6 Exploring the Nature of a Basic Visual-Processing Component of Reading Ability

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Reading is a complex act requiring the integration and interaction of a number of basic cognitive processes. Understanding this complexity is an interesting and challenging pursuit in itself. In our own studies, an additional motivation for analyzing reading is to identify those component processes that determine reading proficiency. By examining the determinants of reading ability, we aim to extend our knowledge of the interactions of basic cognitive processes in reading and provide input for the task of devising effective methods of improving reading skill.

An individual's ability to read, as well as the ability to perform a variety of complex cognitive tasks, may be determined by a small number of basic cognitive skills. For example, general language-comprehension processes may largely determine our ability to understand language both when reading and listening (Perfetti & Lesgold, 1978). Better readers tend to have better comprehension of text both when listening and reading (Jackson, 1980; Jackson & McClelland, 1979). In fact, individual differences in the ability to understand language when listening can account for a large portion of the differences between the same individuals in their ability to read.

In recent years, a view of reading ability has emerged claiming that reading proficiency is almost totally dependent on these general language-comprehension skills (Goodman, 1970; Smith, 1971). If this view is correct, reading ability should not depend on any processes unique to reading per se. In contrast, our research has uncovered a basic visual processing skill that influences reading ability. Better readers, we have discovered, appear to have faster access to information in memory for visual symbols. This faster access allows them to encode more information from each reading fixation. In the remainder of this chapter, we summarize the evidence for this memory access difference between skilled and less-skilled readers and consider whether this visual processing skill is specific to reading. Also, we examine the question of whether this difference in memory-access speed is the result of different degrees of reading practice or is independent of practice.

Before considering the results of our experiments, we wish to emphasize a few characteristics of our subject population. As we are primarily interested in the component skills of more proficient readers, our subjects have been college undergraduates. One potential disadvantage of examining this relatively homogenous population is that the range of reading skills may be much smaller than we would expect to find in the general population. However, our experience has shown that large, stable individual differences in reading skill exist between these proficient readers.

To examine the relative component skills of readers within this population, we test the reading ability of a large sample of subjects and select the top and bottom quartiles (ranked by effective reading speed) as our groups of skilled and less-skilled readers.[1] We compare the performance of these groups on tasks designed to tap component reading processes. The reading tests consist of short stories similar in length and style to selections found on standardized reading and aptitude tests. Each story has a corresponding set of short-answer comprehension questions chosen to minimize the likelihood that the reader may know the correct answer prior to reading the test passage. In different studies we have used other reading tests and found that our subject rankings and experimental results are very stable across reading tests.

EVIDENCE OF A VISUAL ENCODING SKILL

Reading differs from listening in the processes that map the sensory input of letters and words on the page to the representations in memory that serve as input to the language-comprehension processes. These encoding processes begin with the visual pattern of print on the retina and result in a representation of the letters and words contained in that pattern. Because of limitations in our visual acuity, we can encode only a limited number of letters in any one eye fixation. In order to read one or more lines of text, the reader makes a number of eye fixations separated by very brief saccades. Although reading proficiency may be sensitive

[1]Effective reading speed is calculated by multiplying reading speed (in words per minute) by comprehension (percentage correct on a comprehension test). Effective reading speed is used as an index of the reader's speed of understanding, taking into account both the extent of the reader's comprehension and the speed at which the level of comprehension was reached.

to the pattern of eye fixations across the page of text, the control of eye movements during reading does not appear to be a significant determiner of reading ability (Tinker, 1965). Rather, the pattern of eye fixations may be automatically driven by language-comprehension processes anlayzing inputs over a number of fixations (Kolers, 1976; O'Regan, 1975; Rayner, 1975). Also, McConkie and Zola (1979) have reported evidence to suggest that the information that is integrated across fixations are the results of encoding the stimulus into letters, words, and other levels of representation.

The available evidence suggests that better readers are able to process more text *per* reading fixation. The efficient reader makes fewer fixations per line of text while spending the same aount of time per fixation (Buswell, 1922; Huey, 1908). Thus, better readers may be processing more text from each reading fixation. From a methodological standpoint, it is difficult to measure exactly how much text a reader is encoding from each fixation while reading without actually disrupting the reading process itself (but see, McConkie, Zola, Wolverton, & Burns, 1978). However, when good and poor readers are presented with simple five-word sentences under tachistoscopic conditions approximating a reading fixation. better readers are able to report more words and letters than poorer readers (Jackson & McClelland, 1975). Although this result suggests that better readers encode more information from each presentation, this task leaves open the possibility that better readers merely are better at guessing unrecognized letters based on the sentence context.

