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ABSTRACT

Research on adult readers' word recognition skills is used in this paper to develop a general information processing model of reading. Stages of the model include feature extraction, interpretation, lexical access, working memory, and integration. Of those stages, particular attention is given to the units of interpretation, speech recoding and the nature of lexical indices, and the possible influence of syntactic and semantic context clues on word recognition. Although some of the details about the mechanisms underlying those stages can be described, more research must be done on how skilled readers use context before the model can be applied to beginning reading instruction. Discussion following presentation of the paper is included. (RL)

Word Recognition: Theoretical Issues and Instructural Hints

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Running Head: Word Recognition

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I. INTRODUCTION

All of us here are concerned with reading, but there's been a division of labor. Our task is to focus on what psychologists know about the recognition of words, and see what this suggests about the teaching of reading. Right away there are problems. For one, constraints of time and space make it impossible for us to provide an extensive summary of the experimental and theoretical literature on word recognition. So we will be selective in our review of this literature, concentrating where possible on issues that may have some relevance to instructional concerns.

This brings us to our second problem. Since the research literature on word recognition is mainly concerned with adult skilled readers, how can we relate these findings to beginning readers? For example, suppose the adult literature tells us that skilled readers do not need to convert written words into speech in order to recognize them; does it follow that children should be discouraged from using such conversions when learning to read? Not necessarily. Perhaps converting words to some sort of speech code is a necessary first step in the developmental path that culminates in fluent reading without conversion to speech. The problem, in a nutshell, is that while we may have some idea of what skilled reading looks like, we haven't the foggiest notion of how to get there. Without this requisite developmental knowledge, it's simply impossible to draw strong implications about reading instruction from the research on adult word perception. The best we can do under these circumstances is look at the adult literature for hints on what needs to be taught. After all, even though we don't know how to get to skilled reading, it's got to be a help to know where we're going. Some of you may think this an awfully precarious strategy, but may we remind you of Lyndon Johnson's finest line, "I'm the only President you've got." Let's see then what we can do with what we've got.

II. AN INFORMATION PROCESSING APPROACH TO READING

A. Metatheoretical Considerations

The research on adult word recognition is dominated by one approach, called information processing. The general idea is that mental abilities, like reading, can best be understood as an integrated composite of primitive mental operations. This approach is sometimes contrasted with the view that reading is a wholistic activity that cannot be divided into component processes. This business of parts vs. wholes comes up in reading instruction as well, and we are clearly on the side of the parts people. That is, we believe that training on individual component processes of reading is feasible, and that at least some reading problems may be due to problems in a specific component process.

An information processing analysis entails more than dividing a mental ability into component parts. This kind of analysis starts by likening mental processing to a computational system, and then endeavors to spell out the exact sequence of computational mechanisms involved in executing a complex ability. It asks not only what components are involved, but also how they are sequenced and integrated so as to produce the output (reading) we are interested in. This approach therefore differs in a fundamental way from the use of factor analytic techniques to divide a mental ability into component processes. Factor analytic techniques do not tell us how the component parts are sequenced and integrated, while information processing analyses attempt to do so.

The information processing analogy with computational devices imposes some constraints on what can count as a component. The components that information processors are concerned with tend to be those that have wide applicability in a multitude of skills, and that can be realized (at least in principle) on real machines. Some examples would be comparing two chunks of information to determine if they match, or replacing one kind of symbol with another. Information processing models abound with such primitive components, and numerous experiments have attempted to study these components in isolation.

The relevance of all this is that we think an information processing analysis is the best one around for conceptualizing reading. Our main reason for thinking so stems from a consideration of causality. Take an example involving eye movements. Any analysis of reading into subskills might hit upon brief eye fixations as a component of fluid reading; this could lead educators to try to improve reading skills by training students to have brief eye fixations while reading. The folly of this stems from the lack of concern about the causal status of eye fixations in skilled reading. The duration of a fixation has long been known to be partly determined by how long it takes the reader to extract and interpret the input information (e.g., Tinker, 1958). Cutting down the time allowed for these processes is unlikely to help anyone who is slow on these processes to begin with. This does not mean that the study of eye movements per se is useless for analyzing reading; rather, eye movements themselves must be studied within the context of an information processing analysis (see Shebilske, 1975, for a nice example of this). Our next step, then, is an outline of an information processing model of reading. Models of this type, when fully developed, should give us good ideas as to the tasks on which training will transfer to reading.

A. A Partial Model of Skilled Reading

There are numerous information processing models of reading around (see, e.g., Massaro, 1975), but none of these are perfectly suited for our purposes. We need a rather general model so we can remain open on the critical substantive issues. Figure 1 contains such a proposal.

Insert Figure 1 about here

The model, derived from Kleiman (1975), is not intended as a complete description of reading. Rather it consists of *some* of the component processes that must be included in any information processing explanation of reading. We will mention some of the missing components as we go along. What the model is supposed to do is: (a) provide a means of organizing some of what we know about skilled reading; (b) give us a way of raising critical questions about reading and make it possible to draw some distinctions among possible answers to these questions; and (c) force us to think about specific issues in word recognition in the context of reading as a whole. (In what follows, it is important to note that this is a model of skilled, i.e., college-level, reading, and that most of the empirical work we will discuss used college students as subjects).

The input to the model is written text. We know that the eyes make contact with the text in successive fixations. However, to keep things from getting too complex, we will ignore eye movements and fixation span. We will simply assume that the eyes are always in position to provide a visual pattern which serves as the input to the first stage in our model.

The first process involves getting a description of the input. In line with almost all recent work on this issue, we assume this description is in terms of distinctive features, though there must also be some mention of the structural relations between features (see, e.g., Reed, 1973). The exact nature of the features involved remains an open question. Clearly some features will distinguish between letters, like the horizontal line that discriminates G from C; other features may pertain to letter groups or spelling patterns, like the inter-letter spacing that distinguishes th from sh; still other features may be characteristic of whole words, like the length of a word or the pattern of ascending and descending letters within it. While this issue of features is clearly of foundational importance to reading, we have little new to say about it, and we will not pursue it further.

Next the reader must interpret the featural information. A featural description can be said to be interpreted when it has been matched or assigned to some stored category. That is, we think of the reader as walking around with a set of pre-existent categories, corresponding to different letters, different spelling patterns, different syllables, and different words. Since several levels of categorization are possible, a crucial question arises: What is the usual level of interpretation for skilled readers—individual letters, spelling patterns, syllables, or words? Or to use the terminology of Smith and Spoehr (1974), what is the functional unit of interpretation? This question seems potentially relevant to reading instruction, for problems in reading could be associated with inappropriate units of interpretation. Later we shall treat this unit question and related issues at length.

The next stage in our model is Lexical Access. The lexicon is like an the sounds of words, rather than the orthography. This would require a conversion to a speech code before lexical access could occur, and therefore an additonal stage would be needed in our model. We will return to the nature of lexical indices in a later section.

Returning to Figure 1, the reader is now up to the stage of Working Memory. This includes all the processing mechanisms the reader needs to comprehend a sentence once he has the requisite syntactic and semantic information about individual words. But why do we call it Working Memory? Because we believe these comprehension procedures are carried out in a limited-capacity system that both performs computations and stores material on a temporary basis (see Baddeley & Hitch, 1974). Clearly some sort of temporary storage is required. For example, in comprehending a sentence like The boy who has red hair and doesn't like school went fishing, the reader must store the noun phrase the boy while processing the relative clause, and then hook up the stored noun phrase with the action described in the verb phrase went fishing.

