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ABSTRACT

Reading encompasses a wide range of verbal processes, among them such simple verbal processes as word decoding, letter recognition, name retrieval, and semantic access. The question is whether simple verbal processing differences are adequate to account for general reading ability differences. Across different verbal domains and different ages, the hallmark of skilled verbal processing is efficient word retrieval from inactive memory. What varies across different verbal domains and verbal skill levels is the extent to which one or the other of these simple processes is rate limiting for an individual. Research studies have shown that among children, the rate limiting process is word decoding, whereas among college students it is name retrieval. However, verbal knowledge also makes a contribution to general verbal ability that cannot be easily reduced to simple verbal processes. Simple verbal processes cannot account for either differences in the ability to compose a text or to appreciate distinctions between semantically related words. The former entails a number of complex verbal abilities producing wide individual talents while the latter implies fairly simple but powerful semantic and morphological knowledge. Such abilities suggest cognitive components beyond simple verbal processes. (HOD)

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Charles A. Perfetti

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INTRODUCTION

Some persons read well, have large vocabularies, and score high on verbal intelligence tests. Others read with difficulty, have smaller vocabularies, and score lower on verbal intelligence tests. What processes underlie such pervasive differences in verbal ability? Are the processes that underlie differences among children in reading skill the same as those that underlie differences among adults in reading skill or in verbal intelligence? These are the general questions addressed by this chapter.

The outline of the chapter and my main conclusions are as follows: The first section argues for a heuristically useful distinction between simple verbal processes, complex verbal processes, and verbal knowledge as three components of general verbal ability. The remaining sections examine the extent to which four simple verbal processes—letter recognition, decoding, name retrieval, and semantic access—can account for differences in reading ability of children and adults, as well as in adult verbal intelligence. A major conclusion is that across different verbal domains and different ages, the hallmark of skilled verbal processing is efficient word retrieval from *inactive* memory. What varies across different verbal domains and verbal skill levels is the extent to which one or the other of these simple processes is rate limiting for an individual. Among children, the rate-limiting process is

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word decoding, whereas among college adults it is general name retrieval. In addition, verbal knowledge makes a contribution to general verbal ability that is not easily reduced to simple verbal processes. Knowledge of both linguistic forms and concepts is as characteristic of verbal ability as speed of name retrieval. The final section briefly suggests how complex verbal processes can be affected by, but not reduced to, simple verbal processes

VERBAL PROCESSES: A DEFINITION AND THEORETICAL FRAMEWORK

For present purposes, *a verbal process* is any cognitive activity that (by reasonable inference) involves the recognition, retrieval, or understanding of linguistic forms. Thus, recognizing a word is a verbal process and recognizing a face is not Furthermore, a *simple verbal process* is a verbal process that relies mainly on access and retrieval of linguistic elements stored in a memory system [1] In its simplest form, it is access to a specific memory location, whereas in its more elaborate form, it also includes simple decoding operations. Thus recognition of a letter and recognition of a word are both simple verbal processes, even if recognition of a word involves retrieval of decoding rules and decoding operations. By contrast, a *complex verbal process* is one which requires multiple memory access and manipulations of accessed units. Thus, comprehension of even a two-word sentence is a complex verbal process The distinction between simple and complex verbal processes becomes difficult for certain cases. For example, the decoding of a rare word, (e g., *rugation*) or even a relatively common morphological compound (e.g., *nonsexist*) may involve multiple access and manipulation more than the understanding of the two-word "sentence" *No Smoking* Such cases are interesting just because they suggest that decoding may sometimes be complex and comprehension may sometimes be simple. As a general case, however, letter and single-word processes are simple and comprehension, even sentence comprehension, is complex.

In addition to simple and complex verbal processes, verbal abilities rely on *verbal knowledge* Verbal knowledge is the information in permanent memory that is accessed and manipulated by verbal processes. Again, it is useful to assume more than one level. *Word-form* knowledge includes infor-

[1] I refer to such processes as *simple* rather than *elementary* to avoid confusion with *elementary information processes* (Newell & Simon, 1972, also Chase, 1978, pp 19–90) The latter are more *general* and more *elementary* I assume that simple verbal processes are describable, in principle, in terms of those elementary processes, at present, the research on individual differences cannot, by and large, support a discussion at such a level

mation about specific word forms, irrespective of word meanings, stored at specific memory locations. Thus knowledge that *fact* is a word in English and that it is pronounced /faekt/ is word-form knowledge. Closely related, but of a slightly different kind, is *verbal-rule* knowledge, of which rules of grapheme–phoneme correspondence, phonotactic rules, and orthographic rules are salient examples. Grammatical rules are also part of the knowledge system. A third type of permanent memory verbal knowledge is *word-concept* knowledge (vocabulary). It is the meaning of words, including a network of relationships among word concepts. Finally, higher level *schema* knowledge is represented in permanent memory. The difference between word-concept and schema knowledge is essentially one of organization. *Schemata* are parts of a conceptual network that acquire, through experience, some status as higher order concepts.[2]

What would it mean to characterize individual differences in terms of these processing and knowledge components? In fact, these components are interrelated aspects of an information-processing system. There is no reason to believe that there is independence between processing and knowledge components. Indeed, principles of system design include trade-offs between stored information (knowledge) and data-handling procedures. Instead, the knowledge–process distinction is simply a useful organizing device for considering complex cognitive processes. Thus, the characterization of individual differences in verbal ability will be in forms of simple and complex verbal processes and verbal knowledge.

The focus will be on general verbal abilities rather than specific ones. For example, as Hunt, Lunneborg, and Lewis (1975) put the question, What does it mean to be high verbal? What does it mean to be a skilled reader? What is involved in vocabulary differences? How does verbal ability in elementary school years relate to verbal ability of college students? These are the topics discussed in the remaining sections.

INDIVIDUAL DIFFERENCES IN READING SKILL

Reading encompasses a wide range of verbal processes that must be considered a pervasive part of what we ordinarily think of as verbal ability. In a nonliterate culture the concept of "verbal ability," were it to occur at all,

[2]The contents of the verbal memory system are representative of theories of semantic memory. Thus *word-concept* knowledge is represented by semantic networks (Collins & Loftus, 1975; Lindsay & Norman, 1977) and schema knowledge is represented as elaborated conceptual networks (Rumelhart & Ortony, 1977, pp. 99–135).

would have a distinctly different flavor. An individual valued for his storytelling or some other oral talent could be expected not to show verbal ability, even orally, in the tasks devised by literate and technological societies (e.g., Cole & Scribner, 1974). Although some (e.g., Neisser, 1976, pp. 135–144) have taken this to argue against psychology's concept of intelligence, it is more to the point, in the present discussion, simply to note that literacy is likely to be a prerequisite for the sort of verbal abilities that this chapter is concerned with whether the particular research in question is on reading or oral language processing.

The range of reading talents is very wide. Roughly put, they range from children and adults who can barely read isolated common words to individuals who can read several hundreds of words per minute with some comprehension. The question is how can we account for this wide range of talent, or at least characterize it usefully? A related question is whether being skilled in reading at college age is roughly the same as being skilled in elementary school. Can ability differences among third-graders be described in the same processing terms as ability differences among college students?

ELEMENTARY SCHOOL READING ABILITY

Children begin formal reading instruction in the United States at age 6, although most have had considerable reading-relevant experience before then, at least in the form of "readiness" curricula offered in kindergarten. From the first day of instruction, there is a wide range of reading talent. As reading increases in comprehension demands, the contrast between high- and low-ability readers increases. Considering reading comprehension as the ability to be accounted for, what components of verbal processing are responsible?

SIMPLE VERBAL PROCESSES

The elementary reading activity is word *decoding*. Word decoding is the transform of a printed input into one or more of its corresponding linguistic forms. Thus, *lead* is decoded as /led/ or /lid/. In principle, the fact that the two forms are connected with different semantic structures is irrelevant. Because decoding, *prima facie*, is the essential simple reading process, the question is not so much whether it is a source of individual differences, but whether such differences reduce to other simple processes. One such process is *letter* or *letter pattern recognition*. Another is *name retrieval*.

Letter recognition is a simple verbal process which is some part of decoding. In general, recognizing constituent letters of a word mediates recognition of the word This is not to say that reading is a letter-by-letter process (see Brewer, 1972, pp 359–364, Gough, 1972, pp 331–358) but rather that detailed process models of word recognition include some early state of letter recognition (e.g , Massaro, 1975) By an interactive model of word recognition, letter identification is facilitated by word recognition as well as vice versa (McClelland & Rumelhart, 1981, Rumelhart & McClelland, 1981, pp 37–60) A good deal of letter processes for skilled readers involve using knowledge about letter patterns (Gibson, 1971) or constraints on permissible orthographic patterns (Venezky, 1970) Specific higher order letter patterns can be thought of as being accessible in memory as a function of learning (e g , LaBerge & Samuels, 1974) Thus, pattern processes are not necessarily just recursively applied single-letter processes. The letter-pattern processes and letter processes are grouped together only by distinction from word decoding

Another simple verbal process closely related to word decoding is name retrieval Given any input which corresponds to a location in permanent memory, name retrieval is the process of accessing the location and producing the name Thus name retrieval is patently part of decoding when oral reading is involved and implicitly part of decoding during silent reading However, some decoding tasks, particularly lexical decisions, do not have to involve name retrieval, at least in principle. Note also that in some tasks letter recognition can involve retrieval of letter names

A fourth simple verbal process is *semantic access* Semantic access occurs when meaning components stored with a word in memory are activated. Reading comprehension, unlike decoding, cannot occur without semantic access One of the individual-differences questions is whether ability differences exist in semantic access when differences in decoding are accounted for.

In summary, there are four simple verbal processes to consider Two of these, decoding and semantic access are independent in principle Decoding is the linguistic translation of a graphemic string which may or may not have a semantic entry in memory. Letter recognition is part of decoding Name retrieval is also part of decoding, but it is a general process operating on name information in memory.

