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ABSTRACT

A view of skilled reading is suggested that emphasizes an intimate connection between coding and comprehension. It is suggested that skilled comprehension depends on a highly refined facility for generating and manipulating language codes, especially at the phonetic/articulatory level. The argument is developed that decoding expertise should be a basic goal in reading instruction and that reading objectives should include facility or speed of performance, as well as accuracy. (Author)

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CODING AND COMPREHENSION IN SKILLED READING AND IMPLICATIONS FOR READING INSTRUCTION

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In this paper, we will suggest a view of skilled reading that emphasizes an intimate connection between coding and comprehension. Our thesis is that skilled comprehension depends on a highly refined facility for generating and manipulating language codes. This will be the basis for suggesting that decoding expertise should be a basic goal in reading instruction.

We would like to place our argument in perspective by outlining a few of our basic assumptions. Although these assumptions are widely shared, they are not without controversy. In any event, they provide the framework through which we view reading and research on reading.

Assumption 1. Skilled reading can be partly understood as a set of interrelated component processes. These processes can be described within an information-processing framework or within any other framework that is functionally equivalent in its ability to provide insight into component processes and their relationships. There are two corollaries of this assumption:

Assumption 1a. The components of the reading process are not necessarily functionally independent. We tend to agree with those, for example, Guthrie (1973), who have concluded that subskills in reading are mutually facilitative rather than independent. One fairly important consequence of this assumption is that skilled readers are superior to unskilled readers in many components of the reading process.

This means that a gain in one subskill allows gains in other subskills, that an insufficiently developed subskill may limit the apparent adequacy of other subskills, and that the processes underlying the skills are difficult to study in isolation While these processes may seem to be hierarchically organized when viewed from some perspectives, we assume that a "lower level" process can be affected by a "higher level" process, and vice versa. For example, knowledge of subject matter and syntactic structure can influence word recognition, and the shape of words in peripheral vision may bias syntactic segmentation.

Assumption 1b. The component processes are isolable in principle, although interrelated in practice. Thus, despite Assumption 1a, understanding skilled reading processes does entai. ysis of components. Consider an analogy of high-fidelity syste . with overall reading skill analogous to measurable sound quality ar d component processes comparable to hi-fi components.[1] If any component is defective, or if components are mismatched, sound quality suffers. The components can be independently tested and, more importantly, independently improved. However, improvement of one component may not immediately improve sound quality (but it may increase the potential of the system to benefit from later improvement in other components). For example, an improved cartridge, capable of encoding more high-frequency information, will improve the sound quality only if the other components are capable of handling the information, but not otherwise. Likewise, one might improve the speakers by making them more accurate at high frequencies, but this will improve

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[1]J. B. Carroll (in press) has used hi-fi imagery for a somewhat different point, suggesting that an indicator of cognitive ability shows the upper limit of language competence, which, in turn, indicates the upper limit of reading ability.

the sound quality only within the limits of the cartridge. Changing one component affects the functional characteristics of another component by affecting the quality of the signal or, in some cases, by affecting the speed of the operating system (as in speaker damping). Thus, the situation in both reading and hi-fi is one of structural independence but functional interdependence. In particular, components of reading may sometimes be testable only in situations outside of "natural" reading, just as for some tests one must take an amplifier to the repairman, while the rest of the system is left at home.

Assumption 2. Within the constraints of Assumption 1, reading is highly flexible. We agree with Gibson and Levin (1975) that an analysis of reading process components, even allowing for their interdependence, does not comprise a complete description of skilled reading. This flexibility is sometimes difficult to describe because it involves strategies and purposes. This difficulty affects only the theoretical status of reading flexibility, not its practical importance.

Assumption 3. The relationship between skilled reading and beginning reading instruction is not straightforward. This is merely a particular manifestation of the more general principle that a theory of instruction is not identical to a theory of competence, nor is one necessarily a subset of the other. At the same time, a theory of performance which can model both skilled and unskilled readers is likely to be a useful subgoal in efforts toward a theory of instruction.

We will return to this assumption in the final section. Now we turn to a sketch of skilled reading processes that stresses the importance of rapid automatic decoding and its effects on comprehension. Assumptions 1 and 2 are particularly relevant to the discussion below since we are speaking there of a limitation on the human information-processing system as a whole--inadequate processing capacity. While there are many ways in which capacity can be increased or decreased, we will argue that in reading, capacity limitations are largely the result of properties of the decoding process.

The Bottleneck in Comprehension

The capacity for reading comprehension is limited by momentary data-handling requirements. Working memory is thus a potential "bottleneck" in reading comprehension. Working memory is particularly taxed if it must keep track of partial solutions for heuristic processes that "home in on" decisions in an iterative manner. On the other hand, if some of the components of the reading process are ballistic, (i.e., not requiring attention once they are initiated), there will be less working memory congestion. In our view, skilled reading does not imply a larger working memory capacity but, rather, a more effective use of this capacity.

There are several candidates for components in reading that, when not fully developed, could increase the working-memory bottleneck. We will mention three: access to long-term memory, automation of decoding, and efficiency of reading strategies. The first candidate is tied to the structure and content of the reader's knowledge. Small vocabularies lead to low comprehension and, presumably, so do under-practiced vocabularies or those with low interconnectedness among concepts. One hypothesis is that improving rapid access to word meanings and prior conceptual structures is a means of relieving the bottleneck. Knowing the exact meaning of a word prevents the cognitive load that would otherwise result from having to figure out its meaning from context. It makes comprehension more of a recognition task and less of a problem-solving task.

The second, related candidate is speed and automation of decoding. When print maps automatically to phonologically referenced words, the decoding requires no monitoring and, hence, does not waste limited working memory. This is a good example of two conceptually independent components that are functionally intertwined. Because decoding leads to meaning, affecting the efficiency of print decoding affects the efficiency of meaning access.

The third candidate is processing strategies, particularly those that take advantage of language structure. Skilled readers might acquire and use segmentation and organizing strategies that less skilled readers lack. One example of this hypothesis is that skilled readers use sentence and clause boundaries to segment the flow of print as well as the flow of speech. A second example is that more knowledge of grammatical and semantic constraints is acquired and used by skilled readers than by less skilled readers. This, too, has the effect of relieving the bottleneck. Any information-handling procedure that aids in grouping language units accurately has this effect because it is both a form of chunking and a means of more rapidly converging on a correct sentence parse.

Language organizing processes of this sort are patently important in reading processes. However, there may be some reasons to doubt whether they are critical sources of reading skill differences beyond their dependency on rapid verbal coding. Elsewhere (Perfetti & Lesgold, in press), we discuss these reasons in some detail. In the remainder of this paper, we prefer to focus on coding operations as they relate to reading skill and the comprehension bottleneck.