To test the ability to encode information from a single fixation—independent of differences in the ability to fill in missing information—we presented readers with simple sentences under the same tachistoscopic conditions followed by a probed forced-choice test. A typical stimulus sentence presented to the subject was:

Jane wore a plaid scarf

followed by the test alternatives:

Jane wore a plaid / plain scarf.

Subjects were required to choose which of two test words was presented in the stimulus sentence. The choices differed by a single letter, and both choices fit the sentence context. The choice word and critical letter location were equally likely to occur in any position in the sentence. If subjects had not seen the critical letter and had to guess which word was presented, they would choose either word with equal probability. However, we found that better readers identified the correct word more often than poorer readers, indicating that they had encoded the critical letter more often. Thus, better readers were able to pick up more information from the briefly presented sentences.

When reading, the amount of text encoded from any one fixation may depend on the efficiency of language-comprehension processes analyzing information gained from successive fixations. However, the visual processes responsible for the better-reader advantage on these tachistoscopic tasks appear to operate on units smaller than sentences or words. Using the same tachistoscopic presentation to approximate a reading fixation, we found that better readers could report more letters from a string of *unrelated consonants* than less-skilled readers. Although the ability to report unrelated items is influenced by the span of short-term memory, recent studies indicate that skilled and less-skilled readers do not systematically differ in their short-term memory *capacity* (Jackson & McClelland, 1979; Perfetti & Goldman, 1976). Rather, better readers were able to *encode* more letters from the briefly presented string. Thus, the visual-processing advantage underlying performance differences in these tasks is independent of language-comprehension processes and effects the encoding of single letters.

VISUAL ENCODING PROCESSES

Comparisons of skilled and less-skilled readers have consistently failed to yield any differences in visual sensory function that could account for the differences in performance we observe on these tasks. No systematic differences have been found between mature readers in their sensitivity to light (Buswell, 1922), parafoveal sensitivity (Jackson & McClelland, 1975), or sensitivity to lateral or temporal masking (Jackson & McClelland, 1979). Rather, the performance differences indicate a visual encoding difference that lies within the stages of processing that identify the letters and words represented in the sensory pattern.

A basic claim of many recent models of reading is that the recognition of patterns in the visual input depends on a hierarchical organization of subprocesses (Estes, 1975; LaBerge & Samuels, 1974; McClelland, 1976; Rumelhart, 1979). These models claim that the recognition of letters and words is achieved by recognizing configurations of subpatterns. Encoding of patterns at one level of analysis (i.e., letters) serves as the input to recognition of patterns at the next level of organization (i.e., letter clusters or words). Thus, the sensory pattern of a line of text may be analyzed for simple configural features, letters, letter clusters, and words.

The speed or efficiency at which information can be processed through this hierarchy may determine how much information can be encoded in a fixed amount of time. Studies by McClelland (1976) and Turvey (1973) suggest that as new information enters the visual-processing hierarchy, the processing of previous input is disrupted at each level of analysis or organization. During a reading fixation, information that travels through the hierarchy to more abstract levels—before lower-level information is disrupted by masking or dissipated by decay—will have a greater chance of becoming available for report. Better readers may be able to encode more letters and words from a brief fixation because they analyze the input pattern faster at any or all levels of representation in the recognition hierarchy.

To tap the speed of the visual-encoding processes, we tested skilled and less-skilled readers with a number of simultaneous matching tasks. In each task, the subject is presented a pair of items and is required to respond "same" or "different" as quickly as possible. By varying the stimulus items or the basis for comparison, we can index the relative speeds of different encoding processes by examining subject reaction times for making the correct response. In one matching task, the stimuli were letters, and subjects were required to respond "same" if the letters were either physically identical or identical in name, as in the paradigm developed by Posner (Posner, Lewis, & Conrad, 1972). In another task, the display elements were words, and subjects were required to respond "same" if the words were synonyms. In two other versions, the display elements were words or pronounceable pseudowords, and subjects were required to respond "same" if the words had the same sound (i.e., were homonyms). Examples of same and different stimulus pairs for each task are shown in Fig. 6.1. Thus, these tasks attempted to reflect the processes of forming visual-letter codes, letter-identity codes, semantic-word codes, and verbal codes.

