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ABSTRACT

The report discusses speech processes in reading by critically considering recent available evidence and by proposing a general model of speech processes. Stating that much work has been guided by the question of whether speech recoding precedes lexical access, the report proposes that a richer understanding of speech processes in reading must include attention to postlexical processes. Although there is little direct evidence, the report suggests that postlexical demands of reference securing make it reasonable to hypothesize that activation of some phonemic information is automatic and concurrent with lexical activation, and that the phonemic code is not a mere replica of a speech production. The report also proposes that experiments employing speech suppression paradigms are inadequate to detect the speech processes involved, and suggests both that there is a continuum of speech activation and that suppression operates at a higher level than the relevant speech processes. The report argues that recent research provides at least weak evidence for phonemic processes involving consonants, and also considers whether reading ability is related to the use of speech processes in reading. It is noted that there is considerable evidence to support this; however, there is little evidence presented to show that activation of speech codes fails to occur for less skilled readers. Evidence suggests that activation is slower or less automatic for less skilled readers, and that a speech code, once activated, deactivates more rapidly for such readers. The report concludes by suggesting that encoding conditions and memory demands may be related and that compensation between them can be arranged. (CRH)

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Speech Processes in Reading

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The silent inner voice described by Huey (1908/1968) in his classic study of reading is a pervasive part of an otherwise visual performance. Despite informal observations and considerable research demonstrating speechlike processes in reading, much doubt has remained about the role such processes play. Indeed, whether they play any functional role at all, as opposed to an epiphenomenal role, has been questioned.

In this article, we discuss speech processes in reading by critically considering recent available evidence and by proposing a general model of speech processes in reading. We emphasize skilled reading but we also consider less-skilled reading and how individual differences in reading skill might be accounted for. Support for the model will be indirect and partly argumentative rather than empirical. In that sense, although we will summarize some recent relevant evi-

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dence, the discussion will be more in the spirit of an empirically testable proposal than a directly tested model. First, however, we consider the dominant perspective on speech processes in reading—that of speech recoding.

I. THE SPEECH RECODING PERSPECTIVE

There are three general components of skilled reading involving speech processing assumptions. Since reading, whatever else is involved, begins with visual input, the visual processes are an essential starting point in a description of the information processes of reading. Beyond an initial visual input stage, the processing description must take into account contact with a word form in permanent memory (lexical access), computation of meanings (comprehension), and, at least on occasion, memory for words, clauses, or sentences (memory). A model of speech processes in reading can suggest an obligatory, optional, or nonexistent role of speech processes at any of these points. However, a processing description of reading may need further assumptions concerning the nature of the speech processes if their function is to be clearly understood. Indeed, there has been considerable effort directed at the reading part of the speech–reading interaction but very little directed at the speech part. Thus, whether lexical access and comprehension occur without speech activity has been the subject of much investigation, whereas the nature of the speech processes has not received attention.

A. Lexical Access

The process by which a word form is accessed is the essential minimal reading process. The question of whether speech plays a role in such a process has been often cast as a recoding issue. Is there an internal speech transform on the visual input prior to word access? The recoding view of the lexical activation problem is illustrated in Fig. 1.

By a recoding view, the bottom path indicated in Fig. 1 is the path to a word. Recoding of a letter string into speech occurs and the speech form is used to access a word location in memory. The top path allows the direct access of the word without recoding.

There have been a number of proposals concerning the state of affairs depicted in Fig. 1. Perhaps the consensus view is that, as Fig. 1 suggests, access to the memory location of the word is possible either by the direct route or the indirect route. For example, Baron (1973), Barron and Baron (1977), and Frederiksen and Kroll (1976) emphasized this optional strategic process, and similar proposals have been made by others (Allport, 1977; Davelaar, Coltheart, Besner, & Jonassen, 1978). This optional direct-access model also typically assumes that young readers follow the recoding path and that skilled readers do also when they encounter an unfamilar word.

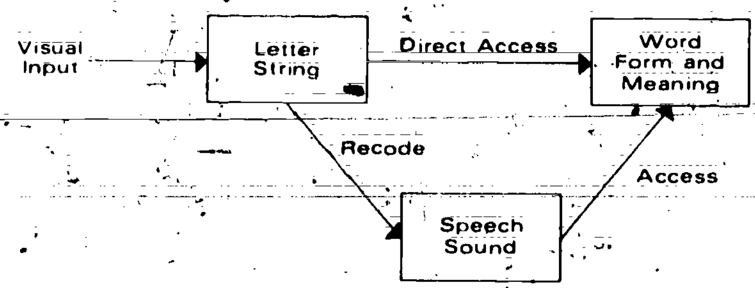

Figure 1. The conventional view of direct access versus mediated access. A word's memory location is accessed either from the visually encoded letter string (direct access) or following a recoding of the letter string into sound.

Information processing models, of course, require more detail than the simple scheme shown in Fig. 1. Massaro (1975), for example, describes a model that allows direct access while filling in the gap between visual input and word access with a synthesis of letter patterns from sensory information. Knowledge of orthographic patterns assists this process, but phonological mediation ordinarily does not. Other information processing models make somewhat different specific claims about the processes (see LaBerge & Samuels, 1974), but with few exceptions (e.g., Gough, 1972), phonological mediation is not assumed.

Although Fig. 1 represents a very simple view of the lexical access problem, it has been useful as a heuristic model and seems to capture the experimental strategies detectable in much of the research. The bulk of this research adds up to the conclusion that, for skilled readers, contacting a word form in memory happens without an earlier stage of phonetic recoding. For example, Coltheart, Davelaar, Jonasson, and Besner (1977) and Davelaar *et al.* (1978) interpret the results of their lexical decision experiments as supporting the direct access hypothesis. Their work is particularly important because results of lexical decision research have occasionally suggested that phonetic recoding does occur prior to word contact (e.g., Rubenstein, Lewis, & Rubenstein, 1971).

Whereas there is some variance in experimental results, the set of reliable results relevant for speech recoding is fairly small. A central result is the pseudohomophone effect. A nonword that has the same phonetic shape as a real word (e.g., *brane*) takes longer to reject than a nonhomophone (e.g., *brone*). As Coltheart (1978) pointed out, the evidence for this effect is convincing, although in a few experiments the effect did not reach statistical significance (e.g., Frederiksen & Kroll, 1976). This effect is evidence that there is some phonetic code activated by a pseudoword that, when it matches that of a real word, slows down the time to decide that it is a nonword. This effect says nothing in particular about "lexical" access, however, because there is no real word to access. What it does say is that pseudowords can be recoded into sound and that sound may or may not match the sound of a stored word. Results for real words, however, do not suggest recoding. There is no corresponding homophonic effect for real words (e.g., *groan-grown*) when careful frequency controls are present (Coltheart *et al.*, 1977). That is, the fact that *groan* has the same phonetic shape as some other word does not affect its lexical access time.

According to one interpretation of the model presented in Fig. 1, lexical access may be attempted simultaneously along both routes (Meyer & Ruddy, 1973). The speed of the different routes, if indeed different routes exist, could be gauged by comparing lexical decision times for words containing regular orthographic phonemic correspondences with decision times for words containing irregular correspondences (so-called "exception" words). Regular words could be accessed by either the recoding or the direct access route so that access would be accomplished via the faster of the two. Exception words could be accessed only via the direct route, since the recoding route would fail because orthographic-phonemic rules would be applied inappropriately to exception words. If regular words were accessed more quickly than exception words, all else being equal, this would lend support to the notion that multiple access routes do exist. Furthermore, such a finding would suggest that the recoding route is the faster of the two.

Although some studies reveal faster lexical decision times for "regular" words over "exception" words (Barron, 1981; Glushko, 1981; Stanovich & Bauer, 1978), other studies show no regular word advantage in lexical decisions (Bauer & Stanovich, 1980; Coltheart, Besner, Jonasson, & Davelaar, 1979). Glushko (1981) proposed an alternative to the model of Fig. 1, which explains these conflicting results. He suggests that lexical access is visual and that the activation of phonological information occurs after access as activation spreads to orthographic "neighbors"; that is, words containing similar letter patterns. According to Glushko's (1981) model, the regularity effect appears when the activated phonological information from the neighborhood of the regular word is homogeneous (e.g., *rate*, *mate*, *late*) but disappears when the neighborhood is heterogeneous; that is, when the regular word has a prominent exception word as a neighbor (e.g., *save*, *have*). Bauer and Stanovich (1980) report essentially this result. The phonological effects, according to Glushko's (1981) model, occur only after direct visual access, as the phonological information of the activated orthographic neighbors becomes available.