The question to be pursued is whether simple verbal processing differences are adequate to account for general reading-ability differences Complex verbal processing differences are present, almost by definition the ability measure in question is measured reading comprehension The question is whether such differences can be characterized in terms of simple verbal processes Furthermore, since decoding includes letter processes and general name retrieval processes, we want to know whether these last two are more basic to individual differences

DECODING AND NAME RETRIEVAL

Given an ordinary printed word, a high-ability reader identifies it more rapidly than a low-ability reader. Among third-, fourth-, and fifth-grade subjects, we have found the mean difference in latency to vocalization ("naming time" as it is usually called) to be as high as 400 milliseconds (Perfetti, Finger & Hogaboam, 1978), although smaller differences are more typical (e.g., 200 milliseconds [Perfetti & Hogaboam, 1975], and 120 milliseconds [Hogaboam & Perfetti, 1978]). The magnitude of the difference is a function of word frequency and word length. The difference is less for high frequency words than low frequency words (Perfetti & Hogaboam, 1975) regardless of word length (Perfetti, Goldman, & Hogaboam, 1979) and higher for two-syllable words (Hogaboam & Perfetti, 1978) and especially large for three-syllable words when frequency is controlled (Perfetti et al., 1978). As a general characterization, the magnitude of the ability difference is a linear function of average naming time; the more difficult the word-decoding process is, the greater the ability difference.

Decoding measured by naming time clearly involves name retrieval. Is general name retrieval a verbal-processing component that differentiates high- and low-ability readers? Perfetti et al. (1978) required subjects to name a variety of visually presented stimuli—colors, digits, and pictures as well as words. High-ability subjects were significantly faster than low-ability subjects only for word stimuli. Among other stimulus types, color-naming speed was completely unrelated to reading ability and digit-naming speed was significant only in a correlation using the full-ability range and not in the contrast between reader groups. For picture naming even the correlation of speed with reading ability ($r = .29$) was of no more than marginal reliability.

One of the comparisons obtainable from Perfetti et al. (1978) is especially useful for understanding any potential name-retrieval factor. In digit naming, there were two conditions, one in which the set of numbers that could occur was small and known to the subject. In the second condition, the set of numbers that could occur was large (100). The comparison between small-set and large-set performance can be considered a difference between *activated* memory and *inactive* memory. With a small set, all three digits can be kept active by the subject. When one is present, the response is mainly a matter of (1) encoding the digits; and (2) producing their name. Both the digit representation and its name are presumably already active in memory, so there is no retrieval in the ordinary sense. Under such a condition, the results were that there was no ability factor. In the large-set condition, by contrast, there is a third process, namely, *retrieving* the name of the digits of memory. The names are not active because the set is too large.

Under these conditions, there was a subject verbal-ability difference, detectable as a small correlation (r = .38) but not as a group contrast

A related comparison from Perfetti et al (1978) was between closed sets of words that were small and predictable (e g , names of the four seasons) and open sets that were large and unpredictable (proper names) Unlike the case with the digits, ability differences were found regardless of set size However, differences were much larger for open large sets than closed small sets Again, the key seems to be whether retrieval from permanent memory is required (open sets) or whether the items to be produced are already active; hence, retrieval is not involved.

In addition to the name-retrieval factor, it is clear that a factor specific to linguistic forms is involved. Thus, for word identification, ability differences interacted with set size but even small closed sets produced significant differences For digits, no differences were present for closed sets. In a multiple regression analysis of these data, Perfetti et al (1978) found that even when the correlations between ability and all other variables were removed, verbal ability correlated significantly with times to name words from a closed set (r = .33) and times to name open-set words (r = .42) Perfetti et al (1978) suggest that the various tasks can be ordered to reflect the following components (1) name retrieval from permanent (inactive) memory; (2) large-memory search space, and (3) alphabetic inputs Reading unpredictable words has all three components.

Based on the studies cited, the present conclusion is that name retrieval is one of the simple verbal processes that produce ability differences in reading However, it is not the core component. Word decoding is an important process beyond name retrieval. This conclusion may not apply to the entire range of individual differences Denckla and Rudel (1976), for example, have shown striking name-retrieval differences between normal readers and severe dyslexics However, these studies have not ruled out the possibility that there is a decoding difference remaining when name retrieval is accounted for In any case, the normal range of reading talents seems to require at least two factors—verbal decoding and general name retrieval from inactive memory

There are tasks other than vocalization latency that can be used to index decoding. Three that have been used in my research are same–different judgments on simultaneously presented words (Hogaboam & Perfetti, 1978), same–different judgments on successively spoken and visually presented words (Perfetti, Hogaboam, & Bell, reported in Perfetti & Lesgold, 1979, pp. 141–183), and lexical decisions (unpublished, summarized in Perfetti, Note 1). All of these tasks are performed without the subject producing the word and the first two tend to produce smaller ability differences than tasks requiring word vocalization. For example, Hogaboam and Perfetti (1978, Experiment 2) presented subjects with word pairs for same–different judgments. Although high-ability readers performed these judgments more quickly than low-ability readers, the difference was not significant (in contrast to vocalization latencies of the same subjects). In a task in which a word is spoken and then immediately followed by a printed word for a same–different judgment, a similar unreliable difference was observed (see Perfetti & Lesgold, 1979, pp. 141–183) Lesgold and Curtis (1981, pp. 329–360) also found performance on this task to be somewhat less related to reading ability than is vocalization latency. These task differences can be related to the observation concerning retrieval and activation above. When a printed word is preceded by its oral equivalent, there is an activation of the word's memory location. Upon seeing the word, retrieval demands are minimal.[3] A related (but more complex) argument can be made for simultaneous word–word judgments. Such an account might help explain why lexical decisions for words *are* reliably related to ability (e.g., Perfetti, Note 1). Although naming is not involved, neither is prior activation of the word.

So far, all the tasks have involved a response to a single word. Thus, the decoding and retrieval processes are inferable as part of a single-response latency that includes other components. The reaction-time methodology of multiple stimulus arrays (Sternberg, 1969) provides a separation of the reaction time into processes (and error measurement) that accompany each trial (intercept components) and processes that are uniquely associated with processing rate (slope components). If word-decoding rate is a critical ability difference, it should be reflected in slope parameters of linear functions that relate reaction time to display size (e.g., number of words). There are two tasks of interest. A visual word-scan task provides information concerning word decoding rates. A memory scan task (Sternberg, 1966) provides information concerning rates for scanning memory for verbally stored items.

Visual Scan Two experiments by Perfetti and Bell (Perfetti, Note 1) provide relevant data because they involved a population totally comparable to the one sampled in the studies cited above. Because the study is unpublished, a brief description is in order: Twenty-four third-grade subjects formed groups of high-ability and low-ability readers based on the reading subtest of the Metropolitan Achievement Test, with the high-group mean in the seventy-seventh percentile and the low-group mean in the nineteenth percentile. Two subgroups of eight each provided an IQ match, based on

[3]By this account, greater ability differences might be expected for a "different" word because its memory location has not been activated. Unfortunately, comparisons of same and different judgments are lacking.

second-grade scores In Experiment 1, subjects participated in three visual search tasks: words, pseudowords, and category instances. In Experiment 2, subjects search for consonant bigrams. In the word-search task of Experiment 1, a target word was presented followed by a visual display containing one, three, five, or seven words which contained the target on half the trials. The word target remained constant for a block of eight trials, in order to minimize encoding and memory demands of the target stimulus (For the other two tasks, the procedure was the same.) The data of interest are the functions relating search time to display size, particularly whether differences are to be found in intercept, slope, both, or neither

For word search, there were significant differences between high- and low-ability readers in both intercepts and slopes. These data are shown in Figure 1 for the subgroups matched on IQ For positive trials (target present), the intercepts were equal. This is consistent with the *activation* hypothesis described above: There are minimal decoding differences when the presentation of a target can prime the word about to be seen This effect is maximum when display size is 1 and it is the target However, there is an increasing ability difference as the set size increases to 7, this is reflected in a small—but significant—slope difference of about 100 milliseconds When the target was absent (right panel of Figure 1), the situation might be slightly different. Even at set size 1, high-ability readers were faster, although this was not reflected in different intercepts, and low-ability readers were especially slow at the largest set size. Again, there was a significant slope difference Thus, whether one considers strictly the data (a significant set size × ability interaction) or the best fit straight lines, the conclusion is that for this sample, low-ability readers have a slow *rate* of word decoding, not just a slower composite of the processing factors that are present in any trial. The rate parameter in this case can be interpreted as the time to identify a word in the display and compare it with the target word in memory

There is at least one study that did not find slope differences between high- and low-ability readers Katz and Wicklund (1971) had subjects search either a two- or three-word display for a word target. There were main effects of ability (intercept differences) but no interaction of ability with set size (slope differences) It is possible that population differences are responsible for the differences (Katz and Wicklund's subjects were two years older) However, it is also possible that larger display sizes are necessary in order to detect slope differences For example, it is clear from the negative trials shown in Figure 1, that slope differences would not have been observed for set size one through five; the lines would have been parallel It is conceivable that with a large set size, some less able readers change their scanning strategies and the rate difference includes some additional variance

