G.'s writing was only mildly impaired, and his spelling errors were almost always phonologically correct, such as writing "enfant" as *enfans* or "eglise" as *aiglise;* A. M., on the other hand, had a severe writing deficit and never produced phonologically correct misspellings. However, all of these patients showed a major deficit in nonword reading coupled with good performance in reading single-morpheme content words. For example, R. G. read 40/40 nouns aloud correctly, whilst being able to read aloud only four of 40 four-letter or five-letter nonwords; G. R. N. performed at a normal level on reading tests involving reading aloud of single words, and read 39/40 words correctly, whilst being able to read only 3/40 nonwords. On another occasion, her scores were 19/20 with words and 1/20 with nonwords.

This dissociation between word reading and nonword reading is also characteristic of deep dyslexia (described below); but the two syndromes nevertheless must be distinguished. Deep dyslexics make semantic errors in reading aloud, and their reading aloud is better with concrete than with abstract words; neither of these symptoms occurs in phonological dyslexia. Furthermore, the incorrect responses made by phonological dyslexics are sometimes nonwords, whereas deep dyslexic responses, to words or nonwords, are essentially always words.

In addition to the disparity between word reading and nonword reading, there are several other symptoms evident in phonological dyslexia. Amongst these are:

1. Visual errors in reading aloud nonwords (e.g., *bef* → "beef" or *clest* → "calest").

2. Derivational errors in reading aloud words containing bound morphemes – that is, such words may be read with their root morphemes correct but their bound morphemes incorrect.

3. Function-word substitutions – when a function word is misread, the response is likely to be another function word, even a visually and semantically dissimilar one (*yet* → "that", *those* → "you").

4. For several of the patients function words are more likely to be misread than content words. However, this has not been observed with cases G. R. N. and B. T. T., the two patients studied by Shallice and Warrington (1980). Since the other phonological dyslexics studied were not very impaired at reading function words, it is necessary to test such patients with a large number of function words if one is to show a deficit, and this has not been done with G. R. N. and B. T. T.; so it is not yet entirely clear whether or not a deficit with function words is an invariable aspect of phonological dyslexia.

5. In two patients (R. G. and A. M.) an attempt has been made to discover whether nonword reading is improved when the nonword is a pseudohomophone (i.e., sounds identical to a real word); in both cases such improvements were observed.

6. Lexical decision ability has been studied in one patient (A. M.); it was intact.

7. Patient A. M. could match uppercase letters to their lowercase equivalents perfectly; but his naming of single letters was very much impaired.

The interpretation of this dyslexia is relatively straightforward: the syndrome arises when brain damage impairs the operation of the nonlexical phonological recoding component of the reading system. This is sufficient to explain the main feature of the disorder, namely, the severe difficulty in reading aloud nonwords. Some other aspects of the syndrome might also be explained in this way. Visual errors where the response is a word and the stimulus is a nonword (e.g., *bef* → "beef") could occur because of attempts to use the word pronunciation component to read nonwords aloud. In deep dyslexic patients, who, like phonological dyslexics, have great difficulty in reading nonwords, it has been noted that, when they attempt this task, they produce visually similar words as responses. The method, presumably, is to locate an entry in the word recognition component which is orthographically highly similar to the nonword stimulus – "approximate visual access" (Patterson, 1978; Coltheart, 1980 c).

The finding that success in reading nonwords aloud is increased when the nonwords are pseudohomophones (i.e., sound identical to real words) might perhaps be explained in the following way. If a normal reader is asked to read *phocks* and to decide whether it sounds identical to the name of an animal, he can do so. Therefore it is possible to use the result of nonlexical phonological recoding to access the word comprehension component of the system described in Figure 1. Such access could not occur with a nonword like *phacks;* it could only occur with pseudohomophones. If in phonological dyslexia difficulties in using nonlexical phonological recoding arise not only in converting print to phonology, but also in converting phonology to articulation without being able to use a stored set of prelearned phonological representations, then pseudohomophonic nonwords will encounter only the first of these difficulties, whilst non-pseudohomophonic nonwords will encounter both. This may be why reading aloud is better for the former than for the latter.

Although the symptoms just discussed might all reflect an impairment of nonlexical phonological recoding, it is not obvious why such impairment should affect the reading of *words* in any way. Nevertheless, phonological dyslexics display two kinds of difficulty in reading words: they make derivational errors, and they may be unable to read some function words aloud correctly. These symptoms are interesting because they could be taken to indicate a role for nonlexical phonological recoding in normal reading of single words, a role which has been disputed (Coltheart, 1980b). If the *only* impairment of the reading system in phonological dyslexia is in the component responsible for nonlexical phonological recoding, then the difficulties with derived words and function words evident in this syndrome would imply that the normal reader uses nonlexical phonological recoding in reading such words.