Taken together, lexical decision results suggest that recoding is not required prior to lexical access. The difference between homophonic effects for pseudowords and the lack of such effects for real words, along with the lack of a consistent regular-exception word difference, suggest an interpretation that holds that direct access is the usual route to the lexicon, at least for skilled readers. The homophonic effect for pseudowords can be understood as the activation of speech sounds due to the extended search of the lexicon prior to the final decision that the string is not a word. That is, the phonetic shape /bren/ is activated by *brane* and a check is then required to make certain that a real word had not been encountered. It has nothing to do with lexical access, however.

There is other evidence, less consistent perhaps, concerning phonetic recoding versus direct access. Prominent among these findings are priming effects in lexical decision tasks. Especially interesting for separating visual and phonemic similarity are the negative priming effects found for nonhomophonic spelling patterns in lexical decision; for example, *touch* preceding *couch* slows the *couch* decision (Meyer, Schvaneveldt, & Ruddy, 1974). There is not a consistent corresponding positive priming effect for homophonic pairs, *groan* and *grown*, however. Davelaar *et al.* (1978) found no homophonic priming, whereas Hillinger (1980) did find such an effect, even when the prime was presented auditorily. Hillinger could not, however, replicate the negative priming effect (*couch-touch*) but argued that evidence (Shulman, Hornak, & Sanders, 1978) suggests that the two effects may not result from the same process.

One final lexical decision study worth describing exploits a situation not present in the other studies. Lukatela, Popadic, Ognjenovic, and Turvey (1980) took advantage of the fact that the Serbo-Croatian language is written in two alphabets, Roman and Cyrillic, which require different pronunciations for a subset of shared graphemes. For example, Roman *p* is /p/ whereas Cyrillic *p* is /r/. Examining the lexical decision performance of subjects who were fluent readers in both alphabets, Lukatela *et al.* (1980) found that letter strings that had different pronunciations in the two alphabets, but were words in both, were accepted more slowly and produced more errors than words that could be read with only one pronunciation. Since this result cannot be attributed easily to response competition or to conflicting visual information, Lukatela *et al.* (1980) attribute it to conflicting phonological information and suggest that phonological information is involved at some point in lexical access for bi-alphabetic Serbo-Croatian readers. This does not necessarily mean, however, that the graphemes were recoded **prior** to access.

Tasks other than lexical decision also have been used in examining the recoding issue. Studies requiring semantic judgments demonstrate that subjects require no longer to reject a phrase as nonsense when it contains a homophone that would render it sensible when pronounced; for example, *My knew car* (Baron, 1973). This suggests, again, that the direct visual route is sufficient. Otherwise, the judgment time would be slowed down as the homophones are inappropriately accessed. Another strategy has been to demonstrate that some variables that affect latency of word vocalization, a task clearly requiring speech recoding, do not affect lexical decisions (Frederiksen & Kroll, 1976). Still another strategy has been to show that word vocalization does not interfere with a visual semantic decision (Barron & Baron, 1977).

The literature on this topic, as we are suggesting, is extensive. We do not wish to examine all the studies in detail, however. Our purpose is to suggest that the consensus of evidence clearly indicates that recoding is not involved in a skilled adult's access to a word's memory location. We have discussed the lexical decision task more than the others because, in principle, it has seemed to some to approximate the ideal of "pure" access. In fact, Coltheart *et al.* (1977) have argued that all other tasks are unsuitable for the issue. Other tasks are suitable for other questions of speech processing, however, and we will discuss these in turn.

In summary, we have briefly reviewed a few of the many relevant studies of single word reading to demonstrate that the schematic model of Fig. 1, for better or for worse, has guided much of the thinking about speech processes in reading. The consensus is that the direct route, and not the recoding route, is used in skilled reading.

B. Memory and Comprehension

With or without speech recoding prior to lexical access, there remains the question of whether subsequent reading processes make use of speech. This question has appeared to be answered in the affirmative in a general way although there remains doubt about the details. A wealth of evidence supports the assumption that memory for visually encoded language is recoded into speech form (Conrad, 1964; Hintzman, 1967; Murray, 1968; Wickelgren, 1965). This evidence originally came from memory paradigms using syllables or letters presented visually and observing phonemically based confusions in recall. In the well-known work of Conrad (1964), subjects tended to confuse *F* with *S* and *D* with *T*, for example, when they recalled visually presented letters. Subsequent work suggested that recoding would be suppressed if task demands encouraged sustaining a visual code (Kroll, Parks, Parkinson, Bieber, & Johnson, 1970). Partly as a result of memory research, however, dual-store memory models typically identified short-term memory as a characteristically acoustic storage system (Atkinson & Shiffrin, 1968; Kintsch, 1970). Although this turned out to be a too rigid assumption, it remains accurate to characterize short-term memory functioning as heavily relying on speech properties that are either acoustic or articulatory analogs, or perhaps both.

More directly related to ordinary reading are the studies of Kleiman (1975) and Levy (1975, 1977, 1978). Kleiman (1975) found that when subjects were required to shadow digits, the time they took to judge the semantic acceptability of sentences increased. Since the time required to make semantic judgments that could be made a word at a time was not affected, the conclusion was that comprehension of sentences, but not meaning access, depended on a speech recoding in memory. A similar conclusion originally came from Levy's (1975) research but this conclusion was heavily modified by her later work (Levy, 1978). In Levy's task, subjects counted aloud while reading and then were given recognition memory tests. Their ability to detect meaning-preserving wording changes suffered but their ability to detect meaning changes did not. (Levy, 1978). Levy's conclusion was that verbatim memory, but not comprehension for meaning, depended on speech recoding. Slowiaczek and Clifton (1980) have argued, however, that Levy's task was too easy to allow the conclusion that comprehension was not affected by counting aloud. In the paraphrase recognition test, subjects could discriminate a nonoccurring sentence from an occurring one by recognizing that the seven-sentence story had not contained a word appearing in the test sentence. They replicated Levy's research with a more demanding comprehension task in which distractor items contained agents and actions contained in the original story. Under these conditions, comprehension suffered when counting was required. Together, experiments in this line of research can be taken to suggest that counting while reading for comprehension is interfering to the extent that detailed word-specific comprehension is required. Vague knowledge of what was read remains available.

Another line of evidence for speech processes in memory and comprehension comes from electromyographic (EMG) studies. For example, Hardyck and Petrinovich (1970) found that when subjects were required to minimize their covert subvocal activity by monitoring a visual display of their laryngeal EMG, their comprehension of difficult passages suffered. The EMG procedure was also used by Locke and Fehr (1970), who found increased labial EMG activity during the written presentation and silent rehearsal of words containing labial consonants. While subvocal processes may be related to comprehension, however, suppression of subvocal activity may not be sufficient to eliminate speech processes. In addition to the Levy research described previously, there is work reported by Baddeley and Lewis (1981) on sentence judgments. The relevant suppression result was that subjects could perform judgments of sentence meaningfulness while counting without significant losses in decision times. There were losses in accuracy during suppression, however. The fact that decision times were unaffected by suppression implies that suppression effects may be restricted to memory tasks and are absent in comprehension of sentences. Thus, when subjects have only to process a sentence sufficiently to decide whether it is meaningful, suppression of subvocal speech has no effect on how quickly a decision is reached. However, error probabilities are increased because the subject sometimes needs a temporary memory support to reach a decision and the suppression task has made the articulatory loop (Baddeley & Hitch, 1974) unavailable.

More surprisingly, Baddeley and Lewis (1981) report that rhyme judgments of pseudowords are unaffected by suppression (*frelame* and *phrelaim*). Since nonrhyming pairs were similar in spelling, this task was not likely to have been performed by strictly visual means. Similarly, subjects' judgments of whether a pseudoword was pronounced like a real word (e.g., *cayos*) was unaffected by suppression. Of course, what is surprising about such results is that they appear to demonstrate that an ostensibly phonemic task can be performed at no loss while phonemic mechanisms are occupied with speech production. Furthermore, Kleiman (1975) had found that rhyming decisions were slowed down while subjects performed digit shadowing. Baddeley and Lewis (1981) suggest that such results may be found only when the vocalizing task demands central processing resources, in contrast to a mere articulatory loop. Digit shadowing, but not counting, they suggest, is a likely user of such resources.