As for the processes involved in this stage, there must be at least two different types. First, we need syntactically-based parsing operations that divide a sentence into its grammatical constituents. We have in mind something like a standard phrase-structure analysis. These parsing operations are also useful in determining the function of each constituent, either a grammatical function like subject and object, or a more semantically-based function like agent and recipient. It is these parsing operations that allow the reader to comprehend the difference between The dog bit the man and The man bit the dog, as well as the similarity between The dog bit the man and The man was bitten by the dog. Second, we need semantically-based processes that allow the reader to combine the meanings of individual words into larger meaning units like clauses and sentences. These combinatorial internal dictionary that stores information about individual words. Lexical access is simply the retrieval from memory of this information. As shown in Figure 1, we divide each lexical entry into two parts, the lexical index and the lexical information. The index must be located for lexical access to occur, and consequently these indices must be organized in some way so that the proper one can be located efficiently. (This is analogous to the words in a real dictionary being organized alphabetically.) The index leads to the lexical information, which consists of both syntactic and semantic information.

There are a couple of critical questions that arise in relation to the Lexical Access stage. One is, What is the nature of semantic representations in the lexicon? This question is clearly relevant to listening as well as reading, and consequently we will not dwell on this issue here. (See Clark & Clark, in press, and Smith, 1976, for recent review of this issue.)

Another important question here is: What is the nature of lexical indices and how are they organized? As our model now stands, this is closely tied to the issue of the functional unit of Interpretation. For example, if the lexicon is organized by the individual letters of each word (like a real dictionary) then individual letters must be the output of the Interpretation stage. If the lexicon is organized as a syllabary, then syllables must be the output of Interpretation. However, we are open to the possibility that the output of the Interpretation stage does not directly provide the input to the Lexical Access stage, but rather must undergo some transformation first. For example, it is possible that lexical indices are specified in terms of procedures must be capable of selecting out particular meanings of words in the context of other words, as when we interpret the container to be something like a bottle in The container held the drink, but something like a basket in The container held the apples (Anderson & Ortony, 1975). In any event, parsing and combinatorial processes together yield a representation of a clause or sentence. This is the output of the Working Memory stage.

The questions that arise about this stage form the core of most contemporary work in psycholinguistics. Thus psycholinguists are concerned with the nature of: (a) parsing devices (e.g., strategies as in Bever, 1970, or algorithms as in Kaplan, 1973); (b) semantic combination rules (e.g., Katz & Fodor, 1963); and (c) the final representation of a sentence (e.g., Anderson & Bower, 1973; Clark & Clark, in press; Norman & Rumelhart, 1975). Obviously these questions are relevant to listening as well as reading, and we again plead for a division of labor as we are primarily interested in the initial stages of the reading model. There is, however, one question about the Working Memory stage that is relevant to the initial stages. Can the result of this stage—a larger meaning unit—in some sense feed back to earlier stages of processing? That is, can the Interpretation or Lexical Access of words be facilitated by semantic context? This is one of the most fascinating issues in current research, and we will later spend some time on it.

The final stage of the model integrates the semantic representation of a clause or sentence with the previous context and with other knowledge stored in long-term memory. This is presumably the goal of most reading. Again the issues involved are basic to all psycholinguistic skills (see, e.g., Kintsch & Van Dijk, 1976; Rumelhart, 1975), and again we will not pursue them in this paper.

C. Relevant Issues

In our discussion of the model, we hit upon three critical issues about word recognition that we intend to deal with at length. These include: (1) the units of interpretation, (2) the nature of lexical indices, and (3) the possible influence of syntactic and semantic context on word recognition. The next three sections deal with these issues in turn.

Before turning to them, however, there is one more issue that must be confronted. Our model characterizes reading as a sequential progression through various stages of processing. The information starts as features, is converted to interpreted visual patterns, then to lexical indices, next to syntactic and semantic representations of individual words, then to an integrated semantic representation, and finally becomes part of our general stored knowledge. Such sequential processing is the way of most reading models, in fact of most information processing models in general. But there is an alternative to this. What we have called stages can be thought of as various sources of information about the input, and some of these might operate simultaneously and interactively (as suggested by Norman & Bobrow, 1975). Consider an example. Suppose the reader initially extracts only a few features and forms a tentative interpretation on this basis. Then the reader attempts to access the lexicon via this tentative interpretation and simultaneously checks the input information further for features that would confirm his tentative interpretation. Now the stages of Feature Extraction, Interpretation, and Lexical Access are all going on simultaneously; furthermore there is an interaction between the first two stages since the tentative outcome of Interpretation is directing the future course of Feature Extraction. We could complicate this still further by also permitting Lexical Access and semantic representations to be tentative and feedback to earlier stages. In this way, we would eventually arrive at a situation where all stages operate simulataneously and interactively.

This example essentially modifies the model in Figure 1 by allowing information to flow from higher-level stages to lower-level ones. In the parlance of computer science, this is known as top-down processing, while information flow from lower to higher levels is called bottom-up processing. Using this terminology, the issue we are concerned with is whether reading consists entirely of bottom-up processes, or whether top-down processes also play a role? This strikes us as one of the most important questions that one could raise about skilled reading (Don Norman has been raising it for years), but we do not think it can be given a global yes or no answer. Rather for each stage or source of information, one must ask whether specific higher-level sources affect it. Only if the answer is no in each case (a most unlikely event), can the model in Figure 1 remain unchanged. This top-down issue will be considered further in the following sections.

III. UNITS OF INTERPRETATION AND RELATED ISSUES

In the past decade, there has probably been more experimental research on the perception of letter strings than on any other topic that relates to reading. A good deal of this research has dealt with the effects of structural factors (like orthographic regularity and lexical status) on the perceptibility of letter strings. The major results that have emerged have substantially altered the way psychologists think about the Interpretation stage of reading. These results indicate that certain structural factors, once thought to influence reading only at later stages, instead have their effect as early as the Interpretation stage. In what follows we will first present some of the findings of interest, and then consider some theoretical explanations of these results. (The following literature review is quite selective; for fuller discussions see the recent reviews by Baron, 1976; Henderson, 1976; and Kreuger [illegible]

A. Critical Findings

1. Some background. The precursor of the recent research on structural factors is Reicher's (1969) rediscovery that an adult reader can perceive a word more accurately than an unstructured letter string. We call it a rediscovery because much the same thing had been demonstrated by Cattell (1886) more than eighty years earlier. Cattell found that when a letter string was presented tachistoscopically, subjects could accurately report more of the string when it formed a word than when it consisted of unrelated letters. Cattell, however, always required his subjects to report the entire item, and this made it possible that his word-superiority effect was really due to memory or response factors. For example, words and unstructured letter strings may have been equal in their perceptibility, but subjects may have had a bias to report words in those cases where they did not extract sufficient information from the tachistoscopic presentation. To rule out such possibilities, some methodological refinements were needed. This is exactly what the Reicher (1969) study supplied.