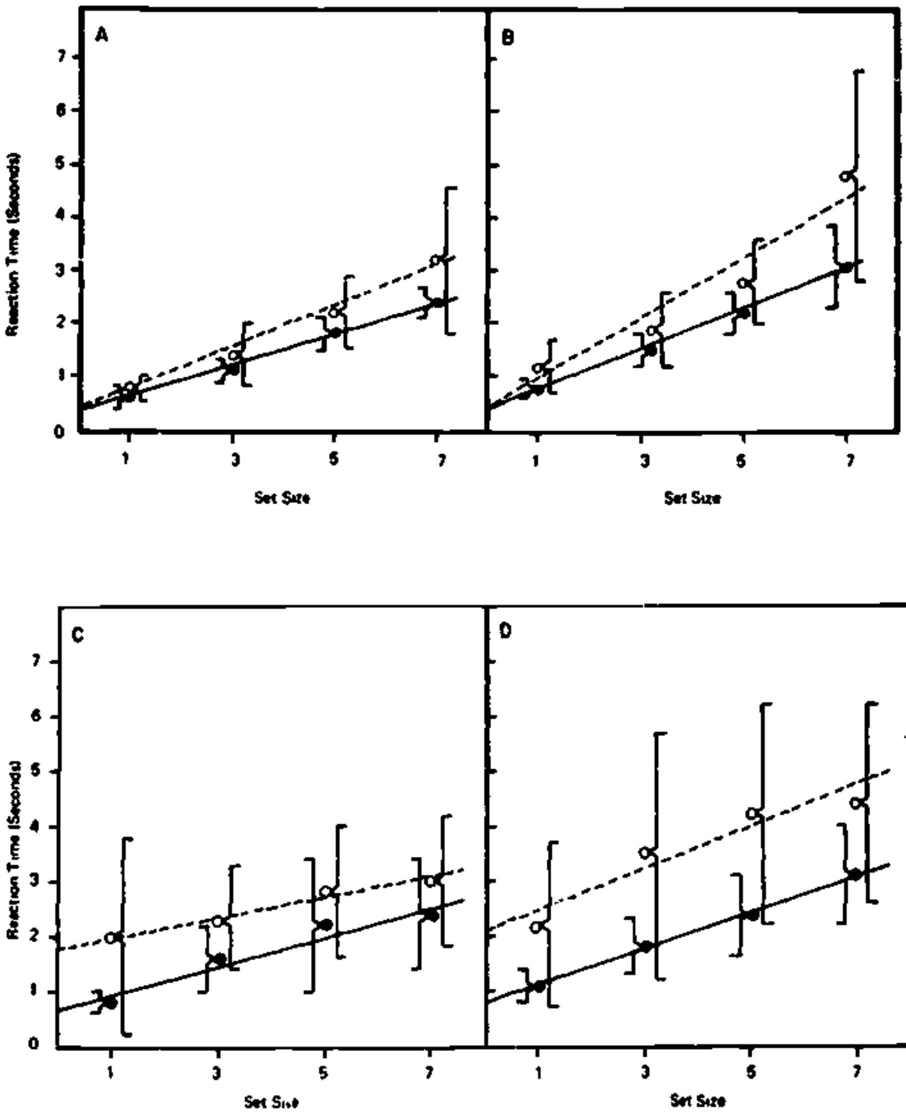

FIGURE 1. Word search and semantic category data for skilled and less skilled third grades (**A**) Target-present word search data. ●——● Skilled (RT = 24 + 31 S) ○- - -○ Less skilled (RT = .23 + 41 S) (**B**) Target-absent word search data. ●——● Skilled (RT = 38 + 40 S). ○- - -○ Less Skilled (RT = 36 + 58 S) (**C**) Target-present semantic category data ●——● Skilled (RT = 71 + .26 S) ○- - -○ Less skilled (RT = 1.8 + 18 S). (**D**) Target-absent semantic category data ●——● Skilled (RT = 78 + .33 S) ○- - -○ Less skilled (RT = 2 1 + 37 S) Data points are means of subject medians

possibly due to rescanning. On the other hand, the positive trials (Figure 1) do not show this possibility, but rather seem to reflect a constant slope effect. Nevertheless, it is easy to imagine that had the data shown in Figure 1 been restricted to sets of sizes two and three, statistically parallel lines might have been obtained. It is difficult to be confident about linear functions based on two points. In any case, such comparisons point to the difficulty of making individual difference comparisons across procedures and subject samples that differ even slightly.

Memory Scan In visual scan, rate (slope) differences include two elementary components: decoding and memory comparison. Thus, a rate difference could mean that reading ability is associated with either or both of these elementary components. By contrast, in backward memory search the main component of the scan rate seems to be the rate of mental comparison. The subject is presented first with a list of items to be stored in memory followed by a probe item. The measure is the time to decide that the probe item is or is not in the memory set and the key variable is the size of the memory set; that is, the number of items presented to the subject. Differences in slope are taken to be differences in the rate of item comparison in memory. This task has been used as an individual-difference measure among college students (Chiang & Atkinson, 1976; Hunt, Frost, & Lunneborg, 1973, pp. 87–122). Data comparing high- and low-ability readers of the sort under discussion are scarce. However, Keating and Bobbitt (1978) compared 9-, 13-, and 17-year-olds on a digit-memory search task. The ability measure was not reading, but performance on the nonverbal Raven's Matrices. The groups can be characterized as superior and average (not below average) in ability. Keating and Bobbitt found significant intercept and slope differences between superior and average subjects, although only intercept values were related to age. The 9-year-old group, which is most comparable to the samples in the reading-ability studies, showed a clear slope difference of about 60 milliseconds. The 17-year-old group did not show a clear slope difference.

Kail, Chi, Ingram, and Danner (1977) and Kail and Marshall (1978) have reported results of memory-scan experiments more relevant to the subjects under consideration. However, their tasks tapped complex verbal processes, rather than simple verbal processes. Kail and Marshall (1978) varied set size by having third- and fourth-grade subjects read either one, two, or three (unrelated) sentences and then answer a yes–no question. While "yes" answers were generally unaffected by set size, latency to answer "no" questions increased as set size increased from one to three, especially for low-skill readers. Kail and Marshall suggest that skilled and less skilled readers differ in their memory search rates. Especially interesting, in light of the present hypothesis concerning retrieval, is that Kail and Marshall found no ability difference in a situation where the necessary information was already activated. This was a situation (Kail & Marshall, 1978, Experiment 4) in which subject response time was measured to verify an answer following a statement and question, exemplified as follows:

1. The man drank the milk.
2. What did the man drink?
3. Milk/water

The measure taken was the time to verify (or falsify) number 3 after the first two have been read. This suggests, consistent with the activation hypothesis offered above, that when the information is already *activated*, reader ability differences are reduced. In the Kail and Marshall experiment, asking the question has activated the answer.

The memory-scan data, considering both Keating and Bobbitt (1978) and Kail and Marshall (1978), is inconclusive because the former did not compare children of average and below average reading ability and the latter used a complex verbal processing task rather than a simple one. This latter difference is nontrivial insofar as memory capacity differences might be involved. That is, when subjects have to search memory for as many as three *unrelated* sentences, there is reason to doubt that the memory load is within capacity limits. The sort of memory-scan processes under discussion are those that take place safely within the limits of short-term memory. Complex verbal processes may or may not lie within the limits of memory capacity, but simple verbal processes must by definition. At this point, although there is evidence to suggest simple memory search rate differences related to reading ability, there is little reason to suppose such differences are a matter of simple verbal comparison processes.

SEMANTIC ACCESS

A second simple verbal process is obtaining relevant semantic information from a single word. If word decoding is a part of *semantic access*, then it is possible that semantic access differences between high- and low-ability readers are accounted for by decoding differences. Evidence from my research group indicates that semantic access time is a source of ability differences beyond decoding. In the Perfetti and Bell (Note 2) experiments referred to previously, one of the tasks required semantic-category decisions. Subjects were provided with a category name and, for a block of eight trials, had to decide whether a given display contained an instance of the category. The decision latencies are shown in Figure 1 as a function of set size. High-ability readers were faster than low-ability readers at all set sizes.

Carroll's (Note 3) discussion of data using the name-identity measures is informative. Although his review of studies measuring physical and name identity showed consistent physical identity differences, name identity provided a processing difference beyond physical identity, when task means for ability groups were compared. More interesting, perhaps, is Carroll's estimation of the NI–PI correlation of Jackson and McClelland's (1979) data on adult readers (discussed previously). The NI–PI difference was estimated to correlate .57 with short-passage, effective reading speed of Jackson and McClelland's (1979) subjects and nearly as highly with their verbal and quantitative aptitude scores, but nonsignificantly with listening comprehension. Certainly, reading ability and verbal ability arise from similar verbal processes, insofar as the retrieval of symbol names (at least letters) is important in both.

Note that in the letter-name-matching task, simple name retrieval is only one component. In fact, in a typical case, there are at least two name retrievals and a comparison process. In reading, it seems important to consider letter recognition (and decoding) processes as potentially independent of name-retrieval processes. The former, perforce, are components of reading; the latter, as general processes that are important in verbal tasks other than reading, are not. It is interesting that research on adult verbal intelligence has so exploited the letter-matching task and not picture or digit naming. The tacit assumption is that the process of interest is access to overlearned codes. Reading is the principle means for acquiring overlearned codes. College adults who differ in verbal ability may essentially represent the upper ranges of reading ability. Indeed, even the low-ability subjects are beyond the verbal ability of high-ability children, at least in terms of practice at simple verbal processes.

The question of rate of processing arises again in connection with adult verbal ability. Because the NI–PI difference is useful in controlling for subject preparedness and response execution, it is partly analogous to a name-processing rate measure. Thus, letter-scan tasks with multiple arrays should produce results comparable to NI–PI in the slope relating RT to set size. Apparently they do, although the relationship of slope to verbal ability is not striking (Chiang & Atkinson, 1976). Similarly, memory-search slopes appear to be related to verbal ability and to visual-scanning slopes (Chiang & Atkinson, 1976).

What of word decoding, aside from name retrieval and letter recognition? The effects reported by Perfetti and Hogaboam (1975) for children of different reading abilities have been found also for college students distinguished by vocabulary tests (Butler & Hains, 1979), as well as high-school students differing in reading ability (Frederiksen, 1978b). Moreover, Butler and Hains (1979) found that word length was a less significant factor for high-ability subjects, in agreement with the results of Hogaboam and Perfetti (1978) for reading ability.

In the case of children's reading ability, I suggested that differences in decoding ability seemed to go beyond both letter recognition and name retrieval. In the case of adult verbal ability, especially college students, this seems less tenable. Although studies using tasks appropriate for all three processes seem not to have been done, the studies on letter comparison and letter search implicate letter- and/or name-retrieval processes. Decoding differences, that is, processes of lexical access and retrieval from print, may depend on these.