Coding and Comprehension

There are a number of important issues in reading and reading instruction that are related to coding. The starting point is that single-word decoding and reading comprehension skill are highly related for children who have already learned decoding. For example, Shankweiler and Liberman (1972) found that reading words in isolation predicted success in reading connected discourse; and Calfee, Venezky, and Chapman (1969) found that accuracy in pronunciation of pseudowords was related to reading skill. Thus, measures of word decoding accuracy are related to measures of comprehension. Still, teachers of reading say that there are children who can read all single words on the Wide Range Achievement Test, but who fail to comprehend sentences and passages. It is possible that something more than decoding accuracy is involved. However, before we conclude that this something else is not a coding process, consider again the bottleneck problem.

The relationship between coding and comprehension is one of sharing processing resources. It is possible that observed deficiencies in reading comprehension are partly due to unobserved differences in the extent to which decoding uses an excessive share of the resources. Measuring accuracy of word identification will not necessarily uncover this excessive dependence of decoding on conscious decision making. Measuring speed of word identification may.

In a series of studies, Perfetti and Hogaboam (1975, Note 1) have found large, consistent differences between skilled and less skilled readers in the third through fifth grades of measures of coding speed. Table 1 shows the basic relationship.

Table 1

Mean Vocalization Latencies (in sec) for Skilled and Less Skilled Readers

Groups	High-Frequency Words	Low-Frequency Words	Pseudowords
Grade 3			
High skill	.95	1.30	1.59
Low skill	1.17	2.38	2.72
Grade 5			
High skill	1.08	1.45	1.48
Low skill	1.25	2.48	2.71

Note. For real words, data are only for words that subjects got correct on a vocabulary test. (Data are based on Perfetti and Hogaboam, 1975.)

The decoding speed measure was vocalization latency, the time taken to begin vocalizing single words displayed in normal type on a slide projector. The groups were divided by scores on the reading comprehension section of the Metropolitan Achievement Tests (MAT). Not all of the letter strings seen by subjects were real words. When nonwords with acceptable English spelling patterns (pseudowords) were used, the speed differences between skilled and less skilled readers increased. This is an important fact because it argues against the hypothesis that decoding speed differences were due to differential reading experience with the particular words tested. This hypothesis is otherwise very plausible because it is probably true that a skilled reader, as measured by a comprehension test, has had more reading experience and a better chance to develop "holistic" word recognition capability. Instead, the Perfetti-Hogaboam data imply the importance of subword components of the coding process.

In a more recent experiment (Perfetti & Hogaboam, Note 2), the "wordness" factor is again clearly seen, along with the effect of syllable length. In this experiment, entire third- and fourth-grade populations were tested in single-word vocalization. A median split on comprehension measures (based on reading subtests of the Durrell Listening-Reading Series) produced two skill levels that were compared for vocalization speed. Word strings were either real words or pseudowords and were either one syllable or two syllables. They were presented in blocks of trials so that any differences in response time could not be attributed to some orientation reaction to a changing stimulus. The results are shown in Figure 1.

Regardless of grade level, the less killed readers were slower than the skilled readers. In addition, there were significant interactions of stimulus type and syllable length with reading skill. There was a greater cost for the less skilled readers, compared with the skilled readers, for either an extra syllable or for a pseudoword.

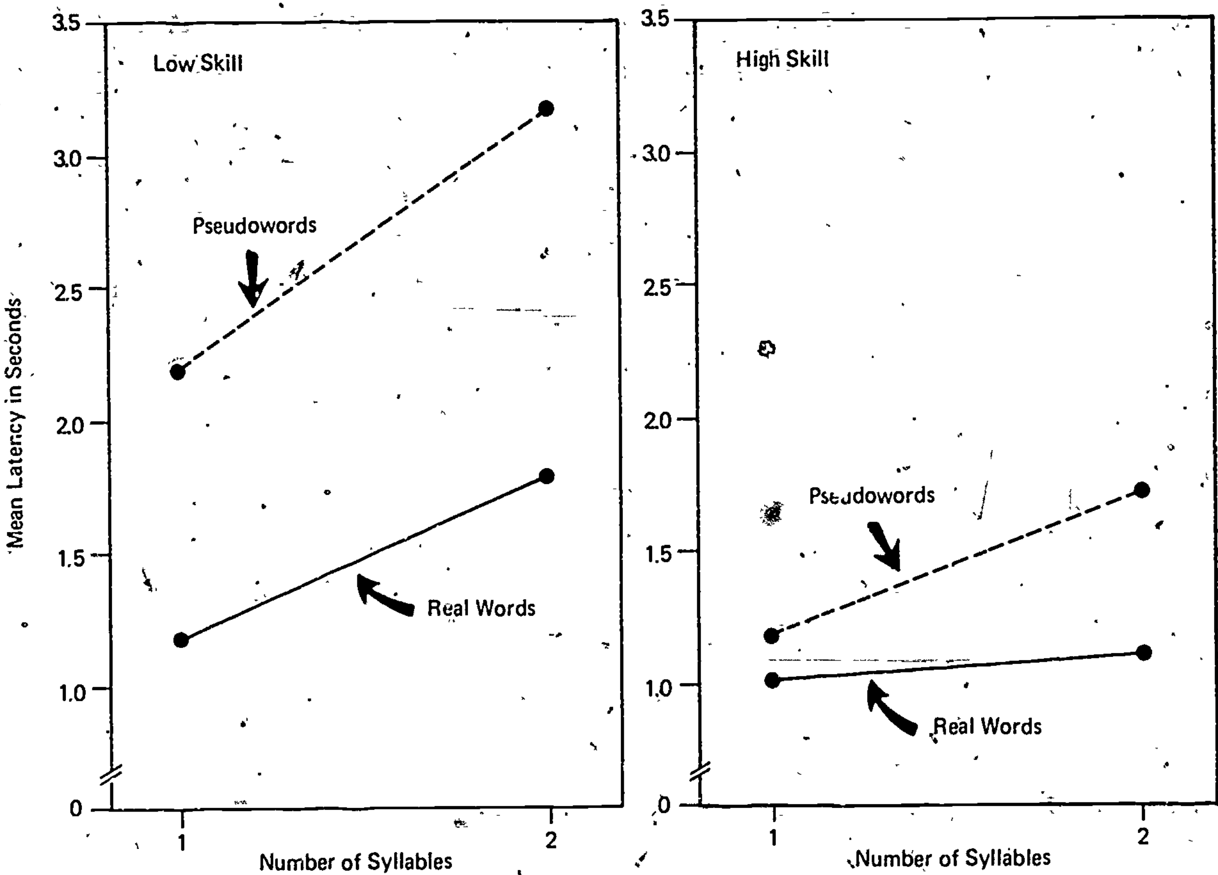

Figure 1. Vocalization latencies for third- and fourth-grade readers. (The data are from Perfetti & Hogaboam, Note 2.)