The reaction-time results for these tasks (see Table 6.1) clearly indicate a processing speed difference between skilled and less-skilled readers for tasks requiring letter or word identification. Better readers were faster than poorer readers for each task. However, the smaller difference between groups for the physical letter-match trials was partially due to differences in accuracy level. The skilled-reader group was significantly less accurate than the less-skilled group, so their faster reaction times primarily reflect differences in accuracy criterion and not faster processing of the stimulus items. For the letter name-match trials and

Task	Same	Different
Letter		
Physical	AA	—
Name	Aa	Br
Synonym	ABRUPT SUDDEN	AGED STAY
Homonym	BARE BEAR	RARE REAR
Homophone	PEEN PEAN	PREN PRAN

FIG. 6.1. Examples of same and different stimulus pairs for letter- and word-matching tasks.

TABLE 6.1
Mean Reaction Times for Good and Poor Readers

	Reaction time		
Task	*Good*	*Poor*	*Difference*
letter			
physical	492	558	66
name	586	694	108
synonym	822	993	171
homonym	983	1132	149
homophone	1221	1365	144
dot pattern	1256	1230	−26

the other tasks, accuracy for the two groups was not significantly different, or better readers were slightly more accurate. Thus, we can infer that the faster reaction times of the skilled readers on the letter- and word-identification tasks reflect faster access to identity codes of the items in memory.

The presence of a reaction-time advantage for the skilled readers on *each* of the tasks suggests the possibility that better readers may be faster than poorer readers on any reaction-time task or any speeded task that requires a comparison of two visual items. To test this hypothesis, subjects were tested on a matching task that required a visual comparison but did not require access to memory codes. In this task, subjects were presented with two unfamiliar dot patterns and required to respond "same" if the two patterns were physically identical. The "different" patterns differed by the placement of a single dot. Unlike the pattern of results from the letter- and word-matching tasks, reaction times for better readers were not faster than reaction times for poorer readers. This result is consistent with the view that the better-reader advantage on the letter and word tasks is not due to more efficient visual comparison processes or general response time.

The correlation of reaction time and reading ability was highest for the letter name-match trials and the synonym task (see Table 6.2). Regression analyses indicated that the letter name-match reaction time accounted for the correlations between reading ability and each of the other reaction-time tasks. Thus, these results suggest that the speed of identifying the names of letters (i.e., the speed of accessing the names for the letters in memory) accounts for the better-reader advantage in each reaction-time task requiring letter identification. If letter identification is a component of word identification, as claimed by the hierarchical models of reading, then faster access to letter codes should be a source of individual differences in any task requiring word identification. Faster access to letter-identity codes in memory would give better readers an encoding advantage in the tachistoscopic presentation tasks because more letters and words would become available for report before processing of the stimulus was disrupted by the postexposure mask or subsequent stimulus.

TABLE 6.2
Correlations of Reading Ability and Reaction Time

	Letter		*Word*		
	Physical	*Name*	*Synonym*	*Homonym*	*Homophone*
Effective reading speed	.33	.47	.45	.21	.22

As suggested earlier, this visual encoding component of reading ability may be independent of general language-comprehension determiners of reading ability. In fact, in two independent comparisons (Jackson, 1980; Jackson & McClelland, 1979), reaction-time performance on the letter name-matching task was not significantly correlated with performance on tests of general language comprehension ($r = .17$ and $r = .16$). Also, regression analyses have indicated that general language-comprehension skills and the relative speed of accessing memory for letter-name codes (as measured by letter name-match reaction time) account for independent components of reading ability.

Although the reaction-time tasks clearly are tapping a visual encoding difference between readers in memory access speed, these tasks do not clearly define the nature of this visual memory access component of reading ability. Is this memory access difference between readers specific to the processing of letters, or does a systematic individual difference exist in the speed of accessing memory for any meaningful visual stimulus? To address this question, Jackson (1980) compared reaction times of skilled and less-skilled readers for a picture category matching task. The stimulus items were pictures of common objects. The objects were chosen from six categories such as vegetables, kitchen utensils, or modes of transportation. On each trial, a pair of pictures were presented, and subjects had to decide whether the objects belonged to the same or different categories. Reaction time for making the correct response is primarily dependent on the speed of accessing the representation in memory for the objects.