Consider semantic access. In the case of children's reading ability, there remains some question as to whether or not access to semantic information stored with words is accounted for completely by word name access. Goldberg, Schwartz, and Stewart (1977) had college subjects classified as high and low verbal make same–different decisions for words based on physical identity (*deer–dear*), or category membership (*deer–elk*). The question is whether ability differences exist in category decisions beyond decoding (name identity). The answer from Goldberg et al. (1977) seems to be "no." Although ability differences in decoding were larger (363 milliseconds) than physical matches (136 milliseconds), category decision differences (360 milliseconds) were not greater than decoding differences. Hogaboam and Pellegrino (1978) used a category-decision task wherein single words and pictures were verified according to a prior semantic category. They report no correlation between verbal ability (SAT) of college subjects and speed of semantic decision. In light of other research showing name-level differences, such null results are difficult to explain. (In fact, Hunt, Davidson, & Lansman [Note 6]) report data showing name-level and category-level differences among adult subjects.) However, the point is that ability differences are typically found at lower levels of code access (letter, word, name retrieval) whereas additional differences in category level are not.

Finally, consider working memory. Just as reading ability is associated with working-memory capacity, so too is adult verbal ability. For example, Hunt et al. (1975) compared high- and low-verbal subjects in their ability to recall four visually presented letters following digit-shadowing task that intervened between input and recall. Low-ability subjects uniformly recalled less regardless of the number of intervening digits. Memory differences related to verbal ability are found also in digit-span tasks (Lyon, 1977). Such results are consistent with those of Daneman and Carpenter (1980) for reading ability of adults. Since coding differences in verbal ability are clearly indicated, it is not possible to be sure whether working-memory processes represent an additional source of individual differences or whether initial coding difficulty leads to memory loss.

size. Pseudoword targets were one- or two-syllable and display words were varied accordingly. Again, the same target was searched for eight consecutive trials to eliminate any memory-for-target problem. The results: skilled readers were faster than less skilled readers, but more interesting their speed advantage was greater for two-syllable than one-syllable words and greater for multiple displays than for single-item displays. The syllable effect supports the assumption that decoding multiple units (of syllable size) is extra processing work for the less able reader. The set size effect, which can be seen in Figure 2, suggests a processing *rate* difference. The slopes for both positive and negative trials were larger for less able readers. That slope differences rather than just intercept differences were obtained strongly suggests that the process of decoding an orthographically regular letter pattern and comparing it with a memory target is a source of reading-ability difference.

In a separate experiment, these subjects performed a consonant bigram search task. The consonant bigrams were random (unstructured) pairings, thus allowing an index of processing much more akin to simple visual scanning. For example, the target WP was searched in one five-item display of MQ, WT, TL, WP, XP. Although this experiment has a few minor design differences from the previously described search tasks (most notably, blocks of 32 trials instead of eight) it can offer a useful comparison: Are slope differences found for this task as well as the pseudoword task? The search functions are shown in Figure 2. They reveal small intercept and slope differences for positive trials, although it is clear that with set size 1, there is no ability difference. For negative trials, presumably the fair test for an exhaustive search assumption, there are also small intercept and slope differences but with a better linear fit. The 70-millisecond slope difference for negative trials is only marginally significant.

To examine whether small ability differences in bigram search could account for large ability differences in pseudoword search, a "decoding" score was derived for each subject by subtracting bigram search time from pseudoword search time. This P–B score is analogous to the SD–WD score discussed previously, but it does *not* have the same interpretation because, unlike SD and WP, pseudowords and bigrams did *not* differ in the level of decision required. Instead, the difference score represents the same decision level (identity match) for two different types of letter strings. One short, unpronounceable, and unpredictable by orthography; the other longer, pronounceable, and orthographically regular. The results of this analysis were that less skilled readers had larger difference scores than skilled readers, but the difference was significantly longer for multiple-item displays than for single-item (set size = 1) displays. This is consistent with the following interpretation: there are genuine pseudoword processing-rate differences

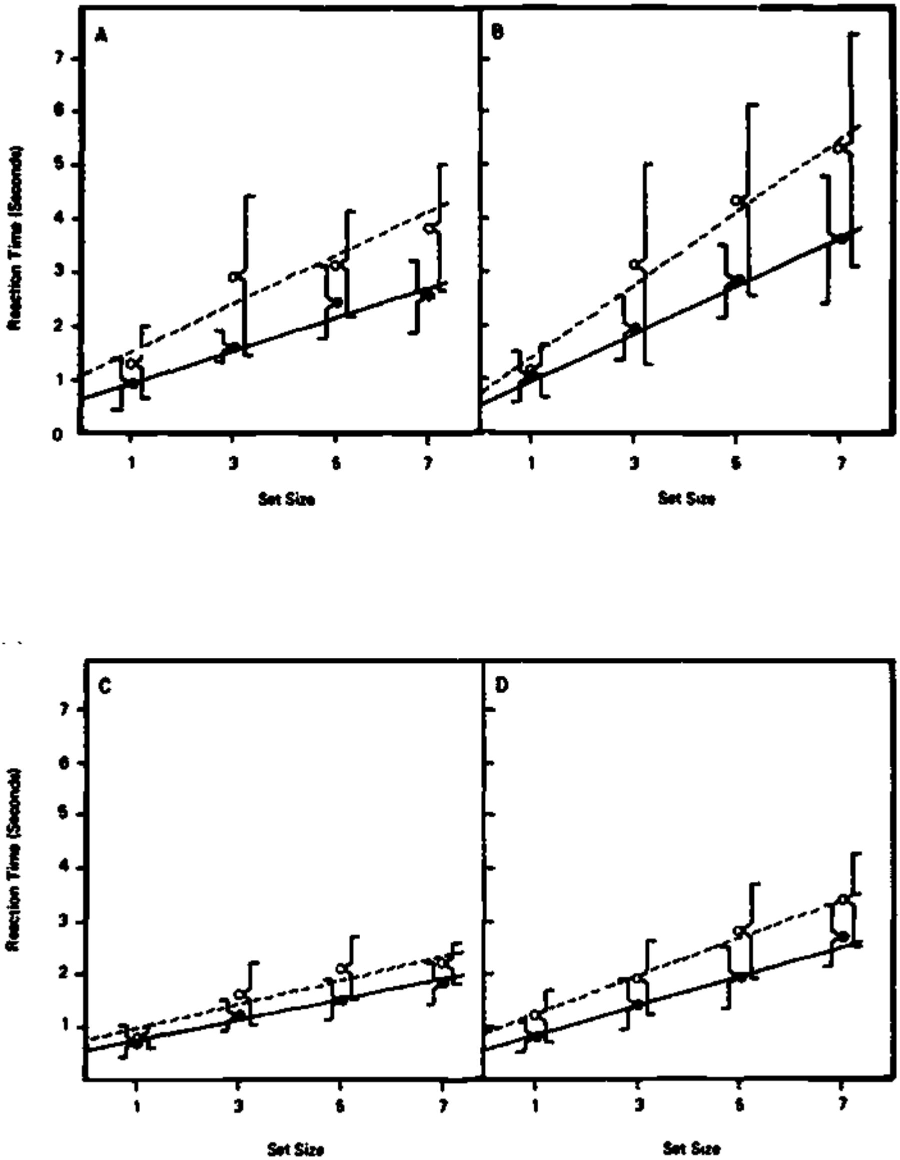

FIGURE 2. Search data for pseudowords and bigrams for third-grade subjects. (**A**) Target-present pseudoword data. ●——● Skilled (RT = 75 + 28 S) ○---○ Less skilled (RT = 1 12 + 42 S) (**B**) Target-absent pseudoword data ●——● Skilled (RT = .52 + .45 S). ○---○ Less skilled (RT = 72 + 69 S) (**C**) Target-present bigram data. ●——● Skilled (RT = 56 + .19 S) ○---○ Less skilled (RT = 79 + 22 S). (**D**) Target-absent bigram data ●——● Skilled (RT = .56 + .28 S). ○---○ Less skilled (RT = 92 + .35 S).

that do not seem to be accounted for by simple encoding of constituent letters. Decodable letter strings show the ability difference most clearly and this difference is seen in rate of processing (slope) both directly and in a difference measure that takes consonant bigram search time into account.

A related letter-recognition ability may be the use of serial position structure. Mason (1975) found that high-ability readers were better than low-ability readers at taking advantage of the positional predictability of a letter. For example, in a six-letter word, *F* is more likely to occur in Position 1 and less likely to occur in Position 5, whereas the reverse is true for *N*. However, when Massaro, Venezky, and Taylor (1979) replicated these search experiments controlling for orthographic regularity, they found that letter position was a relatively minor ability factor.

In some related experiments by Perfetti and Bell (Note 2), subjects performed either forward search (target first, then display) or backward search for target letters. Although high-ability readers showed a general speed advantage in forward search, the advantage was unrelated either to letter position or orthographic structure. In agreement with Massaro et al. (1979), they found search time to be mainly a function of visual-feature overlap between target and display. In backward search (display first, then target), Perfetti and Bell (Note 2) found that the orthographic regularity of the string did influence search accuracy and that its effect was greater for skilled readers. Letter position predictability had only a slight effect. Overall, the studies of Mason (1975), Massaro et al. (1979), and Perfetti and Bell (Note 2) suggest that orthographic structure may provide a significant ability factor for tasks of letter search. This effect is independent of a smaller and less reliable effect of position information.

The source of word-decoding superiority may be traced to letter-pattern recognition, that is, knowledge and use of letter-concurrence constraints. This, in turn, may reflect the ability to rapidly activate reliable phonetic codes associated in memory with these units. In a modification of the experiments of Perfetti and Bell (Note 2), encoding time for the letter string and the memory interval between the letter string and the probe letter were varied independently. An important result was that when low-ability readers were given more encoding time (1.5 seconds) they performed comparably to high-ability readers given less encoding time (.33 seconds) and they took advantage of orthographic structure. Low-ability readers with less encoding time did not take advantage of structure. Moreover, regardless of encoding time, low-ability readers were more affected by an increased memory interval between letter string and probe (4 seconds compared with .5 second). Low-ability readers appear vulnerable to a decoding problem that can show itself when either encoding or memory demands are present.

The exact source of ability differences in recognition and decoding of multiletter patterns remains in need of further research. There seems to be little reason to suppose that these ability differences are traceable to initial stages of visual processing (see Vellutino, 1979; and experiments by Mason & Katz, 1976). The ability to recognize individual letters in isolation is probably not sufficient to account for decoding differences, although this conclusion is less clear. More research that allows separation of processing-rate factors from other response-time factors would be helpful. For now, the Perfetti and Bell data (Figure 2) suggest that rate differences in letter scanning may not account for rate differences in decoding.