In particular, pseudowords took nearly twice as long as real words for less skilled readers (an extra 1,200 msec), compared with 40% extra time for skilled readers (an extra 400 msec). The cost of a second syllable was about 800 msec (50% increase) for less skilled readers, compared with about 300 msec (about 30% increase) for skilled readers. These data support the earlier results of Perfetti and Hogaboam (1975) in suggesting a basic coding difference involving units smaller than words. They go further in suggesting that a syllable-at-a-time process is more characteristic of the less skilled readers than of the skilled readers. The locus of the syllable and stimulus type interaction, of course, could be at the responding stages rather than at one of the recognition stages.

Experiments underway in a word search task could help clarify whether syllable interactions occur in decoding or response stages. For now, it is at least possible to suggest that not all of the difference is a matter of response programming. This is so because the differences between decoding speeds for single-syllable stimuli are not confined to measures requiring vocalization. Perfetti and Hogaboam (Note 2) found group differences in a task in which two strings of letters were displayed and subjects were required to say whether the strings were the "same." Decisions were faster for skilled readers, although the differences were not as large as in the vocalization task, suggesting that both decoding stage and response stage differences are involved in that latter task.

Coding and Comprehension: Cause and Effect

The empirical phenomenon seems well established: Coding speed and reading achievement are highly related for young readers. What causes what is another issue, and there are plausible arguments both for what we call the bottleneck hypothesis and for what we call the by-product hypothesis.

The by-product hypothesis claims that measured comprehension (e.g., a reading test score on the MAT) taps a wide range of knowledge and skills, including word recognition, at something other than the level implied so far. According to this hypothesis, recognizing a word need not involve its sound, but only its meaning. Further, but less critical, recognition of word meanings is contextual in skilled reading. Measures of isolated word recognition, whether involving phonological codes or not, are irrelevant. However, a correlation will be observed with reading skill just because skilled readers are practiced readers, and the same reading behaviors that lead to high comprehension scores produce facility in word recognition and articulation as a by-product. A variation is that good readers happen to read a lot and that this in turn produced decoding facility.

In contrast, the bottleneck hypothesis claims that being fast at decoding leads to high comprehension. The essential processing assumption is that single-word coding operations are a critical part of reading, even when control of the reading process flows from higher level pragmatic and inferential processes rather than from stimulus components (see Frederiksen, in press). These coding operations may share the limited capacity processor to varying degrees with other comprehension work, for example, memory for just-read segments, parsing strategies for text, memory for discourse topics, and so on. Fast decoding is more automatic, in the sense of LaBerge and Samuels (1974), and it leaves more resources for fancier comprehension work.

The weak form of this hypothesis does not require that the coding operations include a "phonetic recoding." It merely assumes that phonetic processes, which are necessarily involved in some single-word decoding tasks, are a subtractable part of the total process for the skilled reader. The strong form of the hypothesis does assume that some phonological representation of a letter string is accessed in skilled reading. It does not assume access to any articulatory component, covert or otherwise.

We will return to phonetic recoding in a later section of this paper. For now, the point is that there are two plausible accounts of the close relationship between decoding speed and reading comprehension skill. No evidence is known to us that directly supports one hypothesis over the other. However, one critical test seems possible. The bottleneck hypothesis will be confirmed if it can be shown that independently increasing decoding speed improves comprehension. This seems a clear and testable consequence of the bottleneck hypothesis. Unfortunately, the opposite prediction, i.e., that independently improving comprehension will increase decoding speed, seems untestable and so, in general, does the by-product hypothesis.

Coding at Higher Levels of Skill

The results reported above apply to children who are beyond beginning reading but still in elementary grades and who range in age from 8 to 11 years. Although our emphasis is purposely on this level of reading development, a comment on higher levels of skill is in order. Hunt and his associates (1976; Hunt, Frost, & Lunneborg, 1973) have discovered a number of differences in college students' performances of basic information-processing tasks. Some of these differences are related to verbal aptitude levels measured by college aptitude tests. For example, differences in continuous paired associate performance and in name matching for letters (Posner & Mitchell, 1967) were found to be related to college verbal aptitude (Hunt et al., 1973). Analogous differences might be expected to relate to more specific measures of reading skill at the college level. Rapid data handling, which Hunt et al. suggest is one of the critical factors distinguishing high and low "verbals," would seem to be particularly important in reading.

The data that we have collected suggest that the relationship between coding facility and reading skill is more subtle in adult readers. An unpublished study by Perfetti and Straub investigated the interference of overt decoding on short-term memory performance. The task required subjects to read five digits for later recall and then to perform an interpolated naming task during a retention interval of unpredictable duration (3, 6, or 12 sec). The interpolated naming task required oral reading of a display of English words, a display of pseudowords, or a display of pictures of common objects. Thus, all three tasks had a vocalization component, but only two had a print decoding component.

One result was that reading pseudowords interfered most with digit memory, while reading English words and pictures were about equal. Thus, for skilled adults, decoding words may interfere with memory no more than decoding pictures. This was true for both the higher skill group and the lower skill group, where the groups were separated by Davis Reading Test scores. However, higher skilled readers did less well than lower skilled readers at the 3-sec interval, equally well at 6 sec, and better than lower skilled at 12 sec. A possible explanation of these data is that at adult skill levels, decoding differences are small enough that their effects are seen only when other processing demands are high, as they are when a digit string has to be retained during 12 sec of decoding. However, the lack of an overall effect in conjunction with the interaction may suggest a strategy difference rather than a simple decoding difference.

A second relevant study is by Lesgold and Danner (1976), who investigated tachistoscopic recognition of letters, number, and trigrams. Measures were taken over three stimulus availability conditions ranging from 50 to 125 msec between stimulus and mask onsets. While this study had other purposes, the relevant data for this discussion are that higher skilled and lower skilled college students, defined by Davis Reading Test scores, showed no differences in accuracy or speed of report, either as main effects or in interaction with stimulus type. However, there may well be important coding speed differences that persist through skilled adult reading that can be revealed by measures more sensitive to specific coding operations.

One possibility in this regard is suggested by a study by Jackson and McClelland (1975). For college students separated on comprehension-corrected reading speed, Jackson and McClelland found that single-letter visual thresholds were not related to reading skill. Nor was performance on pairs of letters presented for 200 msec separated by up to 5.9° of visual angle. What was related to reading skill was report of 5-word sentences presented for 200 msec and report of 8 unrelated letters presented for this same brief duration. Thus, there is evidence from Jackson and McClelland (see also Gilbert, 1959) that skilled readers can report more information from a brief exposure, but no evidence that this difference is operating at the level of visual detection. Furthermore, the difference between groups on sentence "perception" is not eliminated by a forced-choice procedure in which there is only a single-letter difference between two semantically and syntactically acceptable alternatives (e.g., Kevin (fired, hired) a new worker). This last fact argues against the possibility that skilled reading is a matter of superior guessing, and the fact that differences are found for groups of unrelated letters suggests that something more basic than use of linguistic structure is involved.