In Reicher's paradigm, a tachistoscopic presentation of a letter string—be it a word or a set of unrelated letters—was immediately followed by a two-alternative, forced-choice test of one of the letter positions. An illustration should be helpful. On one trial a subject might be presented the word READ, followed by the alternatives R and H above and below the position of the first letter; the subject's task was to decide which of the two alternatives had occurred in the string. On another trial, a subject might be presented the unstructured string RDAE, again followed by the alternatives R and H above and below the position of the first letter; and again the subject would have to decide which of the two alternatives had been presented. This paradigm, called probe recognition, effectively eliminates any report bias favoring words, since when a word is presented both alternatives form words, and when a nonword is presented both alternatives form nonwords. With this more precise methodology, Reicher was able to reproduce Cattell's superiority of words. This implied that words had an advantage over unstructured nonwords at a very early stage in reading. A host of subsequent studies, using comparable paradigms, have documented this basic effect. Reicher's study was thus important not only for the results it produced, but also for the methodology it introduced. We shall not dwell on methodology in what follows, but rest assured that any finding we present has been established (at least once) in a paradigm as pure as Reicher's probe-recognition task.

Finding that words are more perceptible than unstructured nonwords was the first step. The next was to ask what mediated this effect. Was it that words conform to English orthography while unstructured nonwords do not, or that words per se have some priviledged status in the Interpretation stage? Baron and Thurstone (1973) and Manelis (1974) were among the first to explicity raise these issues, and we now have some idea of the contributions of orthography and "wordness" in the perception of letter strings.

2. Orthographic effects. Perhaps the best way to demonstrate that conformity to orthographic rules facilitates perception is to vary the

orthographic regularity of nonwords and show that regular nonwords are better perceived than irregular ones. In this way we can study orthographic effects in isolation. For example, BLOST conforms perfectly to orthographic rules, STOBL less so, and TSXBL not at all. If orthographic regularity facilitates perception, then BLOST should be perceived the best of the three and TSXBL the worst.

Numerous experiments have used this strategy, and they consistently show that the perceptibility of a letter string increases with its orthographic regularity (e.g., Baron & Thurstone, 1973; Gibson, Pick, Osser, & Hammond, 1962; Spoehr & Smith, 1975). Furthermore, at least some of these studies have shown that the structure effect was not mediated by the simple frequency with which letter groups appear (e.g., Spoehr & Smith, 1975). This suggests the effect was due to the reader's knowledge of orthographic structure.

3. Wordness effect. We now want to consider if any of Reicher's word-superiority effect was due to wordness per se. That is, are words more perceptible than nonwords that are equally structured, e.g., is BLAST easier to perceive than BLOST? Several experiments has addressed this question, and the most recent ones leave no doubt that words have a perceptual advantage over comparable nonwords (Juola, Leavitt, & Choe, 1975; Kroll, 1974, Manelis, 1974; McClelland, 1976. So wordness joins orthographic regularity on our list of factors that can facilitate the perception of letter strings. That two distinct factors are involved has been shown by Kroll (1974). She demonstrated that some experimental variables (like whether a block of trials contained items of the same structural type or not) affected the magnitude of the orthographic effect but left the wordness effect unchanged.[2]

4. The word-letter effect. In addition to a difference between words and nonwords, Reicher's (1969) original report also contained another interesting result. Words were better perceived than individual letters. This effect is of considerable importance to anyone interested in reading, for it argues strongly against a letter-by-letter approach (as Brewer, 1972, pointed out in his criticism of Gough's, 1972, controversial letter-by-letter model). The word-letter effect has now been demonstrated in numerous sophisticated paradigms (Estes, 1975; Johnson, 1975; Johnston & McClelland, 1973; Wheeler, 1970), though there is still some uncertainty about the conditions needed to produce it (Johnston & McClelland, 1973; Mezrich, 1973).

We have classified the word-letter effect separately from the preceding factors because of our uncertainty about what the present effect is due to. It seems unlikely that the word-letter difference can be reduced to a wordness factor; A and I are words as well as letters, yet both can be better perceived when embedded in a word than when presented alone (Wheeler, 1970). It is possible that the effect is somehow due to orthographic structure, but this is difficult to determine without a complete list of orthographic rules.

5. Task factors. Thus far we have considered only structural or stimulus effects. It turns out, however, that all of these effects may depend on the reader trying to interpret letter strings at the level of letter groups and words. For when the reader is given a task that induces him to interpret letter strings at the level of features, all of our structural effects simply disappear (Estes, 1975).

Let us illustrate this interaction of task and structure. Thompson and Massaro (1973) studied the word-letter effect in a paradigm where the four words APE, ARE, ADE, and ACE, and the four letters P, R, D, and C, were repeated hundreds of times. Thus the only thing that really varied was whether a P, D, R, or C occurred, alone or in a word, and subjects were aware of this. Under these circumstances, it seems likely that subjects restricted their interpretations to the features of the critical letters, and sure enough there was no longer any difference between the perceptibility of words and letters. In like manner, the difference between words and unstructured nonwords can also be eliminated (e.g., Bjork & Estes, 1973; Massaro, 1973).

We think this set of studies has something important to say about the nature of skilled reading. The reader seems to have remarkable flexibility even in some of the initial stages of the reading process. Specifically, the reader seems capable of varying his level of interpretation so as to fit task demands. We also know from other sources that the later stages of reading are characterized by flexibility (e.g., Mistler-Lachman, 1972). In fact, the only stage of the reading process that does not seem to be very amenable to change is the first one, Feature Extraction (see, e.g., Shiffrin & Geisler, 1973). The general picture of a skilled reader that emerges is of one who can readily alter most of his processing to fit the situation.

B. Theoretical Explanations

1. Overview. We know, then, that orthographic regularity and wordness can facilitate perception, that words are even more perceptible than their constituent letters, and that all three of these effects arise whenever the reader is operating at a level higher than that of letter analysis. The problem is how to account for these effects in the context of the general model we presented earlier.

There has been no shortage of explanations to account for some of the effects we described, but it is not our intention to review all proposed explanations. (For an attempt to do so, see Smith & Spoehr, 1974.) Rather, we will focus on one class of explanations that seems to us to be quite promising. The type we have in mind assumed that the effects of interest are all due to the reader interpreting letter strings in terms of multi-letter units. Thus, while any letter string can always be interpreted in terms of single letter units, structured nonwords can also be interpreted in terms of letter-group units, while words can further be interpreted in terms of word units. This idea derives from Frank Smith's (1971) conception of reading. But we will have to go beyond Smith's theory, for his work was done before some of the findings of interest had been discovered. What we will do, therefore, is combine some of Smith's ideas with recent notions of LaBerge and Samuels (1974), Estes (1975), and Travers (personal communication, 1974), and sketch a detailed account of the Interpretation stage. Our sketch should be treated as a kind of <u>modal</u> model for the class of current explanations that emphasize multiletter units of interpretation.

2. <u>The Modal model</u>. Figure 2 contains our account of the Interpretation

Insert Figure 2 about here

stage. It is an attempt to fill in some of the missing details in the Interpretation stage of the general model we presented earlier. (To emphasize this, the Feature Extraction and Lexical Access stages are also indicated in the figure.)