Differences among Older Readers

It is not necessarily the case that individual talents in reading are attributable to the same factors among older readers as younger ones. Children in the second through sixth grade have recently completed formal reading instruction. Adolescents and adults may have mastered the sort of simple processes that are implicated in ability differences among young readers. Indeed, since adult studies typically involve college students, we may expect individuals who represent below average or less skilled fourth-graders to be selected out of the sample. For such a group, so apparently different, the question of whether simple verbal processes can account for general differences in verbal comprehension is especially interesting.

College Students

Jackson and McClelland (1979) carried out a series of experiments with college undergraduates as subjects. Reading ability was defined by performance on passages designed especially for the research. Subjects' reading times for the passages and the accuracy of their answers to short-answer comprehension questions were both taken into account in deriving a measure of "effective reading speed," the arithmetic product of reading speed and comprehension. In addition, there was a listening comprehension test based on the same paragraphs and verbal and quantitative college aptitude scores. Laboratory tasks tapping several processes were given to high- and low-ability subjects. Unlike early research by Jackson and McClelland (1975), which contrasted superior individuals with average ones, the sample of this study could be characterized as high and low reading ability, *relative* to college freshmen and sophomores in the population. High-ability readers were in the top quartile of effective reading speed and low-ability readers were in the bottom quartile.

One important result is that reading ability was not related to performance on simple letter identification, measured either by single letter report thresholds or double letter ("letter separation") report accuracy. This result, agreeing with Jackson and McClelland (1975) clearly indicates that simple single letter recognition is not a primary ability factor for college readers.

What about simple decoding processes? One set of tasks involved same–different decisions for single letters, synonyms, and homonyms, and nonletter patterns (two-item sequences of plus and square). Ability differences were found in all tasks, even the ostensibly nonlinguistic pattern matching task and the simple letter-matching tasks. Thus, Jackson and McClelland's (1979) subjects cannot be characterized as differing only in decoding ability, insofar as the matching paradigm is concerned.

A multiple display task, similar to the one previously described, was also used by Jackson and McClelland (1979). Targets and displays were single letters and set size was two, four, or six letters. Ability differences were found only in intercept and not in slope. Thus, high-ability college readers can be characterized as differing from low-ability college readers in some component independent of display size, for example, response speed, display orientation, but not rate of letter processing per se.

One other task of Jackson and McClelland (1979) was an auditory memory-span task. Similar to a standard digit-span task, it required subjects to recall—in order—a string of auditorially presented letters following a 1-second interval. Fast readers recalled significantly more than slow readers.

Taking all tasks into account, Jackson and McClelland (1979) report correlations that support the following conclusions. Listening comprehension (measured on the same paragraphs) is the strongest correlate of reading speed. Controlling for listening comprehension, a significant correlation remains between matching performance and reading speed. The task that contributes most to this correlation is "letter match." The contribution of this factor is interpreted as a name retrieval factor since all patterns in the matching task were nameable and performance did not correlate with the letter-threshold tasks. The importance of the naming component was supported by a second experiment that showed no ability difference in matching dot patterns. In an additional experiment with this population, Jackson (1980) found that high- and low-ability readers did not differ in time to match nonsense figures but did differ when the matches were based on names arbitrarily associated with the figures. Such results strongly support the assumption that adult ability differences do not lie in immediate perceptual processes that occur prior to contact with names in memory.

Jackson and McClelland (1979) concluded, on the basis of a multiple regression analysis of their data, that three ability differences were tapped by their tasks. The most important correlate of reading ability was listening comprehension. A second major component was access to letter codes from print, tapped mainly by the letter-matching task. Although there were significant correlations between ability and tasks of homophone matching (Experiment 1) and pseudohomophone matching (Experiment 2) that might be taken to reflect decoding ability, Jackson and McClelland (1979) did not suggest a separate decoding factor. Rather, the letter access factor could account for all the correlation between ability and pseudohomophone matching times.

Jackson's (1980) experiments, at least in part, point to a similar conclusion. There are two major ability factors, a general language factor and a general visual-access factor. The visual access factor is general rather than alphabetic because Jackson (1980) found that reading ability was related to the speed of matching categories of drawings of objects as well as to letter name match. Thus, taken together the Jackson and McClelland (1979) and Jackson (1980) experiments suggest that a major ability difference lies in the speed of access to a name-referenced memory location. The ability does not depend on alphabetic inputs but it does depend on memory access, as opposed to simple perception. Thus, in the terms of the framework offered in this chapter, decoding is not, but name retrieval (access) is, a major ability factor. Letter recognition is not a factor independent of name access. A general language-ability factor (reflected in language comprehension) is independent of this name-access factor.

Part of this picture is consistent with the results for elementary school readers, but some suggest different ability factors in older readers. The identification of a general language factor is consistent. Among children, reading ability is highly associated with memory for *spoken* language (Perfetti & Goldman, 1976) as well as memory for written language (Goldman, Hogaboam, Bell, & Perfetti, 1980). Furthermore, Berger and Perfetti (1977) found that differences between high- and low-ability sixth-grade readers both in the recall of a text and in the answers to comprehension tests were as large when subjects heard the text as when they read it. Curtis (1980), in a thorough multiple-task experiment, found that listening comprehension contributed unique variance to reading ability measures; further, for older readers (fifth grade), the contribution of listening comprehension was greater than for younger readers (second grade). Correspondingly, decoding factors accounted for less unique variance among older readers, although there remained large ability group differences. There is fairly clear evidence that reading ability depends on language ability in a general way. This relationship is seen strongly among young readers and adults, at least for readers beyond the second grade.

However, there appears to be an ability factor that is not continuous across this age range. Jackson and McClelland (1979; Jackson, 1980) conclude that ability differences in decoding can be accounted for by differences in visual name access. By contrast, studies in my laboratory suggest ability differences in decoding exist and are not reducible to more elementary processes. It is possible, of course, that these different conclusions reflect genuine age-related differences. Adult readers are not children and, in the college population, have probably been selected from the average and above average elementary school population. However, the *direction* of the children–adult differences does not encourage this conclusion. College-age readers show differences at the name-retrieval level, a more fundamental process than decoding. If the development of higher level abilities build on lower level abilities, we might expect differences to become negligible at lower levels and noticeable at higher levels. In other words, we might expect letter recognition or name retrieval to be a more important factor for younger readers than for adult readers. Instead, the data seem to say the opposite. Decoding differences do not depend on letter recognition or name retrieval for young readers as they do for adults.

It is quite possible that ability factors for children and adults are not different. The tasks used by Jackson and McClelland (1979) did not include naming tasks, whereas these were the basis of the Perfetti et al. (1978) conclusion that naming time independent of alphabetic input was not the only factor. Similarly, Jackson and McClelland (1979) concluded that letter-processing rate was not an ability factor; however, they did not test units larger than letters in multiunit displays. Thus, the conclusion that rate of processing differences occur at orthographic pattern levels may prove valid for adults as well as for children. In that light, it is possible that adult readers (and children) differ in a number of components that would be reflected in intercept values quite independent of material. The fact that Jackson (1980) found differences in RT to line drawings and letters in single displays is consistent with this. It would be interesting to see whether rate (slope) differences in object categorization were found. Without comparable tasks, it is difficult to compare research on younger and older readers.

HIGH-SCHOOL READERS

Intermediate in age to the two groups under discussion are the high-school subjects of Frederiksen (1978a, pp. 153–169; 1978b; 1981, pp. 361–386). Frederiksen's sample of 20 high-school students was divided into four quartile groups, based on their Nelson–Denny reading test scores. Although the sample size per group ($N = 5$) may seem rather small, there are some interesting results for ability differences. Frederiksen (1978a, 1978b) found that higher ability readers had faster letter-scan rates than lower ability readers. The task was not comparable to either the bigram search task of Perfetti and Bell (Perfetti, Note 1) or to the letter-search task of Jackson and McClelland (1979). Instead, slope values were inferred from the serial position occupied by two adjacent letters within a briefly presented four-letter array. Simultaneous masking of the other two letter positions enabled this comparison. Thus rate differences are the slopes of the function relating letter identification latency to position within a four-letter display. It is not clear whether such slope differences represent letter-scan rate differences or limitations on memory readout imposed by the task. The latter possibility arises because subjects had to report what they saw from a brief exposure. Accuracy results, which are not reported, are necessary in this respect. More straightforward is the finding that high- and low-ability readers differed in vocalization latency to words and pseudowords. Interestingly, the word differences are mainly due to the lowest group contrasted with the others whereas pseudoword latencies appear to distinguish among all groups.

In Frederiksen (1978b), the data from these same 20 subjects are correlated with individual reading scores and interpreted within a structural model that assumes five component skills. On the basis of the structural model analysis, Frederiksen concludes that multiple-letter encoding is a major predictor of general reading ability.[4] This refers to slope differences on the bigram scan task (described above) plus differences in name level, same–different letter judgments (*Aa* versus *Ad*), and facilitation due to bigram probabilities in the bigram scan task. This factor is one which reflects the ability to encode letter strings without facilitation of one sort (letter-sequence redundancy) or another (letter-category facilitation).

Whether there are differences between this analysis of high-school ability and either the college-level ability (Jackson & McClelland, 1979) or the elementary-level ability is again problematic—partly a question of the particular tasks used and the choice of models to test the intertask correlations. Frederiksen's analysis does not allow a general name-retrieval (access) factor nor a general language factor, and Jackson and McClelland (1979) do not allow a multiple letter-encoding factor. Still, it is possible to attempt a tentative characterization of reading ability across the three age levels, based on the work discussed along with some inferring.