We take the data of Jackson and McClelland (1975) to suggest that differences between adult readers will be found just when the task demands the reader to process a segment of text--either a bunch of letters or a phrase--very rapidly. When demands on processing are light, there will be no differences. By comparison with Jackson and McClelland, the Lesgold and Danner (1976) experiment may involve lower processing demands in general, and the Perfetti and Straub experiment may make differential processing demands only at long intervals (or perhaps not at all).

Coding and Meaning Access

The usual purpose of reading, as someone always reminds us, is to obtain not sound, but meaning from print. Coding tasks such as we have been discussing are not particularly interesting from this point of view. However, in terms of the bottleneck hypothesis, two distinct possibilities for the effects of coding in comprehension are implied: One possibility is that the speed of access to phonological information affects comprehension, and the other is that semantic access speed affects comprehension. Semantic access may often require phonological decoding (i.e., semantic information is accessible through a phonologically indexed lexical entry), but in principle it need not. We will ignore the phonological question and simply consider two levels of coding, referred to as <u>phonological decoding</u> and <u>semantic decoding</u> for convenience. The first question we consider is whether semantic decoding comes automatically with phonological decoding. The second is whether it does for skilled readers but not for less skilled readers. We have already shown that phonological decoding is more work for less skilled readers. The question now is: Are they doubly disadvantaged by slower semantic decoding?

An experiment carried out by Perfetti, Hogaboam, and Bell is relevant to this issue, and the data are presented here. Single words or pictures were presented to 8- and 10-year-old subjects separated by reading comprehension scores. In one task, the subject had to decide whether a given stimulus matched an orally presented target. For example, just after the experimenter said, "rabbit," a slide would be shown containing a word (in one condition) or a picture (in a second condition). Blocks of eight trials involved the same target, and the subject responded with a button press according to whether the visual stimulus matched the oral stimulus. Nontarget stimuli in this task were in semantic categories different from the target and, thus, no semantic interference could be involved in this task. The time takes to decide that dog is /dawg/ is perhaps the prototype phonological decoding measure. This can be compared with the time it takes to decide that a picture of a dog is /dawg/.

The other task was categorization. A target semantic category was announced (e.g., "Animals") prior to a block of trials. As in the matching task, trials were blocks of pictures or words. We thus have a measure of semantic decoding speed: the time to make a verification of a salient superordinate semantic category. If any aspect of meaning "comes free" with phonological decoding, it should be this kind of superordinate information. Table 2 shows a summary of the results for "same" judgments on the two tasks for the 10-year-olds.

Table 2

Matching and Categorization Times (in msec) for Fourth-Grade Subjects

Group	Pictures	Words
	Matching Task	
Low reading skill	831	883
High reading skill	833	838
	Categorization Task	
Low reading skill	875	1095
High reading skill	772	939

For purposes of the present discussion, the results suggest that less skilled readers are not different from skilled readers in picture matching and only 45 msec slower (not significant) in word matching. However, in word categorization, less skilled readers are 156 msec slower. In fact, less skilled readers were 103 msec slower in picture categorization. Thus, the difference in semantic judgment time apparently does not depend on whether the stimulus is a word. However, this does not mean that semantic processing is free of phonological coding operations. Indeed, Kleiman's work (1975; see below) suggests otherwise. Our interpretation of this experiment is that lower level feature matching is adequate in the less skilled reader, but that retrieval of semantic information associated with a word or picture name is slower.[2] In this sense, useful semantic decoding may not automatically accompany lower order decoding for less skilled readers.

Our conclusion here must be very tentative. However, we can suggest possible clarification of the coding process implicated by the bottleneck hypothesis. Phonological decoding is slower in less skilled readers and so is the use of semantic information. The decoding difficulty is perhaps not so much due to word recognition as it is to word retrieval. This, at least, is implied by the fact that differences due to reading skill are larger when children have to vocalize a word (which includes name retrieval) than when they hear that word prior

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[2] One of the complexities of these data is that the categorization time of less skilled readers greatly benefited from having the matching task precede the categorization task. In fact, only when the categorization task came first was the difference between high- and low-skill readers statistically significant. This would seem to suggest that the differences are in the processes of either retrieving or using conceptual features. After the name itself has been accessed (matching task), the subsequent use of information stored with the name is facilitated.

to its appearance in print and are required to make only a same/different judgment.

The slower semantic processing of the less skilled reader may be of greater practical significance. This is so because not everyone agrees that phonological decoding is involved in skilled reading. We know of no controversy concerning the importance of meaning. We emphasize though that we are not dealing here with the simple question of word knowledge. Rather, we are dealing with the more subtle question of rapid access, retrieval, and use of word meaning information.

There are data which can be interpreted as being at odds with the foregoing account. Golinkoff and Rosinski (1976) presented a picture naming task to third- and fifth-grade children classifiable as skilled and less skilled readers. Picture naming is subject to a semantic interference effect, that is, the time to name pictures is longer when words from the same semantic category are printed on the pictures (Rosinski, Golinkoff & Kukish, 1975). (For example, the word cow is printed on a picture of a pig.) However, skilled readers showed an effect no larger than less skilled readers. Compared with the control condition in which the printed word did not contradict the picture, both skilled and less skilled readers were slowed down by the semantic interference condition. Golinkoff and Rosinski (1976) concluded that the relevant semantic information comes automatically, or at least compellingly, with a word stimulus. The data presented here on categorization do not necessarily contradict this, but they do suggest a somewhat different interpretation. In the semantic interference situation, meaning is incidental to the naming task. Provided that the words are very familiar, enough semantic information to interfere with naming pictures is automatically retrieved, although perhaps not for younger less skilled readers (Ehri, 1976, Pace & Golinkoff, Note 3). This low-level semantic information retrieval may typically occur when a reader sees a word, but when the reader has to use the word's meaning, there are differences in the speed of semantic use.

Summary: The Primacy-of-Coding Principle

In summary to this point, we have presented a view of skilled reading which argues for dependencies of comprehension on both automatic phonological decoding and semantic decoding. The evidence in support of this view is unfortunately still indirect, but it is, in principle, possible to provide more direct evidence. Meanwhile, we offer the principle of the primacy of coding as a necessary part of a more complete model of skilled reading. We turn now to some related issues that are relevant for our argument.

Some Classical Issues in Reading

There are many issues, both in the psychology of reading and in reading instruction, that predate modern cognitive psychology. Disagreement about some of these remains sufficiently widespread to warrant further research. We will discuss two of these issues that are of most direct concern to our primacy-of-coding principle: phonological components of reading and the implications of a coding emphasis for reading instruction.