The results were strikingly similar to the reaction-time results for the letter name-matching tasks: Better readers showed roughly the same 100 msec reaction-time advantage over poorer readers for making the correct response (see Table 6.3). The correlations of category-match reaction time with reading ability and general language-comprehension skill paralleled those for letter name-match reaction time as well. Category-match reaction time was significantly correlated with effective reading speed ($r = .29$) but not correlated with comprehension performance ($r = .09$).[2] The similar pattern of results for both the object-matching and letter-matching tasks indicates a basic difference between readers

[2]Although the degree of correlation with reading ability is less than previously reported correlations for letter- and word-matching reaction times (Jackson & McClelland, 1979), the range of reading abilities in this sample of subjects was smaller.

TABLE 6.3
Mean Reaction Times for Category and New Character Tasks[a]

	Reaction Time		
Task	*Skilled*	*Less-Skilled*	*Difference*
new characters			
physical matching	404	406	2
name matching			
session 1	1023	1134	111
session 2	835	925	90
category	821	925	104

[a] From Jackson (1978).

in their speed of accessing memory codes for visual input (see Morrison, Giordani, & Nagy, 1977). Individual differences in speed of access to letter-identity codes are only one instance of the effects of this underlying difference in memory access.

MEMORY ACCESS AND PRACTICE

The category-match, letter name-match, and word-match results indicate a basic speed difference between skilled and less-skilled readers in the process of accessing information in memory for a meaningful visual pattern. When reading, this processing difference enables better readers to encode more letters in the brief duration of an average reading fixation. However, better readers can encode other meaningful visual patterns faster as well; their processing advantage is not restricted to alphabetical stimuli. This situation raises an interesting question as to how this memory-access difference developed. One possibility is that better readers achieved relatively faster memory-access processes for letters through additional reading practice. Also, one would have to assume that this increased efficiency transferred to the processing of other visual patterns with associated memory codes. The reverse order of events is much less likely, i.e., that better readers developed faster memory access for all patterns through additional processing of many visual patterns and that this skill applies to reading and letters as well. A more likely alternative is that the better-reader memory-access advantage does not result from more practice, or at least is independent of practice or familiarity with the particular items being encoded.

A conclusive test of the hypothesis that the better-reader memory-access advantage is independent of differences in amount of practice or training requires a comparison of subjects before and after they begin to read. By measuring their relative memory-access speed as they practice reading, we can get some indication of the relationship between individual differences in visual memory-access speed and amount of training or practice. Such a longitudinal study has not been performed. However, Jackson (1980) has examined the question of whether the better-reader advantage depends on the amount of familiarity with the particular visual items being tested. Using the same simultaneous matching format of the letter matching task, skilled and less-skilled readers were tested using a new character set that neither group had seen before the experiment. Examples of the new character pairs are shown in Fig. 6.2. In one version of this task, the pair of characters presented on each trial were either physically identical or different, and subjects responded "same" or "different" on the basis of the physical identity of the pair. As shown in Table 6.3, no difference in reaction time was found between the groups of readers. Also, the correlation of physical-match reaction time and reading ability was small and not significant ($r = .17$). This result strongly reinforces the conclusion that the differences between readers on letter- and word-matching tasks are due to differences in memory-access speed and not due to general reaction-time differences or differences in general visual-processing speed.

After completing the physical-match task with the new characters, each subject learned names for a second set of novel characters. The second set of

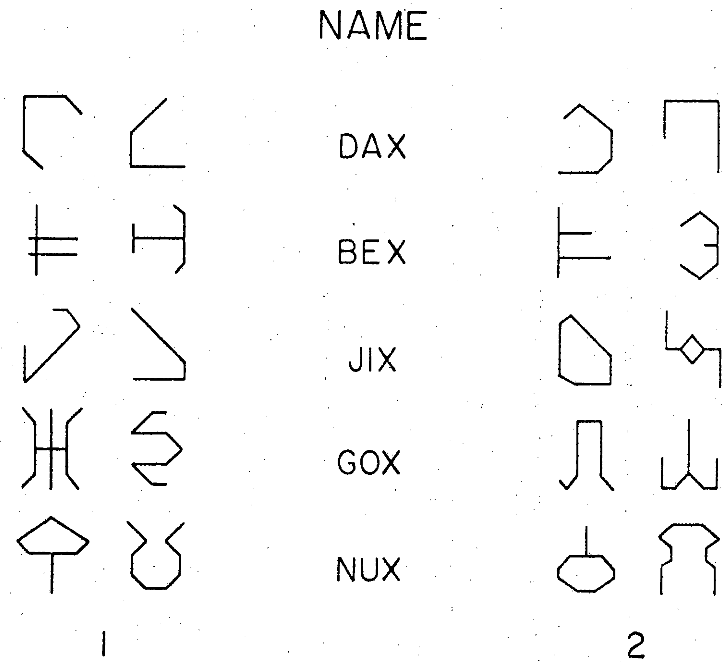

FIG. 6.2. Examples of new character stimulus pairs.