In the elementary-school years, general reading ability has a strong decoding component that is a result of processing efficiency for alphabetic materials. This efficiency includes a general name-access-and-retrieval component, such that digits, pictures, and other nonalphabetic stimuli may produce differences in processing time. However, such differences are smaller and less reliable than alphabetic input differences. Whereas *some*

[4] A second major factor is referred to as "automaticity of articulation," essentially the *duration* of vocalization for pseudowords having extra-processing requirements (either two syllables instead of one or a complex vowel spelling instead of a simple one). As with most of Frederiksen's measures, these measures depend on difference scores. It is not clear whether we should think of this as a strictly speech-based skill or a decoding skill.

low-ability children have name-retrieval problems, there are many without such problems who nonetheless are less efficient processors of printed linguistic inputs. This factor seems to be more than single letter encoding and includes genuine rate differences for multiunit pronounceable pseudowords. These factors continue to be important through high school and with adult readers.

For college adults, the population changes; hence, the range of abilities on the tasks in question changes. Those whose *only* or *main* problem in elementary school was decoding are either not in the college population or they have mastered decoding-related processes to an extent that the limiting performance factor lies elsewhere; that is, in name-code retrieval. In a sense, their reading ability matches their general intellectual ability and within the latter, there is a fairly narrow range—above average to superior. Along the way, high-school-level ability reflects both higher levels of skill than elementary-school-age ability and less selectivity than college-level ability. Decoding factors remain critical but they include more of the processing factors associated with simple processing rates and less (perhaps) with use of linguistic structure. At all levels, general language ability is a major limiting factor.

Thus, by this account, reading ability differences at the lower levels of skill are accounted for by simple verbal processes, including decoding and, apparently, semantic access. At higher levels, these factors remain only as they are associated with generalized processes that are perhaps less susceptible to training. It may be worth adding to this conjecture the apparent fact that at extremely low ability levels the generalized naming process is also seen independent of decoding (Denckla & Rudel, 1976). Thus decoding, over and above name retrieval, is not a critical ability factor for individuals whose general name retrieval ability is extremely low nor for individuals whose decoding *and* name retrieval abilities are very high.[5]

Reading Ability and Memory

I have referred to the processes under discussion as "simple verbal processes," although encoding multiple letter displays may or may not come under this category, depending on theoretical preferences as well as task and individual skill factors. The complex verbal processes are those in which (1) repeated access to a name in permanent memory is required; and (2) more

[5]There is at least one reservation I would add to this account. Studies of adult readers have seldom used sufficiently difficult decoding tasks. The sensitivity of the tasks thus are in question.

than one name must be retained. An ability difference in memory capacity is a good candidate for producing ability differences in reading.

Perfetti and Lesgold (1979, pp. 141–183) argued that an active verbal short-term memory is an ability factor in reading, whereas the storage capacity of a general short-term memory is not. Thus Perfetti and Goldman (1976) found that probe-digit performance, a paradigm short-term memory capacity measure (Waugh & Norman, 1965) did not distinguish high- and low-ability readers in the third and fifth grade who were comparable in IQ. However, they were distinguished by an analogous test of probe-discourse memory. In both tasks, output demands are minimal, the subject producing only the element following the probe, spoken digits in one case and words from spoken texts in the other. The critical difference may be the memory demands added by ongoing language processing. The latter would seem to test the operation of an active working memory (Baddeley & Hitch, 1974, pp. 47–89; Newell & Simon, 1972), and this is probably the memory function critical to reading ability. Perfetti and Lesgold (1979) also suggested that coding and storage processes would compete for functional working memory and for low-ability readers, for whom coding is less facile, functional working memory differences would become significant.

This general hypothesis has been given dramatic support by Daneman and Carpenter (1980). They tesred adult subjects' working memory. The key tesr was to recall final words from sentences read aloud by subjects. A memory-span measure was derived which was analogous to digit-span measures; namely, the number of sentences read before ordered memory for the final word from each fell below criterion. This working memory-span measure correlated highly with comprehension accuracy on sort passages and with verbal SAT scores. Especially interesting was its correlation ($r = .90$) with performance on a pronoun reference test which varied the text distance between a referent and its later pronominal menrton. Grearer disrance implies grearer text demands on working memory, and correct pronoun identification did decrease as a function of text distance, excepr for readers with the highest working memory spans. A span measure involving word lists, rather than sentences produced smaller correlations, not significant, with comprehension measures. In a second experiment, Daneman and Carpenter (1980) found that their sentence-span measure correlated significantly with listening comprehension, although not quite as much as wirh reading comprehension. Interesringly, it did not matter whether the span test itself was written or aural. Given the difference between sentence-measured span and list-measured span, the degree to which working memory is actively taxed by processing demands seems important. The functional processing resources seem to be the limiting facror and they seem to be general factors, not print-specific ones.

These are adult data but they are quite consistent with ability differences among children (Kail & Marshall, 1978; Perfetti & Goldman, 1976). Working memory seems to be a limiting factor in complex verbal processes regardless of age. It seems unlikely, however, that a working memory factor is independent of the simple verbal processes discussed previously. More likely, there is a trade-off between speed of processing and memory ability (Lesgold & Perfetti, 1978). The modification of the backward letter-search experiment described previously (Perfetti & Bell, Note 2) demonstrated this tradeoff. Low-skill subjects given more encoding time performed as accurately on backward letter search as skilled readers with less encoding time. However, with a slightly longer (4 second) memory interval their processing difficulties were reflected in longer decision times. Skilled readers were unaffected by this increase in memory interval. Thus, encoding and memory factors both work against low-skill readers in such a situation.

Given an interest in simplifying explanations and results (such as those just described), a question arises as to whether our ability theories should handicap the low-ability reader with both working memory and decoding problems. Is there a single mechanism to account for both? The problem is that letter-recognition and word-recognition measures are clearly simple verbal processes that require, in most cases, a single access event to a name in memory. It is quite reasonable to say that in complex reading tasks the coding and memory requirements interact to produce ineffective verbal processing (cf. Perfetti & Lesgold, 1977, pp. 141–183). But this account can do little to explain memory-access differences of single decoding tasks. If there is any hope to discover a single mechanism rather than two, it would seem to require explaining memory limitations by coding inefficiency, rather than vice versa. There are suggestions in Lesgold and Perfetti (1978; Perfetti & Lesgold, 1977) along these lines, but a reasonably specific proposal is still lacking.

VERBAL INTELLIGENCE

A subject whose ability is measured on a reading-comprehension test is in a reading-ability experiment. A subject whose ability is measured on a verbal-abilities test is in a verbal-abilities experiment. Aside from such matters of definition, is being high verbal the same as being a high-ability reader? There is no answer to such questions in the absence of research with more attention to criteria-referenced ability tests. However, it seems likely that the verbal abilities important for verbal intelligence are the same as those that are important for reading. The difference, more often, will be one of level rather than type of knowledge. The college-level tests demand higher absolute verbal skill levels and are selectively taken by above-average readers. With that in mind, what simple verbal processes are involved in producing the wide range of general verbal abilities measured by college-level tests, such as the SAT?

The four simple verbal processes previously considered were letter recognition, decoding, semantic access, and name retrieval. Do these vary at the adult level as well? Name retrieval, for example, is a general performance-limiting factor that might be expected to have an effect even after letter recognition and decoding. Carroll (Note 3) summarized naming studies (Carroll, 1976; Carroll & White, 1973), concluding that picture-scanning speed is a parameter of individual differences. According to Carroll (Note 3), these differences in picture-naming were predictable from a set of psychometric tests, but mainly from a picture-naming test and not from other tests ostensibly more related to verbal ability (e.g., vocabulary).

A more typical procedure for examining name retrieval has been the letter-matching task first described by Posner and Mitchell (1967). The key ability question in this task concerns the difference between comparisons based on physical identities of printed letters (e.g., *AA*) and letter-name identities (e.g., *Aa*). Increasing differences between name identity (NI) and physical identity (PI) can be taken as a measure of name retrieval without name production. In the studies of Hunt and his colleagues, high- and low-verbal college students did not differ in PI match times although they did show small differences in NI match times (Hunt et al., 1973, pp. 87–122; Hunt et al., 1975). Hunt (1978), in summarizing studies of name matching and verbal ability, notes that such studies yield small but consistent correlations between verbal ability and the NI–PI difference in letter matching.

It appears from some of the data summarized in Hunt (1978), that ability differences in letter-name matching decrease with increasing abilities of the subjects. Nonuniversity adults show NI–PI differences of 110 milliseconds (Parkinson, Note 4) compared with 64 milliseconds for University of Washington high-verbal students, 190 milliseconds for 10-year-old children and 310 milliseconds for mildly mentally retarded children (Warren & Hunt, Note 6). A general picture emerging is that verbal ability, over a wide range, is associated with the time to perform a comparison based on the name of a letter. Importantly, since it is a difference score this name comparison controls the time to make comparison based on physical identity. Thus, while the complete lack of ability differences in physical matches reported by Hunt et al. (1975) is seldom found (see Carroll, 1976), the conclusion seems to be that, beyond mental comparisons based on shape identity, verbal ability differences are associated with speed of letter-name comparisons.

Figure 1 shows that the function relating set size to semantic decisions was quite linear with low variance for high-ability readers and not-so-linear with large variance for low-ability readers. The lines for high ability and low ability are relatively parallel, implicating intercept differences and not slope differences. However, the poor linear fit for low-ability readers makes any linear comparison suspect. In order to minimize any anomalies due to nonlinearity, a comparison of categorization and word search for set size = 1 is useful. Less skilled subjects, on this measure, show a marginal increase in decision time.

An index of semantic processing, beyond decoding, is obtained by subtracting, for each subject, the word-decision (WD) time from the semantic-decision (SD) time for set size 1, SD–WD. SD–WD can be taken as an index of semantic-processing time controlled for word-decoding time. The mean SD–WD for low-ability readers was 1050 milliseconds and the mean SD–WD for high-ability readers was 209 milliseconds. Keep in mind that a set size of 1 includes general task components as well as rate components of decoding and comparison. Nonetheless, it appears that differences between high- and low-ability readers for single-word comparisons go beyond simple decoding. As set size increased, this SD–WD difference is maintained for size 3 (950 milliseconds) and 5 (1000 milliseconds) and disappears for size 7. At the largest set size, both ability groups had essentially zero SD–WD scores. Thus, semantic-access differences, as measured by this difference between category- and word-level decisions, do seem to exist between some high- and low-ability readers. Unlike word processing, however, they seem to reflect mainly intercept rather than slope components.