Suggestions compatible with these ideas have been made. For example, in expositions of the logogen model, it is often proposed that the entries in the visual input logogen system (the word recognition component in Figure 1) correspond not to words but to morphemes, and root morphemes at that; in this case "the input logogen which transduces between stimulus information and the cognitive system would be exactly the same unit for *walk, walked,* and *walking.* For normal comprehension, information about affixes must reach the cognitive system by a separate (though largely unspecified) process" (Patterson, 1980, p. 289). This view has been proposed by Morton (1978): in considering whether or not morphemically related words such as "sing," "sings," "singing," "singer," and "singers" would each possess independent representations in the word recognition (i.e., visual input logogen) system, he observed that "this seems very inefficient, as one could make do with one logogen plus other devices for recognizing the suffixes and adding them on in production."

Patterson (in press) discusses the possibility that her "largely unspecified process" (which corresponds to Morton's "other devices") might depend upon nonlexical phonological recoding. If this were so, of course, an impairment of nonlexical phonological recoding would result in the occurrence of derivational errors: reading responses in which the root morpheme is preserved whilst bound morphemes are processed incorrectly.

The theoretical approach proposed here by Morton and by Patterson is based upon the idea that a word consisting of a root morpheme plus one or more bound morphemes is segmented into its morphemic constituents prior to access to the visual input logogen system: this is necessary because only the root morpheme is represented in the input logogen system. For the approach to work, then, it would have to be possible to analyze words into their morphemic constituents prior to recognizing them. What kind of procedure could accomplish this? For some words it seems simple enough; for a word like UNSELECTIVELY one can imagine the common bound morphemes UN-, -IVE, and -LY being recognized and deleted, leaving the free morpheme SELECT in isolation. However, there are many words of English whose morphemic structure is much less regular. Consider the past tenses of the verbs GO and DEPART: one could recover DEPART from DEPARTED by deleting the familiar bound morpheme -ED, but how could one recover GO from WENT?

Perhaps it could be argued that irregular inflections like WENT have their own independent visual input logogens, whilst regular inflections like DEPARTED do not, and must be recognized via the visual input logogen for the root morpheme. There are two difficulties for such a proposal. The first is that the main evidence for Morton's claim that DEPARTED is recognized via DEPART is that DEPARTED primes DEPART in a way that is characteristic of a word priming itself (Murrell and Morton, 1974); and hence, if WENT and GO have their own input logogens, WENT should not prime GO. Stanners, Neiser, Hernon, and Hall (1979), however, did find that irregular past tenses primed their root morphemes (although the effect was smaller than the priming of root morphemes by *regular* past tenses). The second problem concerns derivational errors in deep dyslexia. Since nonlexical phonological recoding is abolished or greatly impaired in deep dyslexia (see below) just as it is in phonological dyslexia, the view that derivational errors in phonological dyslexia occur because of this impairment presumably implies the same explanation for derivational errors in deep dyslexia. Now, if DEPARTED is processed by accessing DEPART and using nonlexical phonological recoding to process the bound morpheme -ED whereas WENT is processed directly via its own logogen, one would expect derivational errors of the form *departed* → "depart," but not of the form *went* → "go." However, inspection of examples of derivational errors provided in Coltheart, Patterson, and Marshall (1980: see Table 2.6, pp. 32-34, and also Appendix 2) reveals numerous instances where the stimulus consists of a free morpheme plus a bound morpheme, where these two morphemes are combined in an irregular way, and where the incorrect response preserves the free morpheme, with the bound morpheme having been lost. Some examples are *truth* → "true," *hatred* → "hate," *heat* → "hot," *stolen* → "steal," *mercantile* → "merchant," *met* → "meet," *paid* → "pay," *built* → "building," *speech* → "speak," and *English* → "England."

Even the idea that morphemically regular words could be segmented into their constituents encounters difficulty: if there is a procedure which identifies RINGED as the past tense of the verb RING by deleting the -ED and determining that what remains is the root morpheme of a verb, how could this procedure avoid identifying SINGED as the past tense of the verb SING?

The concept of prelexical morphemic segmentation inherent in the views of Morton and of Patterson thus encounters a number of difficulties, which require resolution if this concept is to be retained. However, if one rejects the concept, then no explanation of the relationship between the occurrence of derivational errors and the impairment of nonlexical phonological recoding in phonological dyslexia is available, and hence two alternatives, both unsatisfactory, remain. One is that the two symptoms are causally related, but in an unknown way; the other is that the two symptoms are independent, and here one cannot explain why all patients with an impairment of nonlexical phonological recoding (whether deep dyslexic or phonological dyslexic) make derivational errors.