Phonetic Recoding

The phrase phonetic recoding captures the classical flavor of the first issue. Is meaning obtained from print without recoding the print into some speech-like code? The sides of the argument are direct visual access versus necessary phonetic recoding. There is a weak form and a strong form of each theory, so the dichotomy tends to break down. We would rephrase the issue as: What is the extent of phonological involvement in skilled reading? For example, Goodman's (1970) theory of reading favors visual access in general, and Gibson and Levin's (1975) theory requires it at least some of the time, as would Kolers' (1970) theory.

It seems quite sensible to believe that skilled silent reading does not engage much overt speech behavior. For one thing, as Kolers (1970) has pointed out, text can be read faster than it can be spoken. And here is where a basic clarification can be made: A theory of skilled reading that includes complete (even if silent) speech recoding is incorrect. However, a theory in which a partial and vastly shortened reference to phonetic features of words is posited might still be correct. Another perspective is to say that access of word meanings in long-term memory requires or is facilitated by the phonological representation of the word.

What evidence is there for direct access, that is, bypassing the phonological representation? We will not review all the evidence, but we can mention some of the more important and/or most cited results. Recently, Barron (Note 4) argued for the direct visual access hypothesis and cited several lines of evidence for it (see also Bradshaw, 1975). We will examine some of the studies cited by Barron in support of the direct access hypothesis for the purpose of questioning how strongly they support it. Since Barron acknowledged that much of the data is open to other interpretation, we include only what he considered to be the clearest data for the direct access hypothesis, namely, data on lexical decision tasks and semantic judgment tasks.

Lexical decision. In a lexical decision task, a subject decides whether a string of letters is or is not a real word. Thus, the processes involve access to internal word representation and, hence, are potentially relevant for the issue of phonological versus visual entry into lexical memory.

There are data that appear to support phonological access in decision tasks for single words (Rubenstein, Lewis, & Rubenstein,

1971) and for pairs of words (Meyer, Schvaneveldt, & Ruddy, 1974). For example, Meyer et al. presented subjects with pairs of words that were graphemically identical after the initial letter, but whose vowels were phonemically distinct, for example, COUCH and TOUCH. These were compared with words having both graphemic correspondence and phonemic similarity in the vowel, for example, BRIBE and TRIBE. The results were that pairs like COUCH-TOUCH required more time to verify as real words than did pairs like BRIBE-TRIBE. Why? Because for BRIBE-TRIBE, phonological features activated in the decision process for the first word were available and useful for the second word. In the COUCH-TOUCH case, the activated phonetic features for COUCH were less useful, perhaps interfering, for the second decision on TOUCH. If information sufficient for lexical decisions could be visual, then these two cases should take equal time, and they did not. Moreover, one interpretation of the visual access hypothesis would predict an advantage for graphemically similar pairs like COUCH-TOUCH over nonsimilar pairs, for example, COUCH-BREAK, but such was not the result of the Meyer et al. experiment. Meyer et al. were quite cautious about their results, suggesting correctly that the occurrence of a phonemic effect but not a visual effect could be due to a processing strategy applicable to lexical decision tasks but not to other reading.

There are two lexical decision experiments, however, which unlike Meyer et al. (1974), are cited to support the visual access hypothesis. Forster and Chambers (1973) gave subjects both naming and lexical decision tasks on the same set of words and pronounceable nonwords (pseudowords). They found that vocalization latency (naming time) was less for real words than for pseudowords, and they found a frequency effect for real words. Further, they found that naming time and lexical decision time were correlated for words but not for pseudowords. According to Barron (Note 4), these two results indicate that naming occurs after lexical meaning access because otherwise there would be no naming speed differences among the three stimulus types. And there was no naming-decision time correlation for pse dowords because naming time reflects time to "decode," while lexical de ision time reflects time to find out that a letter string does not have a lexical entry. This line of argument is problematic, however, because the judgment task is to say yes for words and no for pseudowords. To find a correlation for words but not for pseudowords is to find a correlation for a yes response but not for a no. Why would the phonetic recoding hypothesis predict anything else? It assumes that skilled readers can apply decoding rules and vocalize well-formed letter strings. It has nothing to say about how long it takes to decide that a letter string is not a word. However, the phonetic recoding hypothesis does predict the positive correlation between naming speed and lexical decision time for words, which is what Forster and Chambers (1973) found. This experiment then is consistent with both our position and Barron's.

Another experiment cited as evidence for direct access is Novik's (1974) demonstration that in a lexical decision task, rejection of nonmeaningful trigrams was faster than rejection of meaningful trigrams like JFK or LSD. Such differences might merely reflect extra checking time after a preliminary screening in which JFK and LSD are found to be familiar enough to merit further processing (as in the Atkinson & Juola, 1973, decision model). They present no evidence for direct visual access to complete semantic representations.

Semantic judgment. There are two different types of data based on semantic judgments that support direct visual access, according to Barron (Note 4). In the experiment by Meyer and Ruddy (Note 5), subjects were given semantic categories ("Is a kind of fruit") followed by words. Time to decide whether a word belonged to the category was measured. Consistent with a phonological access hypothesis, it took longer to decide that a word like PAIR was not a fruit than to decide that a word like TAIL was not a fruit. Presumably, this effect is due to a reduced ability to reject pair because of its phonetic connection with pear.

However, the visual access hypothesis appears to be supported in data from a second task in which subjects were required to respond with yes to words that sounded like a category member. Thus, both PEAR and PAIR qualify for yes, TAIL for no. The critical result is for TAIL, which should be equally quickly rejected in both tasks; that is, it neither looks like nor sounds like any member of the fruit category. However, TAIL was rejected more rapidly in the first task, where only category instances were targets, than in the second, where category instances and their sound-alikes were targets. This result, according to Barron, supports the visual access hypothesis because direct visual access operates in the first task leading to a faster rejection of TAIL than in the second task, which takes more time because of phonemic recoding. Also important is the result that PEAR was faster than PAIR in the sound-alike task, thus implicating visual access. Barron assumes that the phonemic model predicts equal latencies for PEAR and PAIR on the assumption that they have identical phonemic representations. However, these experimental predictions should not be attributed to a serious phonological coding hypothesis. A serious phonological coding hypothesis does not claim that orthographic and graphemic information are not used. Obviously, visual information is the starting point in the process of phonological coding.

PAIR takes longer than PEAR because the latter has a quicker convergence of features relevant to the task demands. PEAR "looks" like a fruit and sounds like a fruit. PAIR looks like something else. If this is all that direct visual access means, then it has to be true. The longer rejection time for TAIL in the second experiment is also easy to explain. All rejection will take longer if rejections are defined by conjunctive criteria, that is, reject X if X is not a fruit and is not sounded like the name of a fruit. The data do not shed light on the phonemic recoding issue.

