# Chapter 20: Reading





*The brain--our prior knowledge of the world-- contributes more information to reading than the visual symbols on the printed page.*
Frank Smith (1971)

A literate person faced with a written word is captured by it and seems to have no choice but to read it. Our phenomenal experience attests to this fact, as do experimental demonstrations of the Stroop (1935) effect. Take a set of colored pens or crayons and write a vertical list of color names. Write each color name with ink of a different color. For example, the word red is written in blue ink, the word green in red ink, and so on. Now read aloud the list of words from top to bottom. This task is not meant to insult your intelligence, but to serve as a reference for the next task. Name the colors of the words from top to bottom. Having the colors presented in written words corresponding to color names interferes with the naming of the colors. Although the reader's intention is to name the colors and ignore the words, it is not possible. Reading is such an overlearned skill, it is not easily put on hold.

Adult readers are clearly experts rather than novices in the reading domain of pattern recognition, in the same sense that experts are differentiated from novices in chess or radiography (Lesgold, 1984). Expertise is acquired in reading in the same manner that it is acquired in other domains. A millionaire recently admitted that he was illiterate. What is impressive beyond his deception through school and college is his success in learning to read at the age of 48. For our purposes, it is important to note that his learning to read required 60 40-hour weeks of studying and sounding out words. This extended period of time on task might seem excessive, but probably is in the ballpark of time most of us have spent in learning to read.

## ETHNOGRAPHY OF READING

Despite the onslaught of electronic media, reading remains central to our conduct. The average person reads about two hours a day. The distribution of reading times among adults is highly variable, however. Figure 1 plots a frequency distribution of reading times for a sample of five thousand readers (Sharon, 1973/74). About 15% of these literates read less than one-half hour per day. Less than 10% read more than four hours per day. In the primary grades one through three, about nine hours a week are devoted to reading. This drops to about six hours a week in the intermediate grades. As might be expected, the educated read more than the uneducated, and the young read more than the old. The most common kind of reading is newspaper reading; seven out of ten readers report spending an average of thirty-five minutes with a newspaper. The Bible is the most frequently read book. As every scholarly author believes, his or her book is least frequently read. Averages are not very illuminating, since people differ greatly in the amount of time they spend reading.