An unnamed dyslexia

I refer to a case described by Schwartz, Marin, and Saffran (1979) and Schwartz, Saffran, and Marin (1980). Although this dyslexia has not yet been accorded a name, and although the data come from only one patient, the disorder is of sufficient theoretical importance to deserve discussion. The patient was a 62-year-old woman with a progressive presenile dementia. She could not demonstrate comprehension of printed nouns by matching them to pictures, and her sorting of printed nouns into broad semantic categories was poor. Nevertheless, she could read aloud both words and nonwords well; and what is crucial here is that she could read aloud irregular words correctly. For example, she correctly read aloud such irregular words as *blow, one, post* and *climb* whilst also, on the same occasion, correctly reading aloud the regular words *cow, bone, cost* and *limb.*

If someone reads the segment -ow as /oω/ in *blow* but as /aω/ in *cow,* then he or she must be able to access information about the phonology of specific words, rather than, for example, using general rules for mapping graphemes onto phonemes, since such general rules could not be used to generate different terminal phonemes for *blow* and *cow*. At the same time, this patient could also read aloud even when specific information about phonology could *not* be available, since she could read nonwords aloud. Since printed words could not be comprehended by this patient whilst irregular words could nevertheless be read aloud, this means that access to the stored phonological representation of a word can be achieved even when access to its stored semantic representation cannot. In terms of Figure 1, this means that one must be able to gain access to the word pronunciation component of Figure 1 directly from the word recognition component without needing to pass through the word comprehension component. The question of direct connections from the visual input logogen system (word recognition component) to the output logogen system (word pronunciation component) was raised by Morton and Patterson (1980, p. 94): "Now that input and output logogens (once a single system) have been separated, the question of a direct connection between them must be considered. It is an open question .... For present purposes, the existence of this input-output connection in the normal system will be assumed". It is difficult to see how one could design experiments with normal subjects which could provide evidence concerning whether one need postulate such direct connections or not; the unnamed acquired dyslexia being discussed here, on the other hand, is very difficult to interpret unless one does postulate such connections.

Surface dyslexia

This disorder was named and first described by Marshall and Newcombe (1973); it has also been discussed by Holmes (1973, 1978) and Marcel (1980) and another case is described by Shallice and Warrington (1980, case R. O. G.), who refer to surface dyslexia as "semantic dyslexia."

In this disorder, and not in any of the other disorders, the patient has more difficulty in reading irregularly-spelled words than matched regularly spelled words: for example, R. O. G. correctly read 36 of 39 regular words but only 25 of 39 matched irregular words. (These two matched sets of words are listed in Coltheart et al., 1979). Furthermore, in surface dyslexia misreadings of irregular words often take the form of "regularisations"; i.e., of treating an irregular word as if it were regular: for example *pint* → /pınt/ and *broad* → /broωd/.

An important aspect of this syndrome is that it exists not only as an acquired dyslexia but also as a developmental dyslexia. This was first claimed by Holmes (1973), who described four developmental cases in addition to two acquired cases; and it has been confirmed by comparisons we (Coltheart, Masterson, Prior, Byng, and Critchlow, submitted) made between an acquired surface dyslexic (A. B.) and a developmental surface dyslexic (C. D.). Whether other varieties of acquired dyslexia also exist in developmental forms is an important question which will not be answered until individual case-study work on developmental dyslexia is more prevalent (though see, for example, Boder, 1973). It is already clear, however, that exactly the same pattern of reading errors, the pattern characteristic of surface dyslexia, occurs in some children who have failed to acquire competence in reading despite apparent neurological normality as well as in some adults who had learned to read competently but then suffered a brain injury which left their reading impaired.

If surface dyslexia consisted solely of difficulty in reading irregular words aloud with frequent "regularisations" of these irregular words, one could interpret it by proposing that some words are treated as if they were nonwords during reading aloud: such nonword treatment would allow regular words to be read aloud correctly whilst producing incorrect reading (in fact, regularisation) of irregular words. However, errors of this sort are not the only kinds of error which occur in the oral reading of surface dyslexics.

problem arises here which does not seem to arise in connection with the other varieties of acquired dyslexia. In the other varieties it its possible to describe the various symptoms in an entirely atheoretical way. In the case of surface dyslexia, however, it is curiously difficult to describe some of the symptoms atheoretically. For example, errors like *incense* → "increase" were described by Marshall and Newcombe (1973) as "partial failures of grapheme-phoneme conversion," since the grapheme *c* should be assigned the phoneme /s/, not the phoneme /k/, when the following grapheme is *e*. Here Marshall and Newcombe were assuming that whenever nonwords are read aloud (and, hence, when words are treated as nonwords), the procedure used to do this is grapheme-to-phoneme conversion. However, this assumption has subsequently been challenged (Glushko, 1978; Marcel, 1980), which compromises not only Marshall and Newcombe's theoretical interpretation of the syndrome but also, more seriously, their empirical description of it. This example illustrates the point made earlier, that it is vital to characterise each acquired dyslexia in atheoretical terms.

Advances in the understanding of surface dyslexia have recently been made by testing reading comprehension as well as reading aloud: this work, carried out with the developmental surface dyslexic C. D. and the acquired surface dyslexic A. B. by Coltheart, Masterson, Prior, Byng, and Critchlow (submitted) has revealed the following additional features of surface dyslexia:

1. Not all misreadings of words can be explained as the consequence of treating an irregular word as a regular word. There are letter deletions (*frog* → "fog"), letter additions (*an* → "and"), letter substitutions (*life* → "lift"), and letter-order errors (*sign* → "sing").

2. When a word is misread as another word, the surface dyslexic always comprehends the printed word as the word spoken, even if the comprehension is tested before the word is read aloud. When a word is misread as a nonword, the comprehension response will be "don't know". For example, C. D., when asked to define and then read aloud the word *gauge,* said "a big dip . . . gorge"; and A. B., with the same task, produced *scarce* → "fairly serious cut . . . a mark to remain after . . . scar."