There is at least one other study that can be taken as informative for this question, and that is one by Baron (1973). In one experiment, Baron gave adult readers a sense-nonsense task in which time to reject nonsense phrases (and accept meaningful phrases) was measured. Two kinds of nonsense were of interest; phrases like (a) I am kill, and phrases like (b) Its knot so. Baron required phonological coding to predict that (b) should require more time to reject than (a) because (b) "sounds OK," and an extra analysis is required to detect its nonsensicalness. By contrast, the visual access hypothesis predicts no difference because both phrases are rejectable on nonphonetic bases. The results were no difference, as predicted by visual access. However, it must again be noted that the phonological coding hypothesis does not require that graphemic information becomes useless just because phonological coding occurs. Both graphemic information (as well as other visual information) and phonological information have roles in access of the word or phrase representations, which allow a reader to judge meaning properties of a phrase.

In a second experiment, Baron's subjects had to decide whether a word string "sounded as though it made sense." Here the key result is that phrases like Its knot so took longer than phrases like Tie the knot and It's not so. This result was taken to support direct visual access over phonetic recoding on the assumption that the phonetic recoding hypothesis predicts no difference here. It's knot so and It's not so both sound sensible; however, it is not clear that this is the most appropriate assumption for such a task. Instead, one can plausibly assume that any phrase that makes sense sounds like it makes sense, but that a phrase that does not make sense may or may not sound sensible. The visual analysis of It's not so leads to a sensible configuration of word meanings. Therefore, it must sound sensible. It's knot so leads to nonsensible configuration of word meanings. Therefore, a second decision process is engaged: Does it sound like it makes sense? The nonsense phrase's measured decision time is longer because it takes an extra decision process.

The experiments discussed in this section demonstrate the critical role of visual analysis in reading tasks. However, they cannot be used to build a strong case against phonological coding. They can rule out only the possibility that phonological coding erases graphemic and orthographic information. We have labored over these experiments because they are fairly good experiments and because they are taken as evidence against phonetic recoding during reading.[3] We are arguing for a partial phonological coding process during skilled reading, and we know of no evidence against accepting it.[4]

Other reading tasks. Part of the issue of phonological coding versus visual access is the relevance of any single-word experimental tasks for real reading. The question is most likely to be raised with respect to the relevance of single-word experiments which may have

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[3] More recently, Baron (in press) reported experiments which suggest an important role for phonological processes in access to meaning, even in conditions without severe memory demands.

[4] We should comment on another argument sometimes raised in favor of direct visual access. Because certain languages like Chinese use logographic writing, it is claimed (e.g., Kolers, 1970; Barron, Note 4) that phonological coding cannot be a general and necessary part of reading since logographs have semantic value rather than phonetic value. This represents a confusion between coding process and the size of the coding unit. Alphabetic languages allow coding to occur in units smaller than the units having semantic value, that is, in units smaller than words. Logographic languages also allow corresponding phonological coding (for native speakers, at least); they differ in not generally allowing symbol-sound correspondences.

properties that force phonological coding. The implication is that reading text might be quite another matter. However, the tables can be turned on this argument. The bottleneck hypothesis is that comprehension work shares resources with coding work, unless coding is automatic. But this comprehension work has often been said to have phonetic properties. It is here that the silent inner voice is heard. In other words, whether or not individual word coding is phonologically referenced, there is independent reason to believe that cognitive processing makes heavy use of phonological codes. That is, the work of rearranging and interrelating meanings involves phonological codes.

An experiment by Kleiman (1975) is particularly informative on this point. The basic assumption of Kleiman's experiment is that overt digit shadowing (saying digits as they are heard) interferes with phonetic coding. One can determine the phonological involvement of any reading task by noting the effect of concurrent digit shadowing on task performance. In one of Kleiman's experiments, subjects were required to search five-word sentences for targets based on graphemic (visual), phonemic, or semantic categories, with and without digit shadowing. The decisions were always made on visual displays, so if phonological coding was not advantageous, as it would not be with digit shadowing, visual processes could, in principle, suffice.

Significant effects of shadowing were observed on a phonemic decision task (e.g., to decide that a rhyme of cream is present in the sentence He awakened from the dream). However, graphemic decisions and category decisions are relatively unaffected. (A graphemic decision is to decide, e.g., whether a word with the non-initial letters of bury occurs in the sentence Yesterday the grand jury adjourned. A category decision is to decide, e.g., whether there is a word from the game category in the sentence Everyone at home played Monopoly.)

What these three tasks all have in common is that the meaning of the word string, even though it is a complete sentence, can be ignored.

A word-by-word search can go on, the data suggests, with little phonological coding, except for the phonemic targets where phonological coding is required to do the task. The interesting comparison is with the effect of shadowing on judgment of sentence acceptability. Here, all five words of the sentence must be worked on more or less simultaneously. The effect of digit shadowing on this performance was severe, at least equal to its effect on the phonemic task. The implication is that phonological recoding has occurred not on a word-by-word basis, but on groups of words or perhaps the whole sentence.

Based on these data and those from analogous decisions--phonemic, graphemic, and semantic decisions--in a single-word procedure, Kleiman (1975) concluded that direct visual access to meaning is possible one word at a time, but once even a short sentence is in mind, phonetic recoding has to take place. Although it is open to question whether digit shadowing is a complete inhibitor of phonetic coding, this study seems to provide the least problematical evidence to date.

In our opinion, it is most important in showing that, as a practical matter, phonological recoding does take place within the limits of immediate comprehension. We believe it is time to accept the cautious principle that most comprehension, even in skilled reading, takes place within a system that uses a language-speech code, not a visual-symbol code. Coding may be fairly abstract, as Gough (1972) has argued, and it certainly is abbreviated rather than complete, as Huey (1908/1968) pointed out. But, it i a phonologically referenced process for normal readers under most conditions of reading.

We have emphasized the significance of rapid phonological and semantic optimizing mental resources during reading. We acknowledge certainly that the causal relation between coding and comprehension has not been firmly established. Furthermore, the degree of phonological involvement in reading remains an active scientific issue. What is important for the present purpose is: (a) the strong possibility that fast word coding reflecting "automatic" decoding processes can facilitate comprehension, and (b) the overwhelming plausibility that reading does involve phonological coding in many situations.

Implications for the Teaching of Reading

Although the exact causal connections between language coding efficiency and reading comprehension are not well established, it is possible to explore some implications of the strong relationship that appears to be present. As suggested above, it may be difficult to prove the direction of causation. Indeed, the question of causal direction may not even be the most useful question to ask.