The Modal model posits four distinct levels or units of interpretation, features (symbolized as F_i), letters (L_j), letter groups (LC_k), and words (W_1). Each unit has only one function: to detect the visual information that defines it. Let's take some examples. A possible feature unit might be defined by an upright line, and it would be activated whenever such a line was detected in the input. A possible letter unit could correspond to B, and it would be activated whenever all of the features units that define it are activated. A letter-group unit might be BL, and it would be triggered by either the feature units or the letter units that define it. Finally, a possible word unit could be BLAST, and it would be activated by its defining feature units, letter units, or letter-group units.

Note that in the above examples, information may flow in one of two ways. First, information may move sequentially through the hierarchy of units, with feature units activating letter units, which in turn trigger letter-group units, which then activate word units. Thus the activation of letter groups and words is mediated by the prior activation of letter units. Such mediated activation is found in the recent models of Estes (1975), LaBerge and Samuels (1974), and Massaro (1975). Second, information may flow directly between units that differ by more than one level. Thus feature units may directly activate letter-group or word units, and similarly letter units may directly trigger units corresponding to words. Here we have cases of nonmediated activation, an idea borrowed from Smith (1971) that is also part of the LaBerge and Samuels (1974) model. Both types of information flow presumably go on concurrently, and whenever activation of some unit passes a critical level, that unit becomes a possible interpretation of the input or of part of the input.

There is one more critical assumption. Following Estes (1975), we assume the actual task a subject is asked to perform (including the instructions) presets certain levels of units, and that activation at these levels will ultimately determine the subject's responses in the task. A task in which the subject need only discriminate among a few alternative letters would presumably lead to presetting of the feature or letter level, while one that requires the subject to perceive ~~many~~ different structured patterns would supposedly lead to presetting the letter-group or word level.

This model appears to be consistent with all the findings we mentioned earlier. Let's start with the orthography effect. To keep things simple, just consider why a regular consonant cluster, like initial TH, is more perceptible than an irregular one, like initial HT, when the subject is preset to interpret letter strings at one of the higher levels. Our model offers two reasons for this difference, and both follow from the notion that TH is probably one of the reader's letter-group units. First, when the information flow is sequential or mediated, the activation will terminate at the TH unit for the regular consonant cluster, but at the H and T units for the irregular clusters; thus, information about the order of the two letters will be available for the regular cluster but not for the irregular one (Estes, 1975). Second, when information flows directly from features to letter groups, both features and letter units may activate TH while only features can activate the H and T units that define HT. Thus TH will be more perceptible than HT because the former has more sources of activation. (It should also be noted that the features that define letter-groups like TH may be redundant, and consequently fewer features may be needed to activate the TH unit than to trigger either the T or H unit.)

These same two reasons will also account for more complex cases of the orthographic effect; all that must be assumed is that orthographically regular strings are more likely to contain letter groups that correspond to existent units than do irregular strings.

The wordness effect is explained in similar fashion. This effect would be due to the role of word units in the Interpretation stage. The existence of such units means that any string that forms a word will have access to an additional Interpretation unit than a comparable nonword. Hence the two reasons we just discussed can be invoked again, this time to explain the perceptual superiority of words over comparably structured nonwords. The same type of explanation also holds for the word-letter effect. Here word stimuli have access to letter group and word units as well as letter units, while individual letter stimuli must suffice with just letter units. Finally, since all of our explanations depend on the activation of letter-group and word units, it follows that the effects in question should disappear when the subject is preset to respond at, the feature level.

3. Issues. In formulating the above model we have been forced to take a stance on three major issues. Let us spell them out so one can get an idea of what some alternative formulations might look like.

The first issue concerns the distinction between mediated and nonmediated processes in the interpretation of letter strings. In the Modal model we allowed both types of processes, as the reader could either go through letters on his way to words or move directly from features to words. In making this assumption, we line up with LaBerge and Samuels (1974) and Smith (1971), who also permit nonmediated processing. But other formulations are possible, as both Estes (1975) and Massaro (1975) have proposed viable models that permit only mediated processing. Consider in particular the Estes formulation. It looks very much like the one in Figure 2, except that information can only flow sequentially. The orthographic and word-letter effects arise because structured nonwords and words eventually gain access to multi-letter units that supply positional information. Thus this model holds that all the beneficial effects of structure on letter-string perception are due to the reader's gain in information about the order of letters, and not to any gain in information about the identity of letters.

A second issue is one we mentioned earlier: top-down vs. bottom-up processing. The Modal model invokes only bottom-up processes, and this is true of most current models of word perception. However, it may well be possible to construct a model that uses top-down processes to account for the structural effects we are concerned with. While no detailed account of such a model has been published as far as we know, there are some leads in the literature. Thus one of Wheeler's (1970) explanations of the word-letter effect involved a top-down process. When a word is presented, some of the features extracted may lead to a few tentative interpretations of the input. These can then be used to access the lexicon and arrive at a set of lexical candidates; these in turn will direct subsequent feature extraction so as to maximize discrimination among the lexical candidates. When a single letter is presented, no such top-down process can be used. Hence single letters will not be perceived as well as words. A similar explanation could be devised for the wordness effect.

What is the likelihood that theorists will be able to model the Interpretation stage without recourse to top-down processes? Very low, we think. For though we were able to get by without such processes in the Modal model, we were concerned only with structural effects. When we turn to the effects of syntactic and semantic context in a later section of this paper, we will be forced to consider some top-down processes.

The last issue of interest is one we've not mentioned before. Our Modal model, as well as many others, assumes the reader's orthographic knowledge is built into his units of interpretation, rather than in his actual use of rules. But things could be otherwise. For example, in Massaro's (1975) model, the reader presumably makes dynamic use of a set of orthographic rules to aid his interpretations. This issue of fixed units vs. dynamic rules has been raised by Baron (1976) and Massaro (1975), and we think it an important one for theoretical and instructional approaches to reading.

One way to get some insights into this issue is to consider some related work. While we are concerned with how skilled readers perceive familiar inputs, Chase and Simon (1974) have tackled an equivalent problem in chess. They asked, what is it a chess master knows that allows him to perceive a regular chess pattern better than an irregular one? Their research suggests that this ability is mediated by units corresponding to regular chess patterns, rather than to the dynamic application of rules that generate permissable patterns. This raises the credibility of the unit approach to word perception. We get a different message, however, if we look at the research on speech perception. Consider the finding that adult speakers can perceive a string of words better if it follows the syntactic structure of English (e.g., Miller & Isard, 1963). No one has ever seriously suggested that mastery here depends on fixed units, since there are just too many units involved. Rather, mastery in this case presumably depends on the dynamic application of rules. What kinds of rules, though, is another matter. Many researchers now believe that the rules are really heuristic strategies and not algorithms (e.g., Bever, 1970; Clark & Clark, in press, Chapter 5). It thus seems that there are successful precedents for taking either a unit or a rule approach to the use of orthographic structure in reading, though if one favors the latter it might prove profitable to look at heuristic strategies.

One final point about this business of units vs. rules. It may be that people use both units and rules though some rely more on units while others depend more on rules. Baron and Strawson (1976) have proposed such an individual difference in reading strategy, and have offered some nice experimental support for it. This kind of individual difference should be of interest to reading researchers, since it carries with it the suggestion that there's more than one way to internalize the orthography.