characters was divided into five pairs, with both members of each pair assigned the same three-letter name. Examples of the nonsense names are shown in Fig. 6.2. During a learning phase, subjects were presented each character and its corresponding name twice, one character at a time, followed by a test on the names of each character. On the average, both groups of readers took an equal number of learning trials to reach criterion. After learning the names of the characters, subjects were tested on a name-match version of the character-matching task. On each trial the pair of characters was physically different, but on half the trials the characters had the same name, exactly analogous to the letter name-matching task. Each subject was tested on two successive days, and the results are shown in Table 6.3. As was the case with alphabetical letters, better readers had faster reaction times for deciding whether the novel characters had the same name. Furthermore, the size of the better-reader advantage was about the same for familiar alphabetical letters and unfamiliar novel characters. Although both groups of readers improved their reaction time by approximately 200 msec on the second day of testing, the speed advantage for better readers was roughly the same. The correlation of character name-match reaction time and reading ability was if anything better ($r = .48$) than the correlation of letter name-match reaction time with reading ability previously reported. Thus, the better-reader advantage in their speed of accessing the names of the characters in memory does not depend on the amount of practice or familiarity with the visual items being encoded.

SUMMARY

The evidence for a strong relationship between general language comprehension skills and reading ability is well-documented and compelling. Although one may have suspected that reading ability was determined in part by the efficiency of visual information processes, the evidence indicating the role of visual encoding processes in determining reading fluency has been lacking. Our research has uncovered a visual processing advantage that influences reading ability independently of general language-comprehension processes. This reading component appears to lie within the stages of visual encoding that access representations in memory for visual patterns or symbols. During reading, memory-access speed may influence reading proficiency by determining the number of letters and words that can be encoded in a brief reading fixation. However, the advantage in memory-access speed demonstrated by better readers is not limited to the processing of alphabetical letters. Rather, as demonstrated with the picture category-matching task, the same better-reader speed advantage is present when the task required the recognition of common objects.

Perhaps the most surprising characteristic of the individual differences in visual memory access speed is the lack of dependence on practice or familiarity with particular items being encoded. Better readers show an equivalent reaction-time advantage over less-skilled readers at processing familiar and unfamiliar characters. Two possible paths for the evolution of this difference between mature readers remain. One possibility is that better readers always had faster access to memory representations for visual patterns, and the size of their advantage over less-skilled readers remains about the same as overall encoding efficiency improves with practice.

The alternative ties the better-reader advantage to amount of practice. To make this hypothesis work, one could claim that improved memory-access speed results from practice encoding letters while reading and/or from practice accessing memory from visual inputs of pictures, objects, and other visual symbols. By this account, the improved speed gained from reading practice must transfer to the encoding of all new visual patterns. This implies that a poorer reader might reduce the difference in memory-access speed compared to a better reader through increased visual encoding practice. However, because the access-speed difference exists between mature adults with extensive amounts of practice with both reading and other forms of visual encoding, the prospect for dramatic improvement appears remote. There may be particular stages in the process of learning to read when the amount of encoding practice influences memory-access speed. If so, differences in practice between readers at those times may determine relative differences in visual memory-access speed that affect encoding processes and reading ability from that time on.

In any case, important questions still need to be answered before we can address the implications of this visual memory access component of reading ability for methods of teaching and improving reading. One particularly promising line of investigation is to examine further the reaction-time results indicating individual difference in memory access in light of the speed–accuracy tradeoff (SAT) function (Pachella, 1974; Wickelgren, 1977). The SAT shows the relationship of response latency to response accuracy. Mean reaction time and accuracy for any one task is a measure of only one point on the SAT curve. The parameters of the SAT function may indicate important dynamic characteristics of the underlying information processes (Jackson, 1978; McClelland, 1978). Examining the SAT function for reading tasks may shed more light on the interactions of component-recognition processes and language-comprehension processes.

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