Given these results, one could characterize the ability differences in semantic access *rate* as accounted for by word identification. However, low-ability readers do exhibit additional semantic processing difficulties in some task-specific components reflected in intercept. Such components are usually assumed to include orientation and response-execution components that occur once (regardless of display size). Since these intercept differences were so much smaller for word decisions than semantic decisions, it is possible to conjecture that response execution and display orientation are not responsible for the semantic-access difference. What component is in the intercept of a semantic decision but not in the intercept of a word decision? One possibility is the activation of the relevant semantic-category links, or the initiation of a search process for semantic attributes. Once initiated, there are no rate differences for semantic comparisons, but the initial activation of the relevant semantic attributes is subject to an inertia that is not present when simple decoding (word decision) is required. Of course, there are other possibilities, and the difficulty of drawing solid conclusions on the semantic-access question is apparent. More data that eliminate the uncertainty of intercept interpretations and processing models that enable more precise interpretations of semantic access are needed.

LETTER AND LETTER-PATTERN RECOGNITION

To the extent that decoding processes are a part of reading-ability differences, the processes by which letters and letter patterns are recognized are candidates for individual differences. The letter-recognition processes are not the simple form and shape perception that have been the subject of dyslexia theories (e.g., Orton, 1925). When the evidence is examined critically, such strictly perceptual factors do not seem to be significant ability factors as Vellutino (1979) has shown. The letter-recognition processes that make a difference in reading ability presuppose the elementary ability to discriminate letter forms and the ability to retrieve letter names; instead, these include the speed and efficiency with which letters can be identified and assembled into word-decoding units. By assumption, these units are something less than a word (the units, when assembled, add up to a word).

It is unwarranted and unnecessary to suppose that these units correspond to generalized units such as syllables (Spoehr & Smith, 1973), or to morphemic boundaries (Taft, 1979), or orthographic patterns (Venezky & Massaro, 1979, pp. 85–107). However, the assumption that strings of letters that are permissible and familiar achieve some status as higher-order units is pervasive across both perceptually described (Gibson, 1971) and information-processing theories (e.g., LaBerge & Samuels, 1974; Massaro, 1975). It is difficult to describe such units without referring to knowledge of orthographic patterns as well as processing. However, as Glushko (1981, pp. 61–84) demonstrates, it is necessary only to assume that the reader's memory stores the letter patterns of words. Thus orthographic knowledge can be inferred rather than stored directly. In any event, a particular "unit" of recognition does not have to be stated. The critical processing event converts a decodable letter string into its speech form or performs some other task on a letter string that tests the ability to take advantage of the structure of the letter pattern. Pseudowords and nonword syllables have such structure. The questions of interest include the following: Are there ability differences in processing pseudowords? Are there ability differences in processing letter strings that are not pseudowords? Do differences in the latter account for differences in the former?

We know that reader ability differences in vocalization latency are larger for pseudowords than for words (Hogaboam & Perfetti, 1978). However, comparisons of pseudowords with nonwords are what is needed. In the Perfetti and Bell (Perfetti, Note 1) search experiments described, there was a task in which subjects search for pseudowords in display sets of varying

In summary, there is reason to assume that children's reading ability, adult verbal ability, and adult reading ability can be accounted for by a common set of simple verbal processes. Processes of name retrieval, letter recognition, word decoding, and semantic access have been examined because they are patently involved in reading. Name retrieval, as a general mechanism of locating symbols in memory, is a fundamental processing limitation that seems to account for some of adult verbal processing ability. The remaining three processes, each more specific than name retrieval in some way, may not be critical in adult verbal ability *beyond* their reliance on general name-retrieval processes. However, for children with less verbal experience, there are specific linguistic processes still being acquired. At a given level of skill, for example, third-grade average ability, name-retrieval processes may set general processing limitations. However, specific code processes set stronger limits because knowledge and processes relevant for linguistic coding are still being acquired. By the time an individnal is in college, especially given the selection factor, word-specific skills have reached a high level and differences in name retrieval are seen. By this account, even letter-recognition differences are a matter of name-retrieval differences. A representation of this account is shown in Figure 3.

It is consistent with data on children's reading ability and adult verbal ability to suggest that decoding speed does not make a constant contribution to differences in verbal processing rate. As Figure 3 illustrates, the contribution of decoding speed, *relative* to name retrieval, is high for children, especially low-skill children. For college adults, decoding speed has increased nearer to the potential limit set by name retrieval. Thus, the latter makes more of a rate-limiting contribution to verbal processing speed.

VERBAL KNOWLEDGE

Together with the simple verbal processes discussed before, variations in verbal knowledge can be important for general verbal ability. Indeed, despite the attention given to these processes, it is quite possible that verbal knowledge is the fundamental ability factor for reading and verbal intelligence. Three kinds of verbal knowledge were suggested in the introduction: word-form knowledge, rule knowledge, and concept knowledge. It is clear that, especially for reading ability, knowledge of form and rules is critical. Especially insofar as decoding processes are an important source of ability, the question can be asked whether decoding processes are important independent of the knowledge of form and rules. Knowing the formal relationship between a printed word and its phonemic form is one kind of knowledge that can underlie decoding. Knowing that, depending on

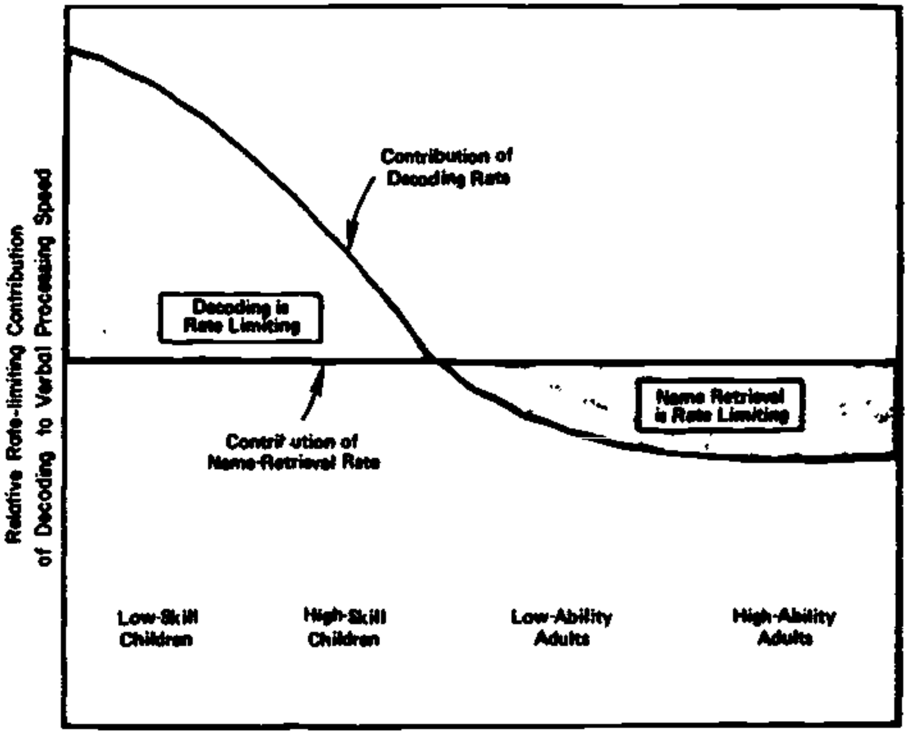

FIGURE 3. Schematic model of the relative contribution of decoding and name-retrieval rates to verbal processing with increasing reading skill development. Decoding is rate limiting at lower skill levels and name retrieval is rate limiting at higher skill levels.

orthographic environment, certain grapheme patterns map onto phonemic sequences, is a second kind of knowledge that can underlie decoding.

It is even possible, as Baron (1979; Baron & Strawson, 1976) has suggested, that individuals, at least children, differ fundamentally in whether their decoding processes are driven by form knowledge or rule knowledge; that is, whether an individual uses whole-word patterns or grapheme–phoneme translation as the basis of decoding. Baron and Strawson (1976) have referred to the former individuals as "Chinese" and the latter as "Phoenicians." There is, in fact, suggestive evidence that although verbal ability is supported by word-form knowledge, it is necessary to have rule knowledge to achieve high-ability levels. The children identified as Phoenicians tend to be better readers than those identified as Chinese. Indeed, encounters with unfamiliar words cannot be routinely successful without implicit rule knowledge, although it is possible to suggest otherwise (Glushko, 1981, pp. 61–84).

Rule knowledge is such a patently necessary part of decoding, at least as a backup system for word-form knowledge, that the debate should be shifted up one level: Are differences in word-decoding ability *only* a matter of word form and word-rule knowledge or are there additional differences in the processes that access such knowledge? In the earlier sections of this chapter, we assumed that there are processing differences over and above knowledge differences, in particular, that speed of decoding is critical. However, the evidence for this assumption is weak. It depends on decoding-speed differences in the absence of decoding-accuracy differences. More sensitive measures of knowledge might reveal knowledge differences. For example, does a low-ability reader know the orthographic rule relating syllable final *e* to vowel tenseness as well as the high-ability reader? Calfee, Venezky, and Chapman (Note 7) presented data showing that such knowledge differences were rather pronounced among younger readers. In general, sensitive tests of such knowledge among older readers have not been done, perhaps partly on the assumption that speed and automaticity are more critical.

Of course, this issue is difficult to decide fundamentally because it involves the trade-off between knowledge and process. To the extent that knowledge representation can be "slippery," there is a sense in which two knowledges that seem to be equivalent may not be. In other words, knowledge that is stable and context-free is not equivalent to knowledge that is labile and context-dependent, even though both sorts of knowledge may produce an accurate response in a given situation. How individual differences in verbal ability can be further understood as differences in the quality of verbal knowledge remains an important question deserving more attention than it has received.