Consider an analogy. Is a mountain climber's heart strong because he climbs mountains, or is his success in climbing due partly to being in good physical condition? In this case, causality runs in both directions--you cannot climb without the stamina, but the stamina comes with exercise, only one variety of which is mountain climbing. It would be silly to argue over whether physical stamina causes mountain-climbing success or vice versa. A more useful research problem would ask which aspects of mountain climbing and other activities provide the most effective stamina-building exercises, and which aspects of mountain climbing are most dependent on physical stamina.

Pushing our analogy further, we note that only after certain exercise patterns have been shown to produce both practical results (feeling better) and objectively measured results (e.g., lower pulse rate) do people accept that those patterns of activity are better than others. Now that pulse rate and related measures are used both to meter exercise and to judge its results, we are finally seeing an emphasis on heart muscle development rather than on skeletal muscle development. The importance of tying exercise to a measure with theoretical, empirical, and face validity should not be underestimated.

Let us note that cardiopulmonary functioning is not the sole criterion of health. If you have cancer, running will not cure you. However, it is also true that a range of mental and physical problems, which otherwise seem to have unrelated etiologies and exotic treatments, will disappear with adequate exercise. Building up basic system functions can result in the curing of disorders that otherwise require specialized treatment.

If we replace mountain climbing with reading and stamina with language coding efficiency, our analogy is made. Several useful questions derive from this analogy. They perhaps can help us determine where to go next in studying the relationship between verbal coding efficiency and reading achievement. We shall consider these problems in turn:

1. What constitutes effective verbal coding practice?

2. How can we measure verbal coding efficiency?

3. Who should receive verbal coding practice, and what are the implications of further emphasis on the mechanics of reading?

Practice. We have argued that the verbal coding tasks, which poor readers do not perform adequately, involve skills that are basic to reading. This suggests that some children need even more practice in word vocalization, immediate memory for text just read, and similar tasks than they currently receive. There is some evidence (Perfetti & Hogaboam, Note 1) that practice will improve verbal coding performance, at least in vocalization of unfamiliar words. There is also more general evidence that practice produces an increase in speed for simple verbal learning tasks, even after a conventional learning criterion has been achieved (Judd & Glaser, 1969).

More extensive drill and practice may be hard to implement in some classrooms. However, there are ways of doing so. One possibility is computer-assisted drill and practice--individualized to match current coding levels. Alternatively, more natural reading situations could be created that still provide extensive verbal coding practice. (The DISTAR program [Bartlett, in press; Popp, in press] and the New Reading System [Beck, in press] do a lot of this.) We consider these alternatives in turn.

Computer-assisted instruction (CAI) was developed initially to provide efficient, palatable, and individualized drill and practice. It was abandoned by educational researchers because it was too expensive and because it proved difficult to move beyond drill to more complex instructional tasks. While there are now computer programs that can engage in sophisticated tutorial conversations (e.g., Carbonell, 1970a, 1970b; see also Collins, Warnock, & Passafiume, 1975), those programs still require massive computer systems. However, the advent of large-scale circuit integration has brought down the price of computer hardware to the point where drill-and-practice systems are quite feasible.

The classical arguments for computer-monitored drill are still valid (see the papers in Atkinson & Wilson, 1969, for example). The computer can deliver immediate reinforcement, keep good records, and (especially important) record not only what the responses are, but also how fast they are made. Finally, it is a relatively unforgiving verbal communications medium in which precision of responding is emphasized. Thus, we believe the computer should be reconsidered as a tool for providing verbal coding drill, although we still need to determine what sorts of drill are effective.

The alternative to verbal coding drill is massive practice in everyday text reading. Again, there is the problem of knowing what constitutes effective practice. If we knew that, we could presumably embed the practice in a meaningful, and therefore more rewarding, activity. A second problem is that because of the very inefficiency of beginning readers with text, there is not much in the primary grades curriculum other than existing reading instruction that depends on reading. The medium is "unsafe" for instruction.

However, reading can be made a more basic component of games (as in the New Reading System [Beck, in press]) and other "enrichment activities" in the school. Consider some of the following forms of competition: How many instruction cards (like chance in Monopoly) can you read and execute before the hourglass runs out? Can you rearrange some scrambled words to find out which square to move to? Can you solve a crossword puzzle in 15 minutes? Can you figure out what to feed a pet gerbil by reading a pamphlet about them? All of these tasks, once children have learned basic strategies for doing them, provide verbal coding practice that is fun. Successful reading classrooms already include many such activities, but further instructional research is needed to assure that such practice is effective.

There are still only a few studies of what constitutes effective practice, but we think we can learn from them. First of all, speeded word recognition practice, even with short-duration presentations, does not, of itself, exert much influence on recognition speed or on comprehension accuracy (Dahl, 1974, 1976; Samuels, Dahl, & Archwamety, 1974). However, when the emphasis on speeded recognition is augmented by instruction in tactics for recognition, both recognition speed and cloze test performance are improved (Dahl, 1974). Similarly, instruction in specific methods of making sense quickly out of sentences whose words are scrambled (Weaver, 1976) can boost reading comprehension (as measured by cloze performance), as can instructions for producing a complete illustration of a story one has been reading (Lesgold, McCormick, & Golinkoff, 1975, which measured improvement in paraphrase recall of text).

On the other hand, practice by poor readers, without further instruction, on a task in which good readers are faster does not produce improved reading performance. There are two possible reasons for this. One is that verbal coding speed is only a by-product of reading expertise; the other is that more conscious processing is necessary to recognize words that are not well known than is needed for familiar materials. Specifically, a current model of high-speed recognition (Atkinson & Juola, 1973) argues that the process is highly automated if confidence in the recognition is high, but that extra verbal processing is engaged when recognition is less certain. Perhaps Dahl's ineffective task was so easy that no mental effort was required. Dahl used frequent words, but infrequent words are the major source of good/poor recognition speed difference (Perfetti & Hogaboam, 1975). Therefore, Dahl may have been giving practice on exactly the material for which practice is least needed.

An alternative view of the role of conscious processing is that it enables the learner to better determine the salient properties of the task and the full range of response components required (Welford, 1976). For example, some tailors have great trouble learning to repair woven fabric. This is not because of a lack of needle-moving dexterify or lack of visual acuity, but rather because they do not understand the structure of the weave (Belbin, Belbin, & Hill, 1957). Similarly, unconscious practice of specific words may produce no transfer while more attention to the task may result in refinement of additional subskills.

To summarize, we do not know the full range of effective reading practice techniques, but it is likely that practice on responses that are already automated will not be as effective as practice in applying specific rules to (i.e., consciously processing in) decoding and other verbal tasks that are accomplishable but not yet highly automated.

Measuring verbal coding efficiency. It is no accident that reading tests are usually time-limited tests, thus giving weight to speed as well as accuracy. The studies of Perfetti and Hogaboam (1975, Note 1), Hunt et al. (1973), and others have shown speed of verbal coding to be a good predictor of reading success. It is a better predictor than accuracy of performance since skill accuracy goes to 100% before skill development is complete (see Judd & Glaser, 1969). For example, one can measure letter-naming accuracy on the first day of first grade and predict reading achievement for a while, but one can measure letter-naming speed throughout the first year and it will continue to be correlated with reading achievement (Speer & Lamb, 1976).