III. LEXICAL INDICES

A. Overview

In our model, the Interpretation and Lexical Access stages are closely interrelated with the output from the former serving as the input to the latter. However, as mentioned earlier, it may be the case that the output of Interpretation is not in the proper format to be used as an input to the lexicon—some sort of transformation may first be necessary. In order to determine whether such a transformation is necessary, we will consider what is known about the nature of lexical indices. Two possibilities will be considered. One is that lexical indices are represented in some sort of speech code. This would require the addition of a speech recoding stage between Interpretation and Lexical Access. The second possibility is that lexical indices are represented in an othrographic code. If this is the case, the output of Interpretation can directly provide the input to Lexical Access.

Before looking at the experimental evidence, we would like to be certain that there is no confusion on one important point. The view that speech recoding is unnecessary for Lexical Access does not imply it is also unnecessary for later stages in the reading process. For example, it may be essential to recode words to speech prior to the Working Memory stage, because the temporary store needed during this stage might hold more speech symbols than orthographic ones (Kleiman, 1975). Since we are focusing on the early stages of the reading process, we will not consider the evidence in regard to this possibility. Rather, we will only consider evidence from experimental tasks we believe tap the Lexical Access stage; i.e., those studies that require subjects to retrieve information about individual words.

B. Critical Findings. As always, there is more relevant literature than can be reviewed here, so we will be selective (for a more detailed review, see Kleiman, 1975). There is a set of studies that have been interpreted as showing that speech recoding occurs before lexical access in skilled reading. In one such study, Rubenstein, Lewis and Rubenstein (1971) found that when subjects are asked to decide if a visually presented string of letters forms a word (a lexical decision task) reaction time is affected by the phonemic properties of the letter string. For instance, nonwords that would be pronounced like English words (e.g., *brume*) take longer to reject than other pronounceable nonwords. Rubenstein *et al.*, interpret this finding as showing that speech-recoding occurs before lexical access. Meyer, Schvaneveldt and Ruddy (1974a) came to the same conclusion on the basis of experiments showing that reaction time to decide that two strings of visually presented letters both form words is affected by the phonemic similarity of the words even when orthographic similarity is controlled. For example, subjects could decide about two phonemically similar words (e.g., bribe-tribe) faster than two phonemically dissimilar words (e.g., couch-touch).

We do not find these experiments convincing. Often there is a crucial problem in that the manipulated phonemic variables may be confounded with orthographic variables (Gibson, Shurcliff, & Yonas, 1970; Meyer & Ruddy, 1973). Also, some of these studies may have biased subjects towards using a recoding strategy (see Kleiman, 1975, for further discussion of why these experiments are not convincing). We do not doubt that skilled readers can recode written words to their spoken equivalents and will do so under certain circumstances. The more interesting question is whether they are capable of lexical access without recoding. We will describe several studies that convince us that lexical access without recoding is feasible. It is interesting to note that the studies supporting recoding generally use tasks that subjects can do without retrieving the meanings of the words, while those that show recoding is not necessary use tasks requiring the use of word meanings.

Baron (1973) reports two experiments of interest. In one, he timed subjects while they decided whether or not short written phrases make sense. The crucial comparison was between two types of phrases that did not make sense when read: those that would have made sense if pronounced (e.g., peace of pie, my knew car), and those that would not (e.g., pie pod, our no car). If subjects recode to speech before deciding whether the phrase makes sense, they should have taken longer on the peace of pie phrases because they would have to check the spelling in addition to the sound. The results showed, however, there was no difference in the time needed to decide about the two types of phrases, although there was a significant difference in error rates. In his second experiment, Baron asked subjects to decide if the written phrases would sound sensible if pronounced. Here the crucial comparison was between two types of phrases that sound sensible: those that are also sensible when read (e.g., peace treaty) and those that are not (e.g., peace of pie). If recoding to speech always occurs before the decision, the time to decide about these two types of phrases should be equal. In fact, phrases like peace of pie took longer to decide on. Therefore it seems that recoding to speech is not necessary.

Kleiman (1975) has also shown that college readers can retrieve information about individual words without speech recoding. Subjects were timed while they made three different decisions about pairs of visually presented words. For some pairs, subjects decided whether the two words were spelled alike after the first letter. The words never sounded alike (e.g., lemon and demon are spelled alike), so that subjects had to make this decision on the basis of visual information. For other pairs, subjects decided whether the two words rhymed. Here, in both the rhyming and nonrhyming pairs, the words were spelled alike (e.g., blame-flame vs. lemon-demon), thereby forcing subjects to recode to speech before making their decisions. For the remaining pairs, subjects decided whether the words were synonyms. Since this task requires information about the meanings of individual words, it was assumed to tap the processes of lexical access. Each subject performed the spelling, rhyming and synonymy decisions both with and without a concurrent interference task. This task consisted of repeating digits that were presented rapidly and was designed to disrupt recoding to speech. The measure of interest was the effect of this interference task on the three decisions. Since the spelling decision doesn't require recoding, it should not show a large interference effect. Since the rhyming decision requires recoding, it should show a large interference effect. What about the synonymy decision? If recoding is required, this decision should show a large interference effect, comparable to that on the rhyming decision. If the synonymy decision does not require recoding, it should show a small interference effect, comparable to that on the spelling decision. The results clearly support this second prediction--both the spelling and synonymy decisions show a small interference effect, while the rhyming decision shows a much larger one.

The issue we have been discussing bears some relationship to the classic phonics method vs. sight method debate in teaching reading. However, we do not think that any implications for teaching can be drawn directly from our conclusion that speech recoding is not necessary before lexical access in skilled reading. It seems quite possible that although skilled readers may not use recoding, teaching a recoding strategy could be a good beginning. One reason why implications cannot be drawn directly from studies of skilled reading to methods of teaching reading is that the child's lexicon might be organized differently than the adult's. Chomsky (1970) suggests that the child's lexicon is organized phonetically, and that with development it is reorganized to code the similarities in meanings of related words. For example, courage and courageous may be totally separate lexical entries for the child, but both may be derived from a single lexical entry for the adult. Chomsky's proposal is very speculative at this point, so we don't wish to push it too far. However, the possibility of fundamental differences between children's and adult's linguistic knowledge must be considered before drawing implications for instructional procedures from studies of skilled readers.

IV. CONTEXT EFFECTS IN THE INITIAL PROCESSES OF READING

So far our discussion of the processes involved in reading has been almost entirely bottom-up. In this section we will look more closely at the need to include top-down processing in our model of reading. More specifically, we will consider the effects of preceding syntactic and semantic context on word perception, where these effects seem to arise because of a top-down process. The psychological literature contains quite a few demonstrations of such context effects. Some of these (e.g., Kolers, 1970; Goodman, 1969) show that certain types of errors that are common in oral reading can be accounted for only if previous context is considered. This is true even with oral reading in the first grade (Weber, 1970). Other studies have demonstrated that the size of the perceptual span or effective visual field depends partly upon characteristics of the preceding context (Marcel, 1974). However, our model of reading does not address either oral reading or the perceptual span. We once again plead a division of labor and limit our discussion to the effects of context on the Extraction, Interpretation and Lexical Access stages.