Taking this interpretation, there are three classes of conclusions: (1) Rhyming is not a phonemic process; (2) counting aloud is not a phonemic process; and (3) rhyming and counting do not occupy the same phonemic processes. Since the last is the only conclusion agreeable to common sense, we must assume that rhyming and counting are very different in their phonemic demands or that time sharing between the tasks is possible. In fact, Baddeley and Lewis (1981) suggest that rhyming decisions and related processes in silent reading of sentences (*Rude Jude chewed his crude stewed food*) involve acoustic images. These images are not the speech processes that are used in subvocalizing and that are suppressed by counting.

We return later to speculate on properties of this image. At this point, we summarize the state of affairs concerning comprehension and memory. Subvocalization appears to play an important role in memory for verbally encoded units, whether they are single letters or entire texts, provided the subject's intentions or the materials make the memory demands nontrivial. This role is also significant in reading when comprehension demands are exacting and the text requires some integration of sentences (Slowiaczek & Clifton, 1980), but not when only vague gist is required (Levy, 1978) or when a single sentence has to be judged (Baddeley & Lewis, 1981). This generalization depends on the assumption that subvocalization is successfully suppressed by counting, but it is quite consistent with the EMG research, particularly the finding that comprehension of difficult texts but not easy ones is facilitated by subvocalization (Hardyck & Petrinovich, 1970).

II. AN ALTERNATIVE PERSPECTIVE: REFERENCE SECURING AND AUTOMATIC PHONOLOGICAL ACTIVATION

If, as our evaluation of the evidence suggests, comprehension and memory, if not lexical access, make use of speech processes, there remain some interesting problems. What are those speech processes like? When do they occur? What function do they serve? We consider now some arguments concerning the last two of these questions.

A. Reference Securing

In principle, it is possible to have reading without speech processes. Certainly, language understanding by machine demonstrates this. For example, speech processes are not necessary for language processing by artificial systems for sentence representation; for example, ACT (Anderson, 1976), direction following (Winograd, 1972), and story understanding (Schank & Abelson, 1977). Furthermore, there is, as far as we know, no such system that uses speech processes in any role at all. The reason is not just that the problems of these artificial intelligence (AI) systems are defined at a conceptual level instead of a speech level. It is that problems of reference are handled by assuming that processes have unlimited access to memory locations. The problem of what a text is talking about is handled in different ways that vary in their reliance on context, syntax, etc.; but they tend to share the strategy of leisurely, repeated access to a data base. As a rule, information in a data base in indexed through spellings. Thus, there are invariant error-free access routes as well as no memory restrictions.

This perspective is informative because it makes clear that speech processes are not logically essential to comprehension of visual language. Speech may have ontogenetic priority to print but it has no logical priority.

Consider instead a system that has some very acute limits to its resources. It does not have the luxury of unlimited continuous referral to its data base nor can it entertain an unlimited number of hypotheses about what it is that it is trying to read and understand. Both limitations exist in normal reading by humans (although certain time-consuming code-breaking activities might resemble machine language processing). The key problem, although it has to do ultimately with resource limitations, can be described as a reference-securing problem. In order to comprehend language, words or phrases must be connected with conceptual objects to construct messages. Lexical access is necessary to accomplish this but it may not always be sufficient. That is, conceptual and semantic information is obtained from lexical memory but securing its reference requires both access and retention.

To see the problem, imagine a reader who, while reading a passage on mid-nineteenth century American presidential history, encounters the sentence *Fillmore appeared to have enough influence to forge a compromise in the Senate*. Lexical access provides the semantic information sufficient to construct sentence meaning, for example, an ordered list of propositions. To take just the case of the first word of the sentence, the information could be represented as a list of features: for example, [+ name, + U.S. President, + nineteenth century]. This is reasonable but imprecise as far as reference is concerned. It allows interpretation but it does not secure reference. That is, there is nothing to prevent subsequent access of Jackson, Pierce, Harrison, or Tyler instead of Fillmore. Of course, when asked to recall what was read, a reader will often produce errors or show difficulty in retrieving a name. Furthermore, where memory for gist rather than memory for words is typical, reference securing is perhaps less of a problem.

However, we assume that the many occasions when a reader has a fairly

complete record of what was read means that reference-securing codes are often constructed. For example, verbatim memory for read texts is high for the most recent sentence (Goldman, Hogaboam, Bell, & Perfetti, 1980). There are at least two ways this might be accomplished. One is to assume that more elaborate semantic encoding secures reference. In the Fillmore example, the reference-securing code could include *the one who was president, 1850–1853* or *the one whose name is the same as a linguist*. Such reference-securing codes would uniquely determine the name needed, provided that memory included the needed data. This solution eliminates the need for holding on to a name code. It allows an abstract semantically based reference code by which a name can be reaccessed when necessary. A problem with this solution is that for words other than names, especially for words other than nouns, it becomes awkward to specify **ahead of time** what semantic information is sufficient for securing reference. This seems true, for example, of the other words from the Fillmore sentence, including *appeared, have, enough,* and *influence*. In fact, it is not until the word *Senate* is encountered at the end of the sentence that a reference seems to be established in which these words, or their case assignments, may participate. *Influence, forge,* and *compromise* will turn out to be links between *Fillmore* and *Senate* in an understanding of this sentence. The point of this example is to suggest that even after lexical access there is reason for at least some retention of name information, or what we have called reference securing, and that although semantic specification will serve for some words, it will not serve for all words.

Problems of postlexical name access are greatly reduced provided phonemic codes are available—even if they are fragmentary. For the Fillmore example, suppose the code was expanded to include [+ name, + U.S. President, + nineteenth century, +/f—/]. Just having information about the initial phoneme greatly increases the opportunity of reaccessing the name. In this case it uniquely specifies it. In cases in which the domain of possible lexical entries is larger the code would require more information. For example, if the next sentence in the history text example were *He was especially counting on support from Missouri,* the Missouri code should read at least [+ name, + state, + /mIz/.../] to assure errorless reaccess rather than access to *Michigan* or *Mississippi*. We propose, in general, that some phonemic information is part of the code held in memory at least briefly following lexical access. It allows the reader to reaccess the word for further semantic processing and, perhaps more importantly, it provides a reference-secured code to be connected to words not yet encountered.

This type of phonemic reference securing most likely applies only to content words that undergo somewhat extensive semantic encoding. It is possible that auxiliary words and determiners (*to, the*) do not receive such phonemic processing. Since their function is more syntactic than semantic, there would be no need to secure a reference to a specific lexical entry. Function words serve primarily to coordinate syntactically items that require such semantic processing. There is evidence from eye-movement studies suggesting that syntactic function words are not processed the same as content words. Nouns and verbs tend to be fixated more frequently and for longer durations than function words (Rayner, 1977; Zargar-Yazdi, 1973). In addition, Bradley (1978) found that lexical decision times for function words were unaffected by frequency, unlike decision times for content words. She suggested that function words are recognized by a mechanism that is independent of that used for content words. Function words, then, do not behave like content words as gauged by two basic measures of reading, eye fixations, and lexical decision times. We might expect, therefore, that function and content words also differ in other processing they receive, specifically reference securing and phonemic activation.

According to the argument we have developed, lexical access can occur without prior translation of graphemes into speech. The need for securing reference during comprehension makes it important, however, for the reader to have access to word names, at least for some time following their initial lexical look-up. The evidence from memory and comprehension experiments is, in part, consistent with this assumption. The final step in the argument is again a logical one. If name codes are useful and if phonemic information allows their recovery, then a system that obtains such information at lexical access is more efficient than one that does not. Of course, a continuously available text that allows regressive fixations to reaccess words also serves this function. However, it does so inefficiently compared with a process that makes phonemic information available with initial word access. We suggest that reading normally involves the automatic activation of speech-based codes during lexical access.

B. Sketch of a Model of Automatic Speech Activation

We present here the form of a model in which speech codes are made available to the reading process. The main assumption is that, contrary to the simple view of direct access versus mediated access of Fig. 1, phonemic translation always takes place. It just happens to take place sometimes after, and other times before, other information that is stored with a lexical entry is activated.

Figure 2 illustrates the important features of this model as a temporal and structural display of what is available to the processing system. The horizontal time line displays events over a brief time frame, less than 1 second for a skilled reader and a moderately difficult text. The model does not show separate processing stages corresponding to, for example, visual stores, short-term memory, and long-term memory. Instead, it assumes a continually active word processor that begins with the activation of a single word and continues with the activation of subsequent words.