We suggest that there are three levels of skill facility that should be distinguished in measurement of verbal coding ability: inaccurate performance; slow, accurate performance; and automated performance. It is the middle level that may most benefit from practice. When performance is highly automated, practice will not help since no conscious processing is required for performance and no load on processing capacity forces skill refinement. A student who performs inaccurately needs to be taught, not drilled. If there is a place for practice, it is at the intermediate level.

Current methods of testing do not make these distinctions very well. There are speed and accuracy measures available from some tests, but those tests are psychometrically designed so that no one does perfectly. Hence, both accuracy and speed scores represent a mixture of the three stages of expertise. However, the steps one might take to develop a reading achievement test that measures processing efficiency in a useful way are straightforward. They would involve procedures that are alien to the normative achievement testing tradition, but not at all alien to experimental psychology.

Let us consider how we would write a testing system for vocabulary. First, we would use the difficulty orderings generated by traditional vocabulary test writers, except that instead of relating the ordinal positions in our word list to grade levels, we would express them in some value-free way. Then we would use one of the traditional procedures of perception research to determine an accuracy threshold, say the point in the ordering at which there is 90% accuracy in recognizing and defining the words.

Determining an automation threshold is not as straightforward since the criteria for speed of processing are normative rather than absolute. The likely task would be vocalization latency (Perfetti & Hogaboam, 1975). The performance of third and fifth graders on frequent words and of good readers in that group on infrequent (for those grades) words is fairly uniform and faster than the performance of poor readers on infrequent words. There is a vocalization speed gap of about 1 sec between the presumably automated and presumably unautomated performances. Thus, there is the possibility that one could produce a chart that said, for example, that recognition of words 1,000-1,200 on the ordered list of words is automated if vocalization time is less than 1.6 sec. Given such a normative chart, one could establish a threshold in the word order below which all words have a probability of say 90% of being recognized automatically. Most probably, the threshold would have to be estimated somehow for each child since there are overall individual differences in speed of responding.

The same procedure could be applied to comprehension testing. There we would establish thresholds for what level of passage difficulty can be handled at all and also for how far in a difficulty-ordered set of passages one can progress with both fast reading and accurate comprehension. Again, there would be norming problems, but that is also true for standard achievement tests. Material just below the child's accuracy theshold would be the subject of specific instruction, presumably based on task analyses, and material between the accuracy and automation thresholds would be used in specific reading practice tasks. It may turn out that for some levels of reading ability, the reading automation threshold could be established by reference to listening comprehension (see Sticht, in press). However, we do not generally believe that poor readers will be adequately efficient in listening comprehension (see Perfetti & Lesgold, in press), and recent data support our view (Berger, 1975; Lesgold, Curtis, & Roth, Note 6).

While it would be possible to do this sort of testing with paper and pencil, it could be unwieldy. Determining thesholds is a complex, time-consuming process if it is done by hand. One can guess that it would become a domain of the reading specialist, not the regular classroom teacher. This means it will be expensive and, therefore, not done too often nor for "better" students. On the other hand, this sort of testing could be done by a very small micro-processor system using cassettes or other recently developed devices to store text material. A classroom teacher could easily learn to make both instructional and practice prescriptions if all s/he had to do was send children to the computer and interpret two theshold measures produced by the computer.

Who needs practice? One outcome of a testing program such as we have outlined could be the discovery that some students, presumably the better readers for this grade, do not have much of a gap between their accuracy and automation thresholds. This is an empirical matter, and we cannot predict whether this will happen. If it did, it would suggest that not all children need the same amount of reading practice and that some children quickly automate the skills they learn. This would be consistent with the work of Royer, Hambleton, and Cadorette (Note 7), which shows that fast learners who meet the same immediate criterion of fact learning as slow learners have actually learned the material better, as shown in later retention tests.

The problems of providing only some students with extra practice in the coding components of reading are twofold. First, there are morale problems and related difficulties that occur when children or their parents realize that not every child is getting the remedial drill activity. We are not social psychologists; we feel that parents, teachers, students, and other experts will hav leal with the question of individualization of instruction. The second problem deserves more comment.

The disparity in reading achievement in different schools, districts, and neighborhoods is such that reading curricula are beginning to appear that are targeted at one extreme or the other of the achievement continuum. While we are heartened to note that programs such as DISTAR, which are targeted at "compensatory education" populations, emphasize verbal coding facility, we must reiterate a warning posed by Bartlett (in press).

Bartlett pointed out, in comparing the Open Court and DISTAR programs, that although DISTAR provides many opportunities for verbal coding practice, it d s not contain, in its earlier levels, much emphasis on the thinking components of comprehension. There are literal probe questions to assure that each word has been attended to, but there are less of the "Why do you think . . ." questions found in programs aimed at easier-to-teach populations. While Bartlett viewed this in a somewhat different way, we have to agree that while reading practice can simultaneously strengthen both the lexical/verbal/ coding and the cognitive/interpretive skills of reading, any given attempt by the teacher to test for coding will deemphasize inferential process, and vice versa.

A common solution of a publisher, when confronted with two incompatible design ideals, is to try to satisfy each for part of the time. While this may be the only solution in terms of materials design, we believe that extensive verbal coding facility and high-level, well-thought-out understanding of text are twin goals, and neither of them should be diluted. Both goals should weigh constantly on the minds of teachers. If the first is not met, the second is, we believe, impossible. If the second is not met, the first is valueless. While it may be necessary to temporarily put great emphasis on coding practice, children should never be misled into thinking that reading fast or accurately saying words is their final goal. By providing opportunities to be rewarded for reading for information, teachers can help children understand the value of reading. By emphasizing analytic comprehension in everyday listening and visual observation situations, they can get the child ready to make use of the decoding facility that extra practice in reading mechanics may provide.

Summary. In simple terms, we can summarize our argument as follows. There is evidence that general verbal coding facility is substantially correlated with reading achievement. We do not know which causes which. However, the analogy with physical fitness suggests that cause runs in both directions and that instead of trying to find out whether lack of verbal facility causes poor reading or vice versa, a bett... goal would be to try to specify what sorts of verbal skills practice produce improved verbal facility.

When children cannot do a verbal task, they need to be taught how to do it. However, even after they have learned what to do, they may need to practice to learn it well. While some normative tests measure speed of decoding as well as the ability to decode, much day-to-day testing of students taps only the low mastery level of correct performance. It now seems worthwhile to experiment with and to learn how to measure higher criteria of mastery for basic verbal coding skills, criteria based not on just doing the job, but instead, on doing the job well.

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