Let us first look at two representative experiments that demonstrate a facilitating effect of context on processing individual words. One of these is by Morton (1964). He measured the threshold to recognize a word presented alone and compared it to the threshold for the same word presented after a context. His results showed that context reduces recognition threshold, and the amount threshold is reduced depends on how highly expected the word is when the context is given. For example, the context The cup was placed on the ______ reduces the threshold for table a great deal, since table is highly expected. The same context also reduces the threshold for saucer, but not as much, since saucer is not as highly expected. Note that this reduction is of the mean threshold for sets of subjects, so that it is possible that the effect is specific to the one most expected word, but that this word differs for different subjects.

The second experiment is by Meyer, Schaneveldt & Ruddy (1974b). They measured reaction time while subjects determined whether or not strings of letters formed words. Each trial consisted of two successive decisions, with the second letter string presented immediately after the first decision. We need only consider the cases where both strings of letters formed words. Meyer et al., varied the semantic relationship between the two words, so that for some trials they were highly related (e.g., bread-butter, doctor-nurse) while for others they were unrelated (bread-nurse, doctor-butter). The finding of interest is that reaction time for the second word is less when it is semantically related to the first than when it is not. That is, context of a semantically related word facilitates the decision.

Both of these studies show a context effect on the early stages of the reading process, and other studies document the consistency of this effect (e.g., Tulving & Gold, 1963; Tulving, Mandler, & Baumel, 1964; Meyer & Schvaneveldt, 1971). The issue is how to account for these results. There is some agreement on the broad outlines of an explanation. A preceding context, like The cup was placed on the ____, somehow activates the meaning(s) of the possible next word, and this activated meaning then provides another source of information to be used during the recognition of the next word. A glance at Figure 1 will show that we are now talking about information from the higher stages combining with information from the lower stages. This is top-down processing par excellence, and it seems to be a useful starting point for thinking about the context effect.

Beyond this outline, there is little agreement on how context works. Roughly, there are two types of theories of the context effect, corresponding to what researchers have called passive and active models. The passive models are probably the better developed, and these include the theories of Collins and Loftus (1975), Morton (1969), and Schvaneveldt and Meyer (1973). Let's take the Schvaneveldt and Meyer formulation as an example of this class. Consider first the case where only two words are involved, with one being the context word and the other the test word. When the context word is recognized, its lexical representation will be activated, and this activation then spreads to the lexical representations of related words. If the test word is one of these, it will be partially activated and so require less processing at the lower levels. Hence the beneficial effect of context on early processing. In the more interesting case where the context involves an entire phrase, the phrase would now become the source of activation, and this activation would presumably spread to all words semantically related to the phrase as a whole.

In contrast, active models (e.g., Norman & Bobrow, 1975) assume that context plays a more selective role. Here, context supposedly sets up some specific lexical or semantic expectancies, which then selectively guide processing at the lower levels. For example, the expectancy of a particular lexical item might lead to a selective examination of features that would tend to confirm it. This is quite similar to the top-down interpretations we have mentioned earlier.

One essential difference between passive and active models thus concerns the range of words whose perception can be facilitated by a particular context; for passive models this range includes all words semantically related to the context, while for active models this range is restricted to a few specific expectancies. Another difference between the two types of models concerns the interaction between contextual and perceptual information. In a passive model, both sources of information simply feed into a common point (say the lexical representation of a word), and in no way does the contextual information directly affect the quality or quantity of perceptual information. That's why they call it passive. In an active model, the context can actually determine what perceptual ~~information~~ the reader should look for.

So what does all this have to do with reading instruction? Unfortunately, at the present time, very little. We don't see any possibility of instructional hints being derived from the work that is currently available, chiefly because so little experimental work has been done. We have included this section because we expect a great deal of attention to be directed to the effects of context in the next few years. More detailed information on how skilled readers use context should then provide hints as to what we should try to teach children about the use of context in reading words.

V. SUMMARY

We began by arguing for an information-processing approach to reading. We then proposed a general information-processing model for adult, skilled reading that included that stages of Feature Extraction, Interpretation, lexical Access, Working Memory and Integration. Of these stages, we focused on Interpretation and Lexical Access, and discussed some of the issues that have arisen in the study of these stages, namely units of Interpretation, speech recoding and lexical indices, and context effects. In the course of our discussion, we were able to fill in some of the details about the mechanisms underlying these stages, but of course much remains to be done.

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Figure Captions

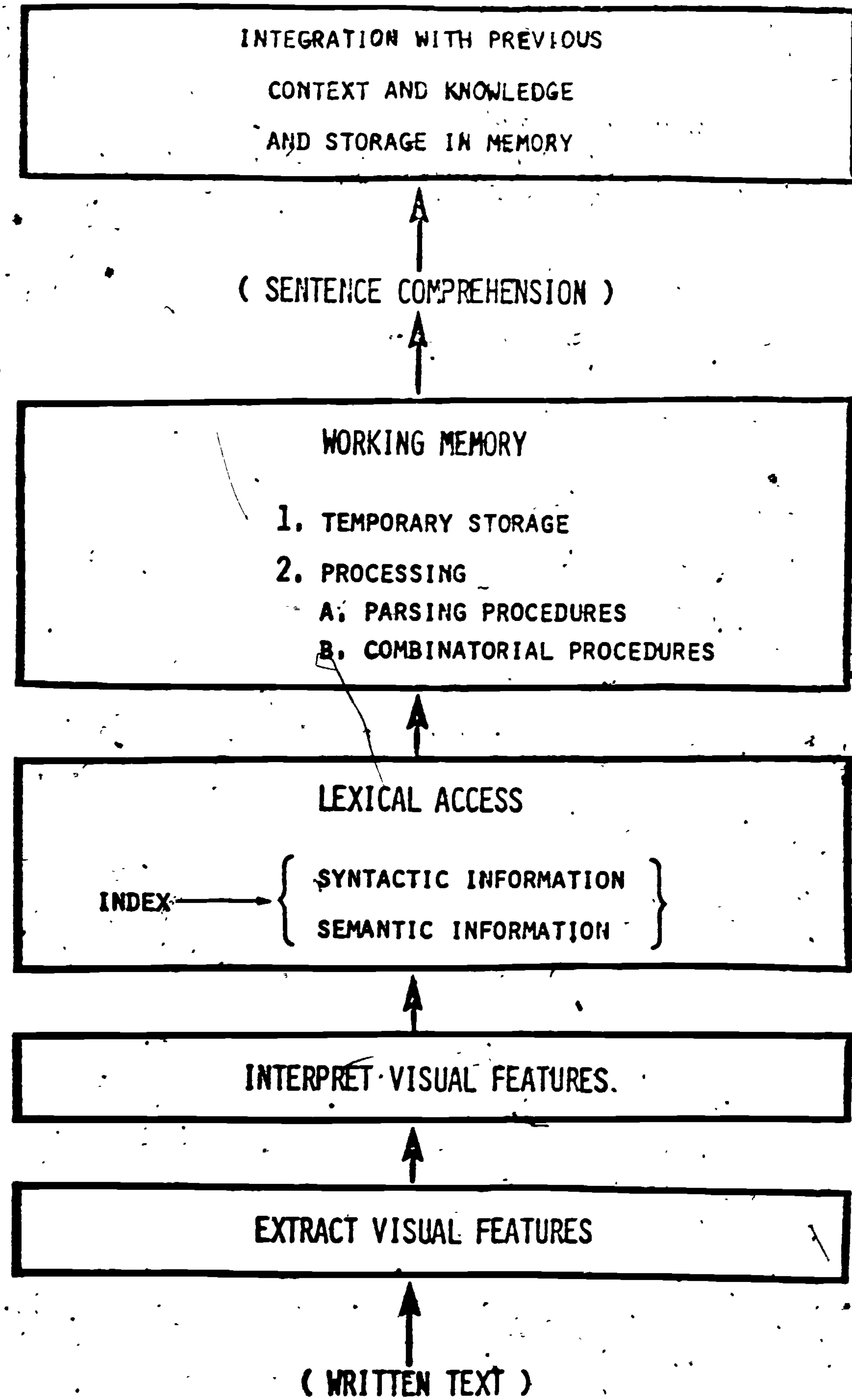
Figure 1. An Information-Processing Model of Skilled Reading