The sketch is read rightward and downward from the starting point at the upper

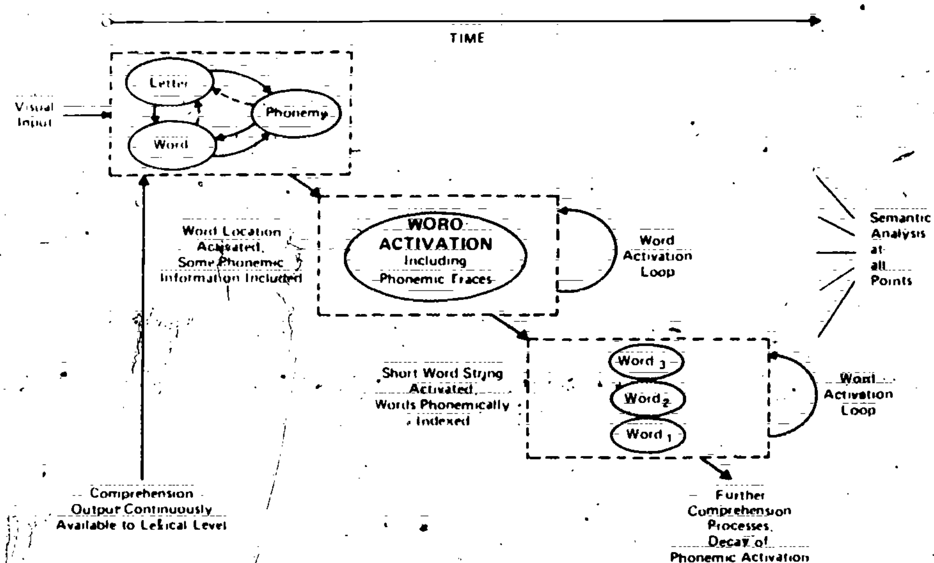

Figure 2. Schematic view of an automatic speech activation model. Visual perception of letters activates both words and phonemes consistent with the current status of letter identification. Following Rumelhart and McClelland (1981), there is feedback (e.g., word-to-letter and word-to-phoneme) as well as feed forward in this process. Automatic phonemic activation occurs during this process and as a result of a word identification decision being made (center box). Thus, a word can be identified before phonemic activation has achieved a high level, but not without some activation occurring. Continuous processing of the word (center box) and reprocessing it as part of a word string (bottom right box) maintain phonemic activation. The processes are continuous (the boxes are not stages) and semantic analysis does not await speech information.

left corner. Visual information initiates processing by activating elements of a lexical memory. The first enclosed box indicates mutual activation of words, phonemes, and letters. Rumelhart and McClelland (1981) provide compelling reasons to assume that this part of the process is interactive. Recognition of letters activates word candidates consistent with them, including those not yet fully "recognized" at the letter level. Thus, a word identification decision is interactive in that activation flows continuously both from the letter level to the word level and vice versa. Also available to the identification process is information already obtained from the text. Thus comprehension outcomes are fed forward to lexical look-up, further strengthening activation of some words at the expense of others. Some interactive processes of this sort are assumed by Morton's (1969) logogen model and have been assumed specifically in discussions of reading processes by Perfetti and Roth (1981), Stanovich and West (1981), and others.

The key assumption, however, is reflected in the connection between the phoneme level and the word level and between the phoneme level and the letter level. If the identification process is slow, perhaps because the reader is not highly skilled or because the word is unfamiliar, the phoneme level is activated by the letter level before the word decision is made. This means that some phonemes, not necessarily all, are activated and the activated memory code for the word will include those activated phonemes. If the word decision is reached fairly rapidly with feed forward from letters, then phoneme activation will follow word identification. But "follow" in this context may be nothing more than the few milliseconds during which the eye is moving forward to its next fixation. The critical assumption is that some phonemic information stored with the word has been activated by the time the next word is being processed.

This state of affairs is represented by the next downward and rightward frame of Fig. 2: The activated word includes phonemic as well as semantic features. The word activation loop represents the potential for continuous reprocessing of a word as an auditory image, not necessarily as a covert articulation (Baddeley & Lewis, 1981).

The next frame illustrates the activated lexical contents following two more word identifications. All words are activated simultaneously and are indexed by phonemic information. We assume that there are deactivation functions for the phonemic activation and the activation loop helps retard this deactivation. This is a function served by phonemic coding. An activated phonemic code reduces the need to reaccess the permanent memory location of the word. It is kept in a state of activation as long as it is needed or until processing requirements (e.g., a difficult long sentence) bring about its deactivation. Regressive eye movements may then be required.

It should be stressed that such a model does not postpone semantic analysis. This is not a mere verbal rehearsal loop. It is, rather, a continuously updated verbal processor that immediately tries to build semantic representations. However, the verbal processing includes activation of phonemic features as well as semantic ones. The phonemic features, together with the semantic ones, aid in securing reference.

At this point, this model constitutes a reasonable proposal for elements of an automatic speech activation model. There is little in the way of direct evidence for it, however, because experiments that demonstrate such activation explicitly within the framework of this model have not been conducted. There are, however, several studies suggesting the existence of such automatic activation.

Using a backward visual masking technique, Naish (1980) presented single-word targets for 30 msec, followed by a 20-msec initial mask, either a word or a pseudoword, and finally a random feature mask. The key manipulation was the relationship between the word target and the word or pseudoword mask. When Naish used targets and masks that were so similar so as to be almost identical, either visually or phonologically, he found that the masking effect was reduced.

He argued that masking disrupts identification of the target by overwriting the outputs of the feature detectors. When the information in the mask is congruent with that in the target, either visually or phonologically, overwriting does not disrupt the target information. By manipulating phonological similarity independently of visual similarity (using nonword masks), Naish showed that phonological information was activated and masking was reduced even with target presentations as brief as 30 msec. (It should be noted that since the mask in question—visually or phonologically similar—was itself masked by a random feature pattern after 20 msec, subjects were not relying on guesses about target-mask relationships.)

Similar results suggesting automatic activation of phonological information were found in a very different paradigm. Using rapid serial visual presentation (RSVP) of sentences at a rate of 12 words per second, Petrick and Potter (1979) tested subjects' ability to determine whether a probe word had occurred in the presented sentence. Subjects made most errors when presented with probes that had not been in the sentence but were semantically similar to words that had been. Phonologically similar probes induced significantly more errors than did unrelated probes, however. Probes were presented either 80 or 240 msec after the final word, but this delay had no effect on either phonological or semantic distractors. The phonological effect seems to be genuine, since in the RSVP method, each word visually masks the previous one. Petrick and Potter (1979) controlled visual similarity as much as possible by printing sentences in lower case and probes in upper case. They also presented visually similar probes and found that phonological distractors, but not visual ones, were rejected significantly more slowly than controls. Thus, similar phonological shape had an interfering effect independent of similar visual shape. These findings suggest that phonological information is rapidly activated and remains activated for at least 1 second or so. We take these findings as evidence for automatic activation of phonological information. We further suggest that studies, such as those reviewed, that have merely manipulated subvocalization, are not sufficient to test this proposal.

C. Suppression and Vocalization Reconsidered

The studies that have required subjects to count aloud or engage in other vocalization while reading have implicitly assumed that reading-relevant speech processes were being occupied by the vocalization task. This may be a mistaken assumption. There are two reasons for this doubt. One is the possibility that vocalization can be time-shared with reading in such a way that speech processes activated by reading occur despite vocalization. With few exceptions, such studies have not measured the quality of subjects' vocalizations to ensure that trade-offs between reading and vocalizing were not occurring. On the other hand, one might suppose that such simple routine activities as counting would not show any performance decrement under any circumstances, so that this is a spurious methodological concern. It may well be if our second reservation about vocalization is a valid one. It is possible that vocalization does not suppress speech activity during reading because subvocalization is not the critical speech mechanism of reading.