Verbal Concept Knowledge

Access to word meanings is a central component of most verbal tasks, including reading. As in the case of decoding, there is again the question of whether individual differences in verbal ability include both knowledge and process. Unlike the case of decoding, however, process differences, over and above decoding and name retrieval, are less well established compared with knowledge differences. Even compared with decoding and name retrieval, concept knowledge is, on the face of it, a more important source of ability differences. Consider, for example, that the correlations between adult verbal ability and the speed of name retrieval (as measured by NI–PI) are typically about .3 (Hunt, 1978) whereas correlations between verbal ability and vocabulary are typically above .8 (Anderson & Freebody, Note 8). Indeed, tests of vocabulary knowledge directly and indirectly constitute a larger part of the SAT and similar standardized tests used to define verbal ability in individual-differences research. Thus, the question is not whether word-concept knowledge is an important component of ability, but rather, What is the nature of the relevant knowledge.

There are two general features of word-concept knowledge that are important for general verbal abilities. One is the number of word concepts familiar to a person and the other is the quality of the knowledge for a given word. These two aspects of meaning have been acknowledged in one form or another for some time; that is, breadth versus precision (Cronbach, 1942), and range versus precision (Kirkpatrick & Cureton, 1949), and simply richness of meaning (Dolch, 1927). Anderson and Freebody (Note 8) refer to *breadth* of word knowledge and *depth* of word knowledge, respectively, and those are the terms I will use here.

Several problems arise in assessing the breadth factor. As Anderson and Freebody (Note 8) point out, estimations of vocabulary knowledge are very sensitive to the form of the vocabulary test, and, in the case of a multiple-choice test, the nature of the foils. For these (and probably other) reasons, estimations of vocabulary size for a subpopulation vary over a vast range, with the highest estimate for college students being more than 12 times larger than the smallest estimate (Anderson & Freebody, Note 8). In any case, it is clear that the number of word concepts familiar to a person will play a role in his ability to read with understanding. Thus, vocabulary breadth is both a part of reading ability and a general verbal-ability factor.

In considering the relationship between breadth and depth and the role of each in verbal ability, a study by Curtis (Note 9) is informative. Curtis (Note 9) classified subjects as high or low in vocabulary knowledge on the basis of a multiple-choice test consisting of items from standardized tests. A second test was then composed, based on the difficulty and discriminability of the items: *known* words (95% of subjects correct), *discriminating* words (50% of subjects correct and discriminatory between high and low scorers) and *unknown* words (28% of subjects correct but not discriminating between high and low scores). In the second test, among other tasks, subjects were asked to define the words and were encouraged to provide any semantic association to an unfamiliar word. An interesting result of this second test was that low-knowledge subjects could provide little semantic information about discriminating and unknown words. They did *not* tend to produce vaguely related associations (e.g., "*desist* is like cease and desist," which was a response of a high-knowledge subject) but rather produced associations unrelated to the meaning of the word or no association at all.

This suggests, as Curtis (Note 9) observed, that low-knowledge subjects missed such items on the forced-choice vocabulary test, not from failure to evaluate semantic attributes of the foils, but because they were unfamiliar with the words. On the other hand, the low-knowledge subjects did produce relevant associations for the known words; however, half the time they could not give a synonym or correct explanation of the meaning, despite being able (twice) to chose the correct alternative in a multiple-choice test. A general conclusion, based on several analyses by Curtis (Note 9), is that vocabulary knowledge as measured by such tests is largely a matter of some minimal familiarity with the words and not a matter of deep semantic knowledge. This is interesting because of the ability implication: vocabulary ability, in the usual sense, includes a large component of very superficial semantic knowledge. Nevertheless, Curtis (Note 9) found that high and low subjects also differ in the depth of their semantic knowledge even when differences in semantic breadth (range) were taken into account. Low-knowledge individuals were not only familiar with fewer words—a fact sufficient to explain vocabulary score differences—they were also less precise in the knowledge of words with which they were familiar.

It was also possible in the Curtis (Note 9) study to relate performance on the vocabulary tests to ability scores based on the verbal SAT. Measures of decoding accuracy, based on identifying the vocabulary test words, semantic range (or breadth), and semantic depth, were all highly correlated with verbal SATs. In fact, the correlations of semantic range and semantic depth with verbal SATS were at least as high ($r = .92$ and $r = .91$, respectively) as they were with performance on the vocabulary test ($r = .88$ and $r = .83$, respectively). It is especially interesting that Curtis also found decoding accuracy to be highly related to verbal SAT scores of low-scoring subjects. Indeed, the results of multiple-regression and commonality analyses indicated that decoding accuracy accounted for more unique variance in the verbal-ability scores of low-ability subjects than did semantic depth (with range controlled). By contrast, high-ability subjects' scores were completely accounted for by the depth (with range controlled) of semantic knowledge. This fact seems to support the possibility, raised previously, that more sensitive measures of word-form and/or word-rule knowledge might well indicate significant ability differences among adults. In this case, the decoding weakness of low-verbal college students is seen in less-familiar words.

At the same time, high-vocabulary-knowledge subjects are faster at decoding, when accuracy is accounted for (Butler & Haines, 1979; Curtis, Note 9). Moreover, the word-identification times of high-vocabulary subjects are less affected by word length (Butler & Hains, 1979). Thus, part of what it means to be high verbal seems to be developing processes for word identification that are less sensitive to word length. And part of what it means is to acquire a passing familiarity with a large number of word concepts and a more refined semantic appreciation of a large percentage of those concepts. Understanding the relationship between these two abilities is a matter for future research.

BEYOND SIMPLE VERBAL PROCESSES

In this discussion, I have largely ignored complex verbal processes, exploring instead the role of simple verbal processes in verbal ability. A question to raise is whether, in general, differences in verbal ability can be reduced to these simple processes and conceptual knowledge. It is useful to consider what is involved in a complex verbal task such as understanding or writing a text. There are at least two ways that simple verbal processes may contribute to performance on these more complex verbal tasks. One way is that simple verbal processes may affect performance because they are *process-limiting* factors. A second possibility for such effects is that simple verbal processes are *learning-limiting* factors. The distinction between process-limiting factors and learning-limiting factors is that the former affect the *processes* occurring at the time of performance, whereas the latter have affected the prior acquisition of *knowledge* and *strategies* which are activated during the task.

One particular mechanism of process-limiting is that the overall rate of a complex verbal task is limited by the rate of execution of its elementary components. This does not necessarily imply that complex verbal processes are merely concatenations of simple ones. For example, a cascade model (McClelland, 1979) that makes weaker sequential assumptions about processes occurring together would imply that a low-level process would be rate-limiting for task performance. Even more completely interactive models (Rumelhart & McClelland, 1981, pp. 37–60) are consistent with the possibility that lower-level processes are rate-limiting. Applied to verbal ability differences, the rate-limiting hypothesis is that performance of a verbal task is limited by simpler component rates that vary with individuals. For example, this possibility has been demonstrated by Perfetti and Roth (1981, pp. 269–297) for the case of children's reading ability: In identifying words in context, low-ability readers are limited by their rate of basic context-free word decoding. It is possible to extend the rate-limiting principle to more complex text-processing tasks (e.g., Lesgold & Perfetti, 1978).

It is unlikely that this can account for all—or even most—of individual ability differences in more complex tasks. The learning-limiting factor is that any complex verbal performance will be limited by the prior acquisition of relevant conceptual knowledge and strategies for the task at hand. Evidence for the importance of knowledge is extensive over a range of tasks (Anderson, Reynolds, Schallert & Goetz, 1977; Bransford & Johnson, 1973, pp. 383–438; Dooling & Lachman, 1971; Spilich, Vesonder, Chiesi, & Voss, 1979). Any factor that inhibits activation of relevant knowledge during processing will limit performance. Thus, verbal ability differences are partly a question of individual differences in relevant knowledge. By the learning-limiting hypothesis, differences in such verbal knowledge arise in part because low-efficiency, simple processes have limited the acquisition of relevant knowledge. The fact that simple verbal-process-rate differences exist among adults can be taken as consistent with this possibility. At any given age, low-ability individuals have had less task-relevant verbal processing and have made less effective use of it. Hunt (1978) made a similar suggestion.

It is obvious that this is a "chicken or the egg problem" and that there is little reason to prefer the hypothesis that simple verbal processes limit acquisition of knowledge to the hypothesis that acquisition of knowledge allows simple verbal processes. Rather than making spurious arguments about what causes what, I suggest that we assume that simple verbal processes contribute to knowledge acquisition and that both simple verbal processes and knowledge acquisition contribute to verbal ability. Even if a stronger case could be made for reducing verbal-ability differences to simple processes, it may not be useful for deeper understanding of complex verbal performances For example, consider the relatively simple knowledge involved in appreciating the difference in meaning between disinterested and uninterested. It is unlikely that such knowledge can be reduced to simple verbal processes. Similarly, the ability to write a coherent and stylish text seems to be more than simple verbal processes. Both these examples represent verbal abilities which are poorly understood. The former implies fairly simple but powerful semantic and morphological knowledge. The latter entails a number of complex verbal abilities producing very wide individual talents. Such abilities have to be examined in their own right by reference to their cognitive components and not only by reference to simple verbal processes. As such work progresses, there will be more to say about complex verbal abilities.

CONCLUSION AND SUMMARY

Individual differences in verbal processes may be traced, in part, to simple verbal processes. Although I have largely ignored complex verbal processes, this does not mean that differences in verbal ability can be reduced to the simple ones discussed here. It will be important for future research to establish individual differences in specific higher level verbal processes and examine other levels of explanation. Such differences in the ability to comp[illegible]e a text and to appreciate the distinctions between semantically related words are just two examples of the many verbal skills that differentiate individuals. That all these can be completely accounted for by simple verbal processes seems more than unlikely.

However, simple verbal processes appear to have some role in general verbal skill. Reading comprehension and related verbal skills, even at the college level, are related to the ability to perform simple verbal tasks. I have emphasized four verbal processes and three kinds of verbal knowledge. The latter are knowledge of word formation (including word form and rule knowledge) and the breadth and depth of word concepts. The processes are name retrieval, letter recognition, decoding, and semantic access. Name retrieval is fundamental in that the rate of other processes is set by the rate at which any over learned symbol is retrieved. It is perhaps rate-limiting for high levels of verbal skill. For lower levels of verbal skill, the other three processes, especially decoding and semantic access may be rate-limiting. Although memory processes also are part of verbal ability, I have suggested that efficient word retrieval from inactivated memory is a particular hallmark of skilled verbal processing.

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