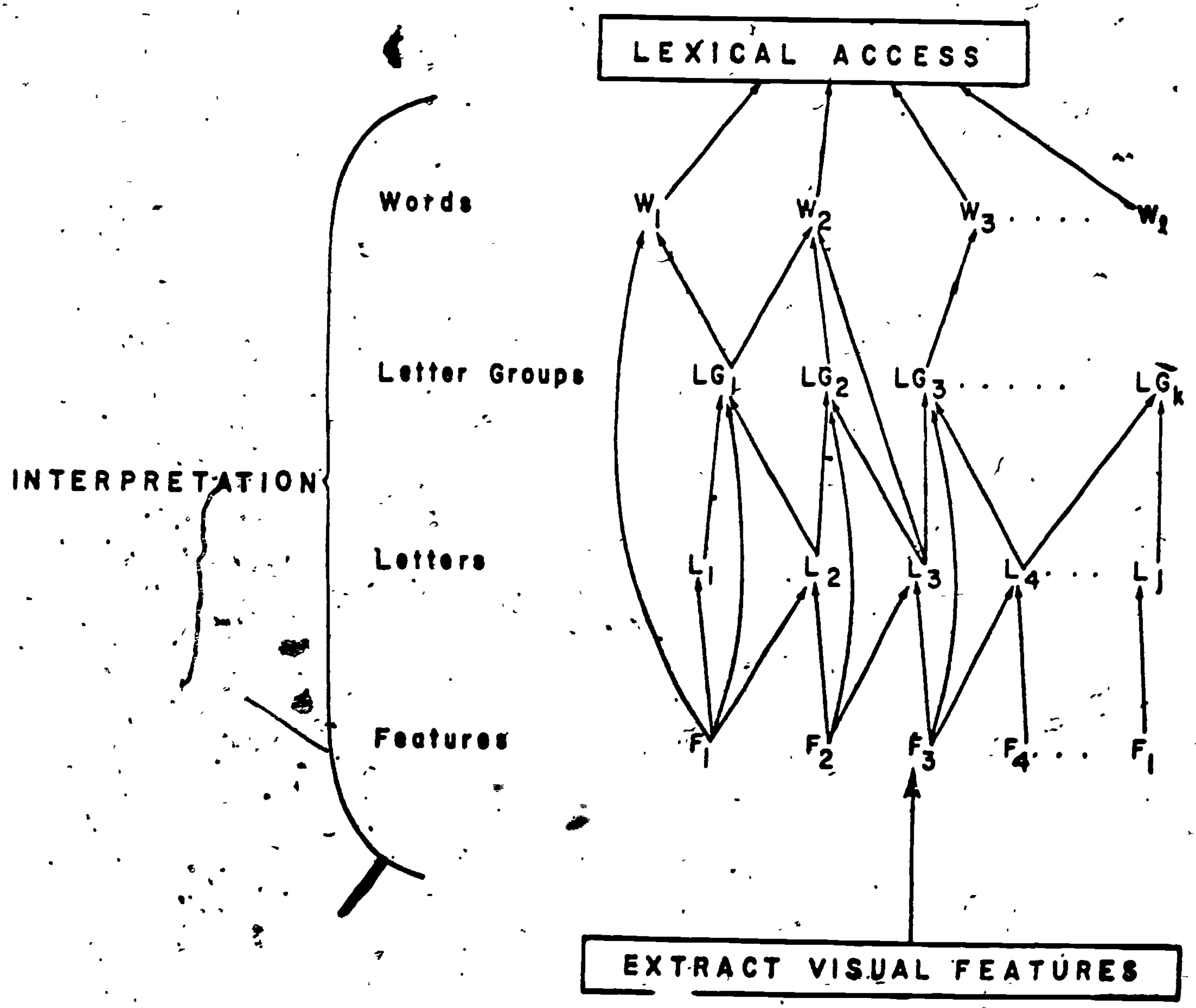
Figure 2. A Multi-Unit Model of the Interpretation Stage.

Footnotes

[1]This research was supported by U.S. Public Health Service Grant MH-19705. The second author is now at the University of Illinois at Urbana-Champaign.

[2]The fact that wordness facilitates perception suggests a further possibility. Perhaps the accessibility or frequency of a word also has an effect, such that more frequent words are more perceptible than less frequent ones. Recent studies, however, have yielded little support for this suggestion (see in particular Manelis, 1974; see also Theios, 1975).


INTEGRATION WITH PREVIOUS
CONTEXT AND KNOWLEDGE
AND STORAGE IN MEMORY
(SENTENCE COMPREHENSION)
WORKING MEMORY
1. TEMPORARY STORAGE
2. PROCESSING
A. PARSING PROCEDURES
B. COMBINATORIAL PROCEDURES
LEXICAL ACCESS
INDEX
SYNTACTIC INFORMATION
SEMANTIC INFORMATION
INTERPRET VISUAL FEATURES.
EXTRACT VISUAL FEATURES
(WRITTEN TEXT)


LEXICAL ACCESS
Words
Letter Groups
Letters
Features
INTERPRETATION
EXTRACT VISUAL FEATURES

May 20--P.M.

OPEN DISCUSSION OF E. SMITH PRESENTATION

GLASER: Ed, you seem to treat the distinction between the fixed and dynamic use of rules as a dichotomy. It seems to me almost a developmental feature of something that happens in instruction. Consider a chess master, for example. I suppose that he operates on the basis of simple rules, but eventually he also develops the capability to see whole patterns; he develops a bigger and more complex vocabulary. Is that fixed application of rules or dynamic application of rules, or is it just ability to apply simple rules in bigger rule systems?

E. SMITH: I guess if you look at it at some level, it may disappear as a dichotomy, but there may be some reasons to maintain a dichotomy. Take the chess work, for example. As I understand it, the notion Chase and Simon have come out with is that one reason a chess master is superior to a novice is that he has perceptual or memory units that correspond to large patterns. It is the same point that I am trying to make: As a result of your familiarity with the language, you build up these large visual units. Also, if you get down to a detailed enough level--suppose you are trying to write a computer program to mimic some aspect of reading--the two ideas are going to look terribly different. In the case of this unit idea, you are going to stick in the possibilities of units, large units, like a whole word, that can be matched to incoming features. If you believe in the dynamic application of rules, you are going to have to do it very differently. You are going to have to take in the features, and somewhere you have to set up all of the rules you are going to use. You are going to have to see what features you have and apply a certain rule to see if that will help you. I am saying that if you get molecular enough, the processes certainly do differ.