One interpretation of the speech mechanism of reading is that it is but the palest copy of a speech process under most circumstances. Under more demanding circumstances, it begins to use speech production processes characteristic of vocalizing. We suggest that an activation continuum can represent this state of affairs. At the lowest level of activation, abstract phonemes are represented. The abstractness here is critical because it means that vocalization is not implied (or even possible). Increasing activation brings motor commands to near threshold level. This is the level at which EMG recordings reveal evidence of specific speech muscle activation. At the highest level of activation the speech motor commands are partly executed and a subvocal speech sound is produced. Actual vocalization is the highest level of activation, accompanied by explicit motor commands for voicing. This activation model is schematized in Fig. 3. Underly-

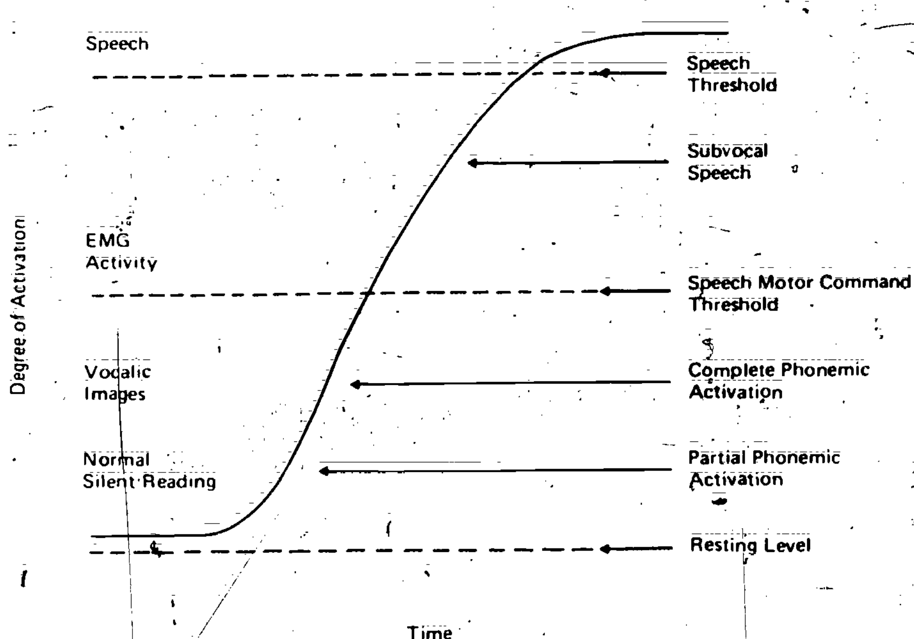

Figure 3. A threshold model of speech activation. Speech analog activity (e.g., vocalic images) occurs below threshold levels whereas subvocal and vocal speech are above threshold.

ing this view of activation are the assumptions that speech processes can be modeled by neural models in principle and that covert processes share some of the neural motor activation patterns required by speech. The abstraction of the implicit neuromotor process needs to be emphasized, however, since it is not demonstrated by an activation model directly. The reason that vocal suppression may not affect these low-level abstract codes is that the suppression is of the motoric activity, not the neural speech activity. The speech code itself could be quite active and hence available to the reading processes. Indeed, one might assume that vocalization increases the level of activation and is then useful to reading, except when central processing resources are used. Suppression will interfere with subvocalization, not with phonemic activation.

There are empirical reasons to doubt that suppression tasks necessarily lower phonemic activation in reading. We have already reviewed the studies of Baddeley and Lewis (1981) that found that the time to judge meaningfulness was not affected by counting. The fact that errors did increase with counting should cause pause with their interpretation that speech processes are not involved in reading. Indeed, we can suggest that errors increase because memory scanning is aided by subvocalization and hindered by counting, and that time is not affected because the processes leading to comprehension do not depend on subvocalization but on phonemic processes.

Another empirical reason to doubt that vocalization suppresses the relevant speech processes is its failure to affect rhyming judgments (Baddeley & Lewis, 1981). If rhyming is not affected, then vocalization, at least counting, is not a phonemically relevant task in the sense implied by a phoneme activation model of reading.

D. Consonants and Vowels in the Speech Code

Consonants and vowels may not have equivalent status in the phonemic code used in reading. This hypothesis is in part based on their unequal information status. In English, the uncertainty reduction carried by a particular consonant is much greater than that of a particular vowel. This is true with respect to syllables and to multisyllabic words. To consider again our reference-securing argument, if the phonemic code for a word is in any way impoverished, it will be more informative absent its vowels than absent its consonants. This fact is not unrelated to the well-known context-dependent nature of consonants in speech perception. Consonants are at once the most informative and least perceptible speech segments. (However, their lack of perceptibility is not serious because this is strictly a matter of the contextual variance of the acoustic signal.)

There is a second related reason to propose that consonants play a special role in reading. Besides being informative, they do not have acoustic duration. Vowels, of course, do have duration and if a premium is placed on rapid processing in reading, then there could be an advantage for a consonant-biased code. The activation of the code is automatic and, as processing rapidly proceeds, there may be only an abbreviated phonemic code. When the process slows down and reference is reexamined, more of the code may be activated.

On the other hand, there is ample evidence that vowels are prominent in short-term memory. The short-term memory paradigms that provided evidence for phonemic confusions were based on vowel similarity (e.g., Conrad, 1964, 1965; Wickelgren, 1965). Even in Chinese, Tzeng, Hung, and Wang (1977) report that when subjects have to remember either a sentence or a word list, confusions were greater for vowel similarity than for consonant similarity. Such differences could represent the distribution of segments over an acoustic event. Vowels have duration; consonants do not. Two syllables sharing consonants but differing in vowels have a more perceptible distinctive cue than two syllables sharing their vowels but differing in their consonants. This is especially likely in memory tasks and in comprehension tasks with comparably high demands in processing. These would include sentence judgments on words that repeat a vowel, as in *Red headed Ned fed in bed* (Baddeley & Hitch, 1974) or *Rude Jude chewed his crude stewed food* (Baddeley & Lewis, 1981).

The question we have raised in this section is the nature of the speech code used in reading. Actually, very little attention has been paid to this question, with most experiments reflecting nothing more specific than the assumption that vowel sounds or, more typically, entire phonemic word shapes are involved. The latter assumption is reflected in the work on lexical decisions previously discussed that employs homophonic manipulations (e.g., Coltheart *et al.*, 1977). The vowel assumption is reflected in the work of Baddeley and Hitch (1974) and Baddeley and Lewis (1981). Other research has focused on suppression of vocalization at the expense of any assumptions at all concerning the nature of the speech code.

A useful description of the code is a matter for further research. For now, we at least assume that the phonological segments activated during silent reading are not a simple replica of the acoustic shape of the spoken word. The code may include consonants, especially initial ones. Priority to initial segments is made plausible by their value as name code indexes. It is also possible that features at the articulatory level are activated. It is consistent with the decomposable character of phonemes to assume that such features as place of articulation are part of the phonemic code.

In summary, we have suggested that consonants may be part of the phonemic code activated during reading. This suggestion has a plausible rationale based on the distribution of information and the speed of processing, both of which favor consonants over vowels. A prominent role for vowels is required by memory evidence, however. Although it is not completely clear how to reconcile these two points, it is possible that activation spreads from consonants to vowels; as the degree of activation increases because of task demands, vowels take on an increasing prominence.

E. Experiments on Tongue-Twisters

Although direct evidence for most of these suggestions is not available, we summarize here the results of some relevant experiments.

These experiments were designed on the assumption that reading activates initial consonants in words. That is, we assume the minimal degree of activation includes some information about its first segment because this provides an informative name code index. As the name is activated by the interactive letter identification process shown in Fig. 2, its initial phoneme segment is also activated. A second assumption is that the importance of the initial segment as a name code index makes it vulnerable to phonemic interference. Its distinctiveness as an index is threatened when other words to be read share its initial phoneme. Finally, we assume that place of articulation features would be activated as part of the phonemic code. Phonemic interference might affect not only specific consonants but consonants that shared a place feature; for example, /t/ and /d/, /p/ and /b/, or /g/ and /k/.

Examples of sentences used in these experiments are shown in Table I. There were three types of experimental sentence—bilabials, alveolars, and velars—plus control sentences. Subjects in these experiments were required to decide whether sentences were meaningful. The experimental sentences repeated initial consonants and the control sentences did not. Sentences that were not meaningful were syntactically well formed as much as possible so as to necessitate semantic analysis. Sentences were constructed in sets of four, one of each consonant type plus a control sentence, with syntactic patterns remaining as constant as possible across sets. Furthermore, each control sentence was a semantic match to one of the experimental sentences (see Table I). Thus, the only systematic difference between experimental and control sentences was the repetition of the initial consonant.