3. Misreadings are not due to errors at the letter identification level. When C. D. and A. B. were given single printed words and asked to define them, then to read them aloud, then to read their letters from left to right, observations of the following kind were made:

enigma → "a picture . . . image . . . E,N,I,G,M,A" (C. D.)
check → "a part of your face . . . cheek . . . C,H,E,C,K" (C. D.)
thyme → "music that the orchestra's playing, sort of meaning of what they're playing . . . theme . . . T,H,Y,M,E"
subtle → "to stand firm . . . stable . . . S,U,B,T,L,E" (A. B.)

Thus, when the reading aloud response is wrong, comprehension is governed by what is *said,* whilst spelling is governed by what is *seen.* In these tests, where errors of oral reading and of comprehension were fairly frequent, errors in spelling aloud were virtually non-existent.

4. Interesting results are obtained with homophones: even when these are read aloud correctly, they may be misunderstood. For example, again when the task is to define a printed word first, then read it aloud, then spell it, one observes:

bury → "a fruit on a tree . . . /bɛri/ . . . B,U,R,Y" (C. D.)
bowled → "fierce, big . . . /boωld/ . . . B,O,W,L,E,D" (C. D.)
mown → "to be grumpy . . . /moωn/ . . . M,O,W,N" (A. B.)
route → "what holds the apple tree in the ground and makes it grow . . . /rut/ . . . R,O,U,T,E" (A. B.)

The basic types of error made in surface dyslexia may be illustrated by considering the following hypothetical example: suppose a surface dyslexic were given the printed word *none* to define, to read aloud, and to spell.

1. One pattern which might occur is: *none* → "Acquainted with . . . known . . . N,O,N,E". Here there has been a "regularisation"; for most words ending *o* plus consonant plus *e*, the *o* is pronounced /oω/.

2. Alternatively, one might find the following: *none* → "A religious woman . . . /n ʌ n/ . . . N,O,N,E". Here the word is understood as its homophone pair.

3. Finally, the word might be read as "one," "nonce," "bone," or "neon" – that is, a letter deletion, addition, substitution or order error might occur.

Whatever the surface dyslexic does, however, two things will virtually always be true: spelling aloud will be correct no matter how incorrect the reading response is, and the word will be comprehended in terms of the spoken response, not the printed stimulus.

Little is known about the speech comprehension of any surface dyslexics except A. B. and C. D. In these two cases, comprehension of single *spoken* words (tested by requiring definitions) appeared to be intact. Thus failures to comprehend single printed words cannot be ascribed to defective semantic representations in the word comprehension component (assuming that the same semantic representations are accessed from print as from speech). We must also assume that the ALI system is intact, because when printed words are spelled aloud errors are not made.

Consider now the three types of error described in the hypothetical example given above. When *none* is read as "known" and understood as "known" there must have been a failure of communication somewhere along the route from the ALI system (itself intact) to the word comprehension component (itself intact). If this failure were at a point *after* correct access to the entry for *none* in the word recognition system, then a double deficit would need to be postulated: from word recognition to word pronunciation (if this route were intact, the word would be pronounced correctly) and from word recognition to word comprehension (if this route were intact the word would be comprehended correctly). Thus, for reasons of parsimony if no other reasons, one might prefer to suppose that the correct entry for *none* in the word recognition system was not accessed. The reader in this case, whether he is trying to read aloud or to comprehend this printed word, must fall back upon the nonlexical phonological recoding route, and because *none* is an irregular word, it will be encoded wrongly, as /noωn/. The resulting incorrect phonological representation is the only encoding of the word available to the reader, and if this phonological encoding is used to access semantics (by a route perhaps the same as that used for speech comprehension), then the word will be both misunderstood and mispronounced. Thus failures of access within the word recognition component will, with irregular words, produce regularisation errors in both reading aloud and silent comprehension.

When *none* is read correctly but nevertheless still misunderstood (as nun), something else must have occurred. Because *none* is irregular, a correct oral reading requires access to the correct entry in the word pronunciation component; and such access can only occur if there has been prior access to the correct entry in the word recognition component. Therefore the failure to comprehend *none* correctly when it is read aloud correctly cannot be explained as a failure of access at the word recognition level: it must instead be due to a failure of communication between the word recognition and word comprehension components. When such a failure of communication occurs, the reader uses a phonological representation (retrieved from the word pronunciation component) to access the word comprehension component (i.e., uses the access method by which speech is comprehended). When a word is a homophone, this method of comprehending print does not allow the reader any way of deciding which member of a set of homophones the word is; thus a word is liable to be comprehended as one of its homophones.

In sum then, these two types of error in surface dyslexia occur because failures of access to or exit from the word recognition component compel the use of "phonological reading." There are two types of phonological reading, corresponding to the two routes from print to phonology: use of the lexical route produces correct pronunciation but possible confusion between homophones, whilst use of the nonlexical route produces with irregular words a "regularisation" and hence an error in both comprehension and pronunciation. What these two types of malfunctioning in surface dyslexia have in common is that phonological aspects of the reading system are working perfectly (retrieval from word pronunciation is intact and the non-lexical phonological recoding mechanism functions normally).