The second source of evidence for this is a paper by John Barron, who has got some nice evidence for two kinds of adult readers. One group is extremely influenced by the regularity of words, when they have to pronounce them. These people really seem to be responding to details of the orthography. People in the other group don't show that kind of difference; they seem to be reading in terms of large units. The first group is like the Phoenicians and the second like the Chinese. You cannot prove this on the basis of only a couple of experiments, but Barron has got convergent evidence that there are really these two types of readers. I think if we can show this at the level of individual differences among skilled readers, then it might become important for the kinds of things people at these conferences are concerned with.

PERFETTI: I wonder if the conclusion about phonetic decoding would be modified, if you ran a visual task that was analogous to the spelling task; i.e., some task that doesn't involve graphemes. If you found essentially zero interference, instead of 100, would you then want to conclude that there is even some graphemic decoding in the spelling and the reading tasks?

E. SMITH: Can you come up with some kind of task?

PERFETTI: Lines and angles; something that is geometric.

KLEIMAN: There is some independent evidence that you are not using some sort of phonemic decoding in the spelling task.

E. SMITH: In the spelling task, it doesn't matter whether you present lemon-demon or blame-flame. Blame-flame sound alike, whereas in lemon-demon, there is a sound change, but both of them take the same amount of time in the spelling task. If people were really using any kind of speech to do the spelling task, you would expect them to be faster with words that sound alike, but they are not. So Glenn is right; there is very little speech going on in the spelling test. But you are right, too. If you can come up with a task that shows zero, it would be a better plan.

LIBERMAN: Do you know the Erickson, Mattingly, Turvey study?

E. SMITH: Not off hand.

LIBERMAN: It's a study of errors of readers of Japanese kanji. The pattern of errors led to the conclusion that the subjects tended to recode phonetically even though the kanji characters represent meanings directly, not the phonology of the language.

E. SMITH: What was the task involved in that?

LIBERMAN: I can't remember the exact procedure.

E. SMITH: That's kind of critical to the argument I am making.

LIBERMAN: The subjects tended not to confuse words that had optically similar kanji, or those with similar meanings, but rather the errors tended to resemble the target words phonetically, as, for example, to be rhymes with the semantic representations of the target words.

E. SMITH: I can't say more, unless I know what the task is. If it's a memory task, I am not surprised.

I think this issue, conceptually, is really quite subtle. For example, it may well be that a skilled reader can gain visual access to the lexicon; "that is, go from a visual pattern to the lexicon. Suppose once he gets to the lexicon, in addition to getting to the meaning, he gets the pronunciation. That would still show that you can get visual access to the lexicon. You can say, "Aren't we quibbling here? Is this distinction between visual and acoustic important in any way?" I think it is, because under this scheme, where you get visual access to the lexicon and get the sound, you can store the sound in the lexicon. You don't have to go through spelling-sound rules. And I think that maybe the critical issue here is: Do you have to go through spelling-to-sound correspondence rules to get to the lexicon?

Under those kinds of circumstances, a lot of studies simply become irrelevant to the point, and you can see it becomes extremely difficult to do a critical experiment.

RESNICK: How relevant is the theoretical point being debated here to the nature of early instruction that would be proposed?

If we assume that even a skilled reader goes through a phonemic encoding, it seems almost self-evident that you have to put a lot of stress on the teaching of that phonemic encoding process somewhere early in the reading process. Suppose, however, that skilled readers do not go through it. Suppose they move more directly from the orthographic information to meaning.

E. SMITH: The first answer to your question is: How relevant is all of this to how you teach early reading?

RESNICK: You raised it at the beginning. It is not a challenge to you specifically; it is really a question to the group.

E. SMITH; If it's a challenge, I give up immediately. Uncle. I don't think it's relevant. I think that in beginning reading, there are a number of reasons why you want to use some kind of speech coding. The obvious one is that you have the whole lexicon, whatever you have of it, coded in speech, and you haven't yet learned how to read. There is some work by Carol Chomsky that suggests that the lexicon is organized differently for children than for adults. For children it may be organized phonetically, so that they have to separate the representations for courage and courageous, for example, because they sound different.

I think that first you have to try to find out if the lexicon is organized differently for children and adults. If it is--if it is really organized phonetically for children, for reasons other than they can't read--there is no question that you have to let them go through speech coding. There may be a point in the educational process at which you want to introduce training that will favor direct access or visual access of the lexicon, but I doubt that you can do it in beginning reading.

VENEZKY: Ed, where do the letter groups come from in your model? Are they things that people have seen very frequently; are they tied to position?

E. SMITH: They would have to be tied to position, or it won't work. Things are only regular or irregular depending on their position. It would be what you have come to expect from your experience with the orthography. I don't know, really, where he comes from. The only issue I was raising is: Given that you extract something from your experience in the orthography, do you represent what you have extracted as units or as dynamic rules?

VENEZKY: Does that rule out the possibility of forming letter groups for things you have never seen before, things that, by some more abstract set of rules, could very easily occur?

E. SMITH: I don't think it does. Once we have noticed these kinds of units, we might be able to make inferences from what we notice about other kinds of units.

VENEZKY: So it's not really a simple mapping from letters into letter groups?

E. SMITH: Yes, right.

VENEZKY: Something a little more complex?

E. SMITH: Perhaps, it really is true that all that is in there are units we have seen. It may be that if you give people situations in which they have to decide if something is orthographically regular, they make their decision, not on the basis of these units, but on the basis of something else, some kind of inference apart from these units.

VENEZKY: Don't you think it is possible to separate out those two hypotheses, though, by looking at, say, bigram counts or trigram counts versus other approaches to regularity?

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E. SMITH: I thought I could separate things by looking at th[illegible] counts. But when those counts start to get sophisticated, so they are counting how often a particular bigram occurs at the third or fourth position of a two syllable word where the syllable boundary splits between four and five, I am not sure you can separate it out any more.

JUST: You indicated that the nature of the reading process is very much task-conditioned. How would you find out what the process is when you are reading the evening paper? At what level are we processing? I expect there is currently no answer to the latter question.

E. SMITH: It seems unlikely that you would be just reading the paper and looking for particular features. I suspect that the task that you set for yourself has to eventuate in deriving meaning. You are not going to try to interpret things at a low level. I guess you could give people words in context and ask them to read as if they were reading an evening paper. You could see if you pick up the same kinds of effects that you pick up in the experiments that I talked about. I think the interesting part of your example has to do, not with the level at which we interpret visual units, but with the level at which the semantic, syntactic, and pragmatic interpretation is going on; I think there would be more flexibility there.

KLAHR: I think you gave up too easily on the issue of skilled performance and the way we design instruction. I think that the more of those kinds of examples you can give, the better off we are with respect to not making simple-minded task analyses of expert performance. As Lauren has found in her analysis of the mathematical instruction, it is possible to demonstrate that skilled later performance is patently unteachable to novices. However, if we analyze entry level performance rather than adult performance we may be able to instruct. There is a lot of task analysis that aims at too skilled a level of performance.