In addition, there were vocalization tasks designed to involve specific phonemes corresponding to the consonants repeated in the experimental sentences. Thus, bilabial subjects vocalized repeatedly a phrase containing the voiceless bilabial, *Pack a pair of purple pampers*. Alveolar subjects vocalized a phrase containing the voiceless alveolar, *Take a taste of tender turtle*. Velar subjects vocalized the voiceless velar phrase, *Catch the crumbs of cocoa cookies*. All subjects read all types of sentences: bilabials, alveolars, velars, and controls. All subjects read half the sentences while vocalizing one of the three consonant phrases described previously and half the sentences while vocalizing a control phrase having mainly vowels, *I owe you an I.O.U.* In the context of other research using vocalization, a "control" suppression phrase may seem odd. We

Table 1. Examples of Tongue-Twister Sentences[a]

	Consonant type	Example
"Yes"	Bilabial	*The press published the poem and promised to pay for permission*
	Alveolar	*The detective discovered the danger and decided to dig for details*
	Velar	*The girl greeted the guests and grinned to calm their cares*
	Neutral	*The investigator knew the hazard and chose to search for answers*
"No"	Bilabial	*The puppies puzzled the peninsula and processed to please for paper*
"Yes"	Bilabial	*The bronze bars were brought in bags to the bank*
	Alveolar	*His tall tales were taken as truth by the twins*
	Velar	*The gas cans were claimed as the cause of the crash*
	Neutral	*His exaggerated stories were believed by his sons*
"No"	Velar	*The ground cloths were concentrated as the cart of the code*

[a] From McCutchen (1981).

have suggested that vocalization itself may not be relevant, however, for speech processes during reading, except insofar as it occupies speech codes at the level that they are used in reading. Furthermore, we imagined that consonants specifically were activated so that for each subject group the difference between the effect of the two vocalization phrases on particular sentences would be the critical comparison. In short, the difference between bilabial vocalization and vowel vocalization is an intrinsic vocalization factor, except as it interacts with performance on bilabial sentences. A similar logic applies to alveolar and velar sentences and the alveolar and velar vocalization.

The results of these experiments have been completely consistent with respect to the effect of consonant repetition in the visual display, which, to use a mixed metaphor, we refer to as the "visual tongue-twister effect." Sentences that repeat initial consonants take longer than control sentences that are matched for semantic and syntactic form. In one experiment (Perfetti & McCutchen, 1979), the magnitude of the effect was about 320 msec for sentences of five content words and about 120 msec for sentences of three content words. In a later study, McCutchen (1981) found a visual tongue-twister effect of about 350 msec for sentences of five content words. Since the effect is observed with shorter as well as longer sentences, it is not an effect that depends on difficult memory demands. The effect was significantly larger for longer sentences, however, indicating that, at least, increased processing demands increased the interference effect caused by consonant repetition.

Although these effects are ostensibly phonemic effects in reading, there are two alternative hypotheses to consider. One is that, despite our attempts to construct semantically comparable sentences, the control sentences turned out to be more easily processed for some semantic reason. Although it is difficult to rule out all forms of a semantic hypothesis, one based on sensibility can be ruled out. An independent group of subjects rated the meaningfulness of the sentences of Perfetti and McCutchen (1979). When these ratings were used as a covariate in an item analysis, the pattern of results remained the same as originally.

A second hypothesis is that the effect is visual since in most cases repeated phonemes were also repeated letters. There is evidence against this hypothesis, however. Some of the sentences used mixed consonant repetition within the place of articulation category. That is, some sentences used a mix of the letters *b* and *p* and some used a mix of *d* and *t* instead of only one consonant. In McCutchen's (1981) experiment this included mixes of three velars, *g*, *c*, and *k*. The pattern of results was the same for the mixed consonant sentences as for unmixed consonant sentences. Thus, there is no reason to accept either the semantic or the visual hypothesis at this point. The visual tongue-twister effect seems to be phonemic.

The phonemic source of the tongue-twister effect may occur as part of reference securing during comprehension of a phrase. A likely place for extra processing time is in the activation of several words from the sentence (lowermost box of Fig. 2), although more processing may also occur at the initial activation of a word beyond the first one (middle box of Fig. 2). Because the task requires precise reference securing for each word, anything that makes reference securing more difficult slows down reading times. The interference caused by phoneme repetition has this effect insofar as it requires more processing; for example, recycling through the word activation loop to hold word identities long enough to assess the meaningfulness of the sentence.

The results concerning vocalization have also been consistent, with one exception. The general result has been that vocalizing task and sentence type do not interact. That is, it does not take longer to read a bilabial sentence when vocalizing a bilabial phrase compared with vocalizing an alveolar or a velar phrase. The exception was in the original alveolar vocalization group of Perfetti and McCutchen (1979). The alveolar group performed more poorly while reading alveolar sentences compared with bilabials and controls, but this was detectable only with a dual task measure. This measure takes into account both subjects' reading times and their fluency in vocalization. It is an important methodological point that vocalization and reading be treated as a dual task problem. The possibility that subjects can trade-off, to some extent, high performance on reading with low performance on vocalizing should be taken seriously. (It is not sufficient to loosely monitor vocalization performance.) That is what happened to this original alveolar group. However, this effect was not found for the bilabial group nor was it replicated by the McCutchen (1981) experiment. Thus, in only one out of five opportunities has a specific interaction been observed and then only in dual task performance and not in reading times.

The conclusion most supportable at this point is that there are two separate factors: (1) a phonemic factor reflected in the visual tongue twister effect, and (2) a processing difficulty factor reflected in the suppression effect. The effect of vocalization on reading times was larger for the consonant phrases than for the I.O.U. phrase (McCutchen, 1981). However, subjects who vocalized the vowels *a, e, i, o, u,* in a manner that prevented use of letter names (/a/; /i/; /ai/; /o/; /u/) produced slower reading times than the consonant suppression groups (Perfetti & McCutchen, 1979). This is consistent with the suggestion that vocalizing will affect reading times to the extent that it makes central processing demands that compete with reading. On a scale of processing demands, we might suppose that counting is at one end and (perhaps) digit shadowing at the other end, among tasks that have been used to "suppress" vocalization. Simple repetition tasks such as "double-double" (Barron & Baron, 1977) would be on the low end of the scale and our tasks would be toward the high end; ordered *I owe you an IOU*; *pack a pair of purple pampers*; and /a/; /i/; /ai/; /o/; /u/. Presumably output demands of our tasks are high but the lack of input monitoring significantly reduces processing.

It may be that vocalization has some speech-specific properties that have not yet been discovered. Perhaps specific phoneme interference can be produced. For now, however, there are no grounds for such a conclusion. Concurrent vocalization does not affect reading time in any specific way aside from its general effect on processing. Although some have taken this to mean that reading occurs without speech processes, it can equally well be taken to mean that vocalization does not interfere with the speech processes used in reading. We take several results to support the second interpretation, including the failure to find interference with rhyming decisions (Baddeley & Lewis, 1981), one of the most phonemic processes imaginable, and the finding that it does not interact with the visual tongue-twister effect. At the same time, the latter comprises positive evidence for speech processes during reading. The thought that such processes are not necessary is possibly incorrect, in light of the reference-securing argument, and perhaps irrelevant, in light of the automatic activation argument.

III. SPEECH PROCESSES IN LOW LEVELS OF READING SKILL

To this point, our discussion has assumed a reader of some skill and fluency. The automatic activation of speech codes during lexical access is, we suggest, a hallmark of a practiced reader who has achieved a high level of skill. What of a child who is learning to read? Or an older child who has a skill deficiency in reading? In what follows, we consider speech processes in reading disability or, more generally, among children of low reading skill.

If speech processes play an important role in skilled reading, it is possible that reading disability is due in part to some failure of normal speech processing in reading. The general basis for such a link is that speech processes support comprehension and reading without speech support would place comprehension processes at risk. To the extent that speech processes assist efficient word identification, there is an additional basis for this link. There are two possibilities consistent with the general scheme of Fig. 2. One is that the lexical activation process does not lead automatically to phonemic activation. We refer to this as the "nonactivation hypothesis." A second possibility is that activation occurs but that subsequent memory processes do not make use of the activation. The mechanism for this disuse would be phonemic deactivation due to a rapid decay of the activated speech code and the inability (or strategy) to keep the code activated in the word activation loop (Fig. 2). Notice that under the simpler view of lexical access (Fig. 1), at least part of this view of disability does not arise.