As already noted, however, there is a third category of error seen in surface dyslexia: the letter deletion, alternation, addition, or position error. One possible explanation of these is that, when the surface dyslexic cannot find an entry in the word recognition component corresponding to the word he is looking at, he does not always use the nonlexical phonological recoding system: he may sometimes settle for an entry in the word recognition system belonging to a word orthographically very similar to, but not identical with, the word he is looking at. This kind of "approximate visual access" strategy is discussed elsewhere in this paper, in connection with phonological dyslexia, and considered in more detail by Patterson (1978) and Coltheart (1980c) in relation to deep dyslexia. However, this explanation is probably wrong, because it implies that letter deletions, changes, additions, and position errors should only occur when the response made is a word, and this is not so, as the following examples from C. D. show: *girter* → /gɩte/, *drɩg* → /drɩd/, *drace* → /dræns/, *civid* → /saɩdɩv /, *golt* → /glot/, *pleck* → /plæk/.

A further complication here stems from considering the original interpretation of surface dyslexia offered by Marshall and Newcombe (1973). They suggested that there are two defects of the reading system in surface dyslexia. Translating from their terms into the vocabulary of Figure 1, the two defects referred to are (a) communication from the word recognition component to the word comprehension component sometimes fails; (b) the mechanism which performs nonlexical phonological recoding has become prone to error. Evidence indicating the need to postulate the first of these defects has been given above; but it has been assumed so far in this paper that nonlexical phonological recoding is intact in surface dyslexia. As evidence for an impairment of the use of grapheme-phoneme conversion rules, Marshall and Newcombe (1973) offered examples like *describe* → "describ" and *lace* → "lass" (here the rule according to which final *-e* should lengthen the preceding vowel is not being applied) or *gauge* → "jug" and *recent* → "rikunt" (here the rules concerning hard and soft *g* and *c* are not correctly applied). However, one could instead interpret such errors as letter deletions or letter changes; and there are many letter deletions and letter changes which could not be interpreted instead as errors of the operation of nonlexical phonological recoding (see examples of these errors given earlier). It is thus not clear whether one does need to postulate a defect of nonlexical phonological recoding in surface dyslexia; it may be that all errors which might be attributed to such a defect could instead be explained as letter deletions, changes, additions, or position errors, and it certainly is the case that one cannot explain all errors of the latter kinds as arising through defective operation of the nonlexical phonological recoding mechanism.

In this analysis of surface dyslexia, I have argued that two of the types of reading error can be explained in terms of a failure of "visual reading" which force the surface dyslexic to use one or other of the two kinds of "phonological reading." The third category of reading error has no such natural interpretation; and it is probably premature to attempt one, since not enough is known about just how one should describe, let alone explain, the errors of this third category. Even the putatively neutral set of terms "letter deletions, changes, additions, or position errors," while descriptively appropriate may at the same time offer a misleading view of this unexplained category of errors.

Deep dyslexia

This is the most intensively studied of the five syndromes described in this paper. Coltheart (1980a) refers to 22 cases described in detail during the period 1931 to 1979, and a recent book (Coltheart, Patterson, and Marshall, 1980) is devoted entirely to deep dyslexia.

The most striking symptom of this disorder, and one which does not occur in any other form of acquired dyslexia, is the *semantic error*: when the patient errs in attempting to read aloud a single word, his response is often a word which is semantically related to the stimulus. Numerous examples are given in Appendix 2 of Coltheart, Patterson, and Marshall (1980); other examples, from patients currently being investigated, are *her* → "woman," *blood* → "pressure," *gift* → "present," *book* → "read," and *soul* → "angel." Newcombe and Marshall (1980) present reasons for rejecting claims that such errors occur through misunderstanding the reading-aloud task, or through attempts to circumlocute or to free-associate.

A number of other symptoms are found in patients who make semantic errors in reading aloud. These include:

1. Visual errors (e.g., *gender* → "garden," *letter* → "lettuce," *moment* → "memory").
2. Derivational errors (e.g., *child* → "children," *paid* → "pay," *mastery* → "master").
3. Function-word substitutions: when a function word is wrongly read, the response is very often another function word (e.g., *for* → "and," *our* → "from," *up* → "at").
4. Words rated high in imageability are more often read aloud correctly than words rated low in imageability.
5. Reading aloud of nonwords is impossible for nearly all patients; a few are reported who could read a small percentage of nonwords.
6. The ability to decide whether printed letter-strings rhyme is abolished when these are nonwords, and impaired when they are words.
7. Content words are read correctly more often than function words.[8]
8. Writing, spontaneously or to dictation, is impaired.
9. Auditory-verbal short-term memory is impaired.