A. The Nonactivation Hypothesis

If phonemic activation is automatic, it is difficult to assume that it does not happen. We noted that direct evidence for automatic activation is in short supply. It follows that strong evidence for nonactivation for disabled readers is also not available. There is some clinical evidence that appears relevant for the issue, however. Patients with "deep" or "phonemic dyslexia" (Marshall & Newcombe, 1973; Patterson & Marcel, 1977; Shallice & Warrington, 1975) show a syndrome consistent with a phonemic deficit at the level of lexical access. One particularly telling symptom is that such patients tend not to read pronounceable nonwords (e.g., *dake*), often not responding at all to such words, in contrast to their systematic errors in reading real words (Patterson & Marcel, 1977). This implies, not an absence of phonemic activation of the word level, but an inability to form a pronunciation program based on letter–phoneme activation. Saffran and Marin (1977) report a patient who shows such an inability to pronounce nonwords but whose reading performance suggests some, albeit defective, activation. On a task consisting of matching an auditorily presented nonword to its written counterpart, the patient's accuracy rose from 30% for bisyllabic nonwords to 79% for monosyllabic (e.g., *vad, vid, ved, vod*) to **100%** when the alternatives differed in initial phonemes (e.g., *zator, vator, jator, sator*). The initial phoneme, which we suggest receives increased activation, was most available to the patient to match against the auditory image, even though she cannot generally activate the program to articulate nonwords.

Such a program, of course, is much more than activation, depending on the ability to synthesize phonemic segments into novel forms. An important characteristic of these patients is that they typically show signs of Broca's aphasia (Patterson & Marcel, 1977). Thus speech production is intrinsically disabled, quite aside from printed word recognition. A second symptom of such patients, also of interest, is that they often misread real words as semantically related words rather than visually and phonemically related words. For example, Patterson and Marcel (1977) describe a patient whose semantically based errors (e.g., *minus* for *negative*) account for the majority of isolated word reading errors. Thus activation along a semantic network occurs in the absence of, or prior to, appropriate phonemic activation of the target word. This fact of general speech production dysfunction makes the nonactivation hypothesis somewhat superfluous, however. It is not that deep dyslexics simply fail to have phonemes activated by visually encoded words; at least some of them fail generally to activate and/or control appropriate speech components.

In any case, evidence from nonclinical populations is needed to support a general nonactivation hypothesis. The most relevant evidence comes from R. Barron (1978, 1981) who has argued that low ability readers may be deficient in the use of a phonographic strategy. It is not clear in what sense this is a strategy, but "phonographic" refers to the transformation of graphic information into phonemic information (see also Glushko, 1981). By our account, strategic control over phonemic activation is limited, and Barron's (1981) account of the possibilities for phonographic strategies seems consistent with this.

The evidence is suggestive but not compelling. In one experiment, Barron (1978) found that less skilled young readers did not take longer to reject pseudohomophones (e.g., *brane*) in a lexical decision task. This contrasts both with adult readers (Coltheart, 1978) and with skilled readers (Barron, 1978). Because the less skilled readers did [redacted] make more errors to pseudohomophones, however, this experiment does not provide strong evidence against phonographic processes of less skilled readers. A similar conclusion applies to the difference between exception and regular words. Less skilled readers in another of Barron's (1980) experiments did not show the speed advantage of regular words in lexical decisions shown by skilled readers, but they did show an accuracy advantage.

In a later experiment, Barron (1981) found that less skilled readers showed a speed advantage for regular words comparable to that of skilled readers when the nonwords were illegal letter strings. Overall, Barron's experiments do not suggest striking consistent differences in word access processes of less skilled readers. Certainly they are slower and more errorful in making lexical decisions, but they do not seem to be unable to have phonemic codes activated by print. It is perhaps important to note that even with a completely consistent pattern of results, lexical decision data of this type do not compel a conclusion concerning activation of the sort of abstract phonemic code that we suggest without some procedure that allows the experimenter to observe specific activation effects.

A similar problem exists in other studies that indirectly imply that less able readers may not be as effective in phonemic code activation. For example, in word vocalization, differences between latencies of skilled and less skilled readers are greater for pseudowords than real words and less for high-frequency words than low-frequency words (Perfetti & Hogaboam, 1975). This is consis-

tent with the hypothesis that some speech process is slower to trigger. However, the activation itself may occur automatically while the speech production program may be less accessible. This could mean either that the connection between a word's identity and its speech production program is "weaker" or that the program itself must be assembled. The latter possibility exists especially for pseudowords and nonwords.[1]

There is evidence from Perfetti, Finger, and Hogaboam (1978) that vocalization latency of less skilled readers increases with number of syllables for printed words more than for picture naming. Thus, the relevant speech program difficulty is not only at the level of production but at the level of decoding. That is, less skilled readers can be thought of as having access to preprogrammed speech routines stored with concepts. When the concepts are accessed through linguistic means, however, there is some effect of word length. It is not clear whether this is strictly a coding effect or a coding assembly effect restricted to linguistic inputs. In neither case, however, does it imply a failure for less skilled readers to activate a speech code from a print input.

At most, such studies are consistent with a form of the nonactivation hypothesis that attributes slower phonemic activation to readers of low skill. Alternatively, activation may be nonautomatic for less skilled readers. In either case, by the nonactivation hypothesis, the representation of the word brought forward for further processing might not include the speech code that we have assumed is important for reference securing and, thus, comprehension. Although we suggest that available evidence does not strongly support this hypothesis, it is not clear what such evidence would imply if it were available. In particular, if lexical access happened not to include automatic phonemic activation, would it include semantic information? It certainly is possible that a lexical activation that does not include phonemic information does not include semantic information either. Indeed, less skilled readers sometimes take longer to reach simple semantic decisions even when nonsemantic coding time is accounted for (see Perfetti & Lesgold, 1979).

This entails a parsimonious assumption of lexical failures in reading disability; namely, that for some disabled readers the access of a lexical location by visual information is often incomplete. The associated phonemic and semantic features are activated less completely or more slowly and sometimes not at all. Whereas the skilled reader brings forward to subsequent processes an enriched code including letters, phonemes, and meaning features, the disabled reader brings forward only an impoverished lexical code. Depending on the task, the word may

[1] By Glushko's neighborhood model, naming words is always a matter of activating stored pronunciations of a target word and its neighbors. For nonwords, activation of real words is involved. However, this is not a relevant distinction for the question of speech production programs. Such programs must be either stored and accessed or synthesized in order to produce spoken words or syllables.

behave as if its phonetic features or its semantic features are not activated. Note that this is not an explanation of reading failure but a nearly definitional description of the dyslexic aspect of it. Of course, it is also possible for the dyslexic process to be one that brings forward semantic information but not phonemic information. This seems to be the spirit of the phonographic hypothesis and, perhaps, the memory hypothesis (discussed in the following). This would be an approximate analog to the deep dyslexia patient whose paralexic errors often show semantic activation without appropriate phonemic activation. However, it may be an unnecesarily exotic characterization of the sort of reading disability that occurs in the absence of profound neurologically based speech problems.

B. The Deactivation Hypothesis

If it is assumed that some phonemic activation, even if less automatically or more slowly, occurs even for less able readers, there remains a second major possibility for a speech-related reading deficit. The "deactivation hypothesis" is that access of a word's memory location initiates phonemic activation but that subsequently the speech index rapidly decays leading to memory loss and comprehension difficulty. The problem lies not in the initial access process at the top level of Fig. 2 but in the word and word-string holding operations farther down in the process.

What might cause deactivation of the speech code? One possibility is that effort expended at lexical activation (decoding) interferes with the memory code. By this view, lexical activation that demands attention competes with other processes for working memory resources. One possible result is deactivation of recently read words. This is essentially the suggestion of Perfetti and Lesgold (1977, 1979; see also Lesgold and Perfetti, 1978; Perfetti, 1977). By this account, decoding (initial activation) and verbal memory problems (deactivation) of the less skilled reader may be closely related. That is, memory deactivation could be partly a result of initially nonautomatic activation. Evidence for this hypothesis has been largely indirect but it is supported by substantial correlational evidence and credible processing assumptions. (See Lesgold and Perfetti, 1978, for a review of these matters.)

Regardless of the mechanism, there is growing evidence that can be taken to support some form of the deactivation hypothesis. Perhaps the major evidence is that less skilled readers appear not to show phonemic confusions in memory tasks to the same extent as skilled readers do. Liberman, Shankweiler, Liberman, Fowler, and Fischer (1977) reported that low-skill second grade readers did not show phonemic confusion errors in a written letter recall experiment. Skilled second graders and adults (Conrad, 1964) tend to make rhyming-based errors in recalling letter names (e.g., *b* for *d* and *c* for *z*) rather than visually based errors. In the study by Liberman *et al.* (1977), phonemic interference was higher in skilled readers' recall than in less skilled readers' recall for both 0- and 15-second retention intervals. A later experiment using aurally presented letters showed that the skill difference in phonetic confusions extended to speech (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). A similar result for speech stimuli was reported by Byrne and Shea (1979) who compared skilled and less skilled second-grade subjects in a continuous recognition memory paradigm. Distractors to target stimuli (e.g., *home*) had either semantic (e.g., *house*) or phonemic (e.g., *comb*) relatedness. Skilled readers made more false positives to rhyming distractors and to semantic distractors relative to control words. By contrast, low-skill readers made false positive responses only to semantic distractors. Interestingly, when Byrne and Shea (1979) replicated this experiment with pronounceable pseudowords (e.g., *jome*), the same low-skill readers did make significant false positives to rhyme distractors (*vome*). Byrne and Shea argue that these results support a qualitative strategy difference in encoding; namely, that low-skill readers encode semantically rather than phonemically. However, they are equally consistent with the deactivation hypothesis.

In another study, Mann, Liberman, and Shankweiler (1980) reported that a phonemic memory difference was obtained when subjects listened to sentences. When subjects' performance on immediate memory for spoken sentences was measured, skilled second-graders were superior to unskilled second-graders only for sentences not containing rhymes. For sentences containing rhymes (e.g., *Tuesday at three, Lucy is free to see T.V. with Dee and Lee*) skilled readers' performance fell off dramatically to a level equivalent to the low-skill readers. Less skilled readers were relatively unaffected by the rhyming condition. These results, we note, do not seem to depend on word order nor on any floor effects. This, then, is an unusual case in the literature of reading disability in that a group of low-skill readers performed as well as skilled readers; that this was just in the case of phonemically confusable words seems to support a general hypothesis that skilled readers use phonemic memory codes more than do less skilled readers. Furthermore, this difference in phonemic memory is present whether print or speech is processed. It is possible that this is a matter of less skilled readers using a semantic, nonphonemic encoding strategy, as some have suggested. The fact that many beginning readers of low skill do not demonstrate much knowledge about the phonemic structure of language (Liberman & Shankweiler, 1979; Mann & Liberman, 1981; Perfetti, Beck, & Hughes, 1981), however, may suggest that the problem is not one of strategy but of knowledge and efficient use of that knowledge.

We note that the evidence has been gathered for young subjects only, primarily second-grade subjects. We raise the possibility that such children who have only recently been exposed to reading instruction, and who have not succeeded at learning to read, may be especially characterized by a failure of phonemic memory. Whether this failure applies to older disabled readers remains to be seen.

There remain at least two specific versions of the deactivation hypothesis consistent with these results. One is that deactivation of the phonemic code is more rapid for low-ability readers (spontaneous deactivation), given that the code is activated initially. A mechanism for this deactivation has been suggested previously (Perfetti & Lesgold, 1977) and others are possible. The mechanism responsible would need to handle speech as well as print decoding, however, given the results on aural input. A second version of the hypothesis is that procedures to delay deactivation are not as efficiently used by low-ability readers. That is, skilled readers refresh the code (by rehearsal or equivalent reprocessing) but less skilled readers do not.

There is at least one study that appears to weigh at least slightly against this second version and in support of spontaneous deactivation. Mark, Shankweiler, Liberman, and Fowler (1977) gave second-graders a single-word oral reading task followed by an unannounced recognition memory test. Skilled readers showed a higher false positive rate to distractors that were phonemically related to initially read words (e.g., *know* and *go*) compared with control distractors. This effect was absent for low-skill readers. Once again, an experimental result suggested an absence of phonemic memory processes in low-skill readers; this time in a situation that did not encourage rehearsal in that subjects did not expect the memory test.

We suggest that memory and memory control processes are difficult to disentangle in general and especially so in young children. More evidence is needed concerning the nature of phonemic memory differences related to reading ability. The possibility remains that factors governing control of verbal memory codes beyond the spontaneous decay of phonemic information will yet be demonstrated.

Finally, it is interesting that the Mark *et al.* (1977) task results would seem to count against the hypothesis of phonemic nonactivation. Although Mark *et al.* suggest that access and use of phonetic information are a source of reading failure, their low-ability readers read aloud both the target words and the foils. Their problem was not initial phonemic code activation but the ability to maintain the code. Although most disabled readers, certainly young ones, have difficulty in readily activating phonemic codes, there is no strong evidence that they fail to do so altogether. There is evidence that their initial activation is slow and nonautomatic and that the code, once activated, is vulnerable to memory deactivation.

C. Coding and Memory Activation Trade-Offs

There is the possibility, implied throughout our discussion, that less able readers are slower at activating speech codes and less able to keep the code active. If so, it is possible that processing trade-offs occur between encoding and memory as far as the quality of this code is concerned. There is suggestive evidence of this from a backward letter search experiment of Perfetti and Bell (1980). The task requires the subject to decide whether a six-letter string, a nonword, did or did not contain a letter probe. Because this is essentially a memory search task, manipulations of letter-string properties can be taken to affect the memory code established and examined to respond to the probe. In one experiment, Perfetti and Bell (1980) found that strings that were well structured orthographically and phonemically (e.g., *sonkie*) produced fewer errors than strings low in structure (e.g., *segrcd*). The advantage of structure was absent in forward (visual) search in which the letter is presented first and then the search display. Thus, the advantage of structure appeared to be due to its effect on establishing a memory code: A well-structured string provides a phonemically based memory code with which to compare the probe letter. Interestingly, the effect of structure was greater for adults and skilled fourth-grade subjects than for less skilled fourth-grade subjects. This seems to be another piece of evidence that less skilled readers do not use phonemic information in memory as well as skilled readers do.

In a subsequent unpublished experiment, the roles of encoding and of memory in the use of structure were examined. Less skilled readers were given either 330 or 1500 msec to encode a six-letter nonword string. After the display was terminated, a letter probe followed an interval of either .5 or 4 seconds. If a useful code requires more time for a less skilled reader to establish, then the longer encoding time of 1500 msec should facilitate performance generally and lead to a facilitating effect of structure. On the other hand, if establishing a phonemic code is less of a problem than retaining it, then the longer memory interval should be especially sensitive to structure and especially difficult for less skilled readers.

The results suggested a trade-off: Less skilled readers who had only 330 msec to encode the letter string showed some advantage of structure if the memory probe followed quickly. When the retention interval was 4 seconds, performance dropped dramatically and there was no advantage of structure. Less skilled readers who had 1500 msec to encode the stimulus performed as well as skilled readers who had only 330 msec. Their pattern of errors was different, however. At the long retention interval only, they showed a large effect of structure. Apparently, they had ample time to form a phonemic representation and were able to keep it active. For strings without structure, they could perform no better at the long interval than subjects with less encoding time. The important results for less skilled readers can be summarized as follows: The effect of additional encoding time was to increase the memorability of well-structured strings. Accordingly, the difference between skilled and less skilled readers in the use of structure is seen when encoding time is short and delay is long.

This kind of experiment demonstrates that speech encoding and memory can be treated as related processes. The conclusion is not that unskilled readers have deficits in phonemic memory, but that when both encoding and memory demands are present, a trade-off can be observed; the greater the demands for a quality phonemic code in memory, the more the demands at encoding play a role.

IV. SUMMARY

In this article we have proposed a model of speech processes in reading and have critically reviewed research on the role of such processes in reading. Much work has been guided by the question of whether speech recoding precedes lexical access. Although that question seems generally answerable in the negative, we suggest that a richer understanding of speech processes in reading must include attention to postlexical processes. Our proposal is that activation of some phonemic information is automatic and concurrent with lexical activation. Although there is little direct evidence for this at present, we argue that postlexical demands of reference securing make it reasonable to hypothesize such a process. We suggest that the phonemic code is not a mere replica of a speech production. In connection with the general proposal, we also conclude that experiments employing speech suppression paradigms are inadequate to detect the speech processes involved. We suggest that there is a continuum of speech activation and that suppression operates at a higher level than the relevant speech processes. We do report some recent research of our own that provides at least weak evidence for phonemic processes involving consonants.

We also consider whether reading ability is related to the use of speech processes in reading. There is considerable evidence that it is. In terms of our activation proposal, there is little evidence that activation of speech codes fails to occur for less skilled readers. Some evidence suggests that activation is slower or less automatic. There is more evidence for the "deactivation hypothesis," that a speech code, even when activated, deactivates more rapidly for a less able reader. It is possible, as we demonstrate, that encoding conditions and memory demands may be related and that compensation between them can be arranged.

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