Two points need to be made about this lengthy list of symptoms. The first is that reading is by no means entirely abolished, despite the occurrence of all the symptoms: comprehension of concrete nouns can be excellent, for example, and Saffran and Marin (1977) estimated, using tests of comprehension, that their patient V. S. possessed a reading vocabulary of at least 16,500 words, even though she displayed all of the symptoms of deep dyslexia. The second point to be made is that this list of symptoms is not an assortment from which each patient displays a subset of symptoms: on the contrary, none of the reported patients who made semantic errors in reading aloud failed to display any of the nine symptoms in the list given above.

How might one explain deep dyslexia within the theoretical framework provided by Figure 1? Firstly, one clearly must propose a serious deficit in, or abolition of, the nonlexical phonological recoding component: this results in inability or near-inability to read nonwords aloud. Furthermore, if abolition of this component also causes difficulties with function words and produces derivational errors, as suggested by the characteristics of phonological dyslexia, then these two symptoms of deep dyslexia could also be explained. Many symptoms remain, however, including the most obvious one, the semantic error, plus the imageability effect, the part-of-speech effect, and the difficulty in phonological processing of words (shown by difficulty in judging whether printed words rhyme).

It follows that, if one wishes to interpret deep dyslexia as arising from the use of a damaged form of the reading system described in Figure 1, more than one of the components of this system must be damaged. Morton and Patterson (1980) offered such an interpretation in terms of multiple damage. In order to encompass all of the major symptoms of deep dyslexia, they had to postulate all of the following loci of damage:

1. The nonlexical phonological recoding component is not functional (hence nonwords cannot be read aloud).

2. The direct connections from the word recognition component to the word pronunciation component are not functional (if they were functional, all words could be read aloud, even if nonwords could not).

3. Semantic representations of abstract words in the word comprehension component are impaired. This means that, of the three routes from print to speech in Figure 1, two are impaired for both abstract and concrete words (namely, the nonlexical phonological recoding route and the direct route from word recognition to word pronunciation whilst the remaining route (via word comprehension) is impaired for abstract words. The result will be that fewer abstract words than concrete words will be read aloud correctly.

4. Communications between the word comprehension component and the word pronunciation component are impaired in such a way that, for some words, the semantic code accessed does not uniquely identify a single entry in the word pronunciation component, but instead identifies only a family of semantically related entries (and an incorrect choice from this family will lead to a semantic error). Alternatively some entries in the word pronunciation component are inaccessible: the words corresponding to these entries will thus be understood but cannot be read aloud (or, if the

patient is reluctant not to respond, he may produce a semantic error which he can identify as an error).

6. A linguistic processor, located in the word comprehension component, is impaired (hence derivational errors; and this may also explain difficulties with function words).

It is plain that to interpret deep dyslexia within the framework offered by Figure 1 is very complex, especially by contrast with the interpretation of the other acquired dyslexias described here; their interpretations do not call for many loci of impairment. This may conceivably be because much more is known about deep dyslexia than about other acquired dyslexias. An alternative and radically different possibility is that, whilst the other acquired dyslexias discussed here do reflect the functioning of a partly damaged version of the normal reading system, deep dyslexia does not. Instead, in deep dyslexia the normal reading system does not function at all, and the patient's reading is mediated by an entirely different system. This view has been argued by Saffran, Bogyo, Schwartz, and Marin (1980) and by Coltheart (1980 c): their view is that the normal reading system, located in the left hemisphere, is entirely non-functional in deep dyslexia, and that a quite different system, located in the right hemisphere, is responsible for reading in this syndrome.

A disadvantage of the claim that deep dyslexia reflects reading by a normal reading system which has suffered impairments to many components is that these components are supposed to be independent; if so, they should be independently damageable. For example, impaired representation of abstract words in the word comprehension component and impaired communications between the word comprehension component and the word pronunciation component should be independently occurring symptoms; this means that patients should exist who have the former symptom without the latter. Such patients would show as large an imageability effect on reading aloud as do deep dyslexics, but would not make semantic errors. I know of no reports of patients exhibiting this pattern of performance. Such patients may nevertheless, be observed in the future, and if they are this would strengthen the Morton-Patterson interpretation of deep dyslexia.

If deep dyslexia reflects right-hemisphere reading, the symptoms of deep dyslexic reading should tally with characteristics of right hemisphere linguistic processing; and some attempts at assessing the degree to which this correspondence holds were made by Coltheart (1980 c), who suggested that studies of normal readers might be taken to indicate the following:

1. The right hemisphere cannot derive phonology from print non-lexically.

2. The right hemisphere possesses more adequate semantics for concrete words than for abstract words.

3. The right hemisphere is liable to make semantic errors.

4. In Japanese readers, the right hemisphere is superior at dealing with the ideographic script *kanji* than the syllabic script *kana*.

A person who could only use his right hemisphere for reading would thus be unable to derive phonology from print nonlexically, would be worse at abstract words than concrete words, would make semantic errors, and (if Japanese) would read kanji better than kana. All of these symptoms occur in deep dyslexia.

A quite different line of evidence which may be used to support an interpretation of deep dyslexia in terms of right-hemisphere reading is provided by studying the nature of the lesions in the brains of deep dyslexic patients. Computerised tomographic brain scans for five deep dyslexics are reproduced in Appendix 1 of Coltheart, Patterson, and Marshall (1980). All five scans indicate extremely large left-hemisphere lesions. In other forms of acquired dyslexia, lesions may be much smaller than these.

Further details of the argument concerning deep dyslexia as right-hemisphere reading are given in Coltheart (1980 c), and will not be repeated here. Instead, two of the difficulties for this interpretation of deep dyslexia will be noted.

Firstly, as Patterson (see Coltheart, 1980c p. 353) pointed out, comparisons between letter-by-letter reading and deep dyslexia raise problems for the right-hemisphere interpretation of deep dyslexia. Letter-by-letter readers with no right-hemisphere damage should be able to use the putative right-hemisphere reading system, and this should permit prompt and accurate reading of at least some words. Instead, in letter-by-letter reading, words are read by the laborious, and often inaccurate, letter-by-letter method. If there is a right-hemisphere reading system, letter-by-letter readers would profit by using it; why don't they? A possible answer to this question emerges from considering the anatomical bases of the two disorders. It appears that in deep dyslexia there is extremely extensive left-hemisphere damage, as mentioned above. In letter-by-letter reading, it is usual for two lesions to exist: one in the left occipital region and one in the splenium (the posterior part of the corpus callosum). A traditional explanation of letter-by-letter reading is that the angular gyrus of the left hemisphere, a region crucial for reading, cannot receive input from either visual half field. Input from the right visual half field cannot occur because of the left occipital damage; input from the left visual half field cannot occur because the pathway from right occipital cortex to left angular gyrus uses the splenium. If the splenium is used generally to transmit semantic information from a right-hemisphere reading system to a left-hemisphere speech output system, damage to the splenium could prevent a reader from making use of an entirely intact right-hemisphere reading system. It would be necessary here to assume that information about individual letter identities can be transferred by some nonsplenial callosal pathway.

A more serious problem is presented by a patient described by Warrington (1981). This patient, with left-hemisphere damage, showed an imageability effect in reading aloud: but for him it was abstract words which were easy to read and concrete words which were difficult. He could read *opinion, manner, truth,* and *nature,* for example, but not *carrot, thigh, garage,* or *cheese.* If the left hemisphere can deal with both abstract and concrete words, whereas the right hemisphere can only deal with concrete words, it is easy to see how a lesion could produce a patient who can read only concrete words; but how could a lesion produce a patient who can read only abstract words? To put this another way: since this patient appeared to have an intact right hemisphere, why could he not use his right-hemisphere reading system to read concrete words?

A RÉSUMÉ

Consider first of all how the system described in Figure 1 is used for reading aloud. The first stage of processing is the accessing of the correct abstract letter identities in the ALI system, and the output of information (about letter identities) to the word recognition component and the nonlexical phonological recoding component. When such output fails to reach these two components, the only method of gaining access to higher stages of the reading system (such as the word comprehension or word pronunciation components) will then be via explicit serial naming of the letters in the letter string being inspected: this will result in the syndrome of letter-by-letter reading.

If the ALI system functions correctly and its output succeeds in reaching the word comprehension and nonlexical phonological recoding components, a defect of the latter component will mean that nonwords cannot be read aloud correctly whilst words can (this is phonological dyslexia), whilst the opposite defect – correct functioning of nonlexical phonological recoding with a defect of access to, or exit from, the word comprehension component – will result in surface dyslexia, in which there is extensive reliance on the nonlexical reading route even for lexical items for which the lexical route is normally available.

An inability to access entries in the word comprehension component will not, in terms of Figure 1, affect reading aloud: it will only affect reading comprehension.

Consider next how the system described in Figure 1 is used for reading *comprehension*: here what is needed is access to the correct entry in the word comprehension component. In letter-by-letter reading such access cannot be achieved in the normal way via the word recognition component. It is achieved instead by just the method that an intact subject would use when asked to make judgements about the meanings of words which are spelled out to him. In phonological dyslexia, since it is proposed that the lexical route is intact and that the only damage is to the component responsible for nonlexical phonological recoding, reading comprehension should be intact.

Comprehension in phonological dyslexia has been studied by Patterson (in press: patient A. M.). This patient's performance at matching pictures to printed words, and at judging whether pairs of printed words were synonymous or not, was good, as was his performance in lexical decision tasks (even with function words or abstract words). However, reading comprehension for single printed words did not seem to be entirely intact: there appeared to be comprehension difficulties for certain function words, and there were derivational errors in comprehension. The latter kind of error was demonstrated by showing that A. M. made errors when asked to choose which of two derived forms of the same root morpheme was the one which fitted correctly into a sentence frame. These results suggest that we may need to conclude, from studies of phonological dyslexia, that the nonlexical phonological recoding component of Figure 1 has a part to play in reading comprehension, and this would be a particularly clear example of the way in which neuropsychological data can be used to indicate ways in which models of normal reading may require revision or extension.

In surface dyslexia, since "phonological reading" is used so extensively, comprehension will often be achievable only by using phonological representations to access the word comprehension component. This will happen whenever access to the correct entry in the word recognition component fails, or when it succeeds but communication from the word recognition to word comprehension component fails. In these circumstances regular non-homophonic words may be comprehended correctly from print, because their phonological representations can be encoded correctly by nonlexical phonological recoding and are unambiguous. On the other hand, homophonic words whose phonological representations are ambiguous may be mutually confused in tests of comprehension of printed words; irregular words, which will be assigned incorrect phonological representations by nonlexical phonological recoding, will sometimes therefore not be comprehended correctly.

If there is impairment to the word comprehension component, then, of course, comprehension of the printed word (and the spoken word) will be reduced or abolished, even though reading aloud may be intact (the unnamed dyslexia).

This summarises how one might interpret the characteristics of oral reading and reading comprehension in four acquired dyslexias (letter-by-letter reading, phonological dyslexia, surface dyslexia, and an unnamed dyslexia), using the same approach to all four. This approach consists of starting off from the model described in Figure 1, then indicating for each disorder which components are intact and which are impaired, and finally attempting to show how the particular pattern of deficits and preservations proposed should yield the particular set of symptoms observed.

The fifth acquired dyslexia described in this paper, deep dyslexia, appears not to be amenable to this approach; I have argued that a different kind of account is needed for this syndrome. The view I have taken is that one cannot account for the symptoms of this syndrome in terms of a pattern of deficits and preservations of the components of the model shown in Figure 1. Instead, it is suggested that deep dyslexic reading is accomplished by a quite different system – a system located in the right hemisphere. If this is so, then one cannot use deep dyslexia as a tool for investigating the nature of the normal reading system, as one can use the other acquired dyslexias. On the other hand, one may be able to use deep dyslexia as a tool for investigating the nature of right-hemisphere linguistic processing. In the limit, if the right-hemisphere account of deep dyslexia were correct, then testing the reading of a deep dyslexic would be equivalent to testing the reading of the right hemisphere of a split-brain patient, with the advantage that in deep dyslexia language lateralisation may be assumed to have occurred normally (since there was no preadolescent brain damage) whereas in the split brain patients abnormal lateralisation is very likely (since in most of these patients there was brain damage dating from infancy). Thus the right hemisphere of the deep dyslexic may be comparable to the normal right hemisphere, whilst the right hemisphere of the split-brain patient may not.

1. In this situation the term "abstract visual code" is sometimes used, the claim being made that a comparison of abstract visual codes would allow the response "Same" to DENGAR/dengar. This use of the term "abstract visual code" is, however, logically incoherent. It may well be that an abstract code could be used to identify D with d; but surely there is no sense in which this code is *visual.* The adjective "abstract" here conveys the idea that the code is *not* tied to some physical modality such as sound or vision, but is abstracted away from concrete physical representation.

2. Occasionally one finds that the term "name code" seems to be used in such a way that it is not synonymous with "phonological code." This seems to me a misuse of the term "name," and in fact Posner has used, as a synonym for "name code," the term "phonetic code" (Posner and Rodgers, 1978). I therefore treat "name code" and "phonological code" as synonymous.

3. If "Different" pairs are chosen randomly, there will obviously be a high correlation between visual similarity and homophony/nonhomophony, and so a high degree of accuracy might be achieved using visual criteria. This confounding can be avoided by judicious choice of "Different" pairs, as in the example above: the degree of visual similarity between SO and SEW is identical to the degree of visual similarity between NO and NEW. Thus use of visual criteria with such stimuli could not produce above-chance accuracy: using phonological codes is the only way to succeed.

4. Many letters (e.g., C O U I etc.) are very similar in their uppercase and lowercase forms. For these letters, matching across case might be a visual process. We avoided this possibility by constructing all our nonword stimuli from the letters GARDE and N; for these six letters, uppercase and lowercase forms are quite dissimilar.

5. Of course, one could judge that A and a are the same by using letter names; but if one assumes, as is assumed in Figure 1, that when letters are named they must first be assigned correct ALIs, then correct letter naming implies that the ALI component is functioning correctly. Therefore, even if cross-case matching of letters or non-words uses letter names rather than letter identities, intact performance on this task indicates intactness of the ALI component in Figure 1.

6. This assumption would certainly not be accepted by all of those to whom a model of the form shown in Figure 1 is congenial. It might well be argued, for example, that the word comprehension component is involved when lexical decisions are made. The occurrence of semantic priming effects in lexical decision tasks does not demand this, however, since feedback from the word comprehension component to the word recognition component could account for such effects even if lexical decisions are made solely by monitoring the word recognition component.

7. *Route* and *root* are homophones in British English.

8. It has been claimed in the past that even within the category of content words, there is a part-of-speech effect, nouns being read better than adjectives, which are read better than verbs. However, since there is a correlation between part of speech and imageability/concreteness, the previous work on this subject, which has not balanced imageability/concreteness across the different parts of speech, is unsatisfactory. Allport (personal communication) has selected a set of nouns and a set of verbs matched on imageability. This material has been administered to four deep dyslexics so far: and none has shown worse performance with verbs than with nouns.

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Word Processing in Reading: A Commentary on the Papers

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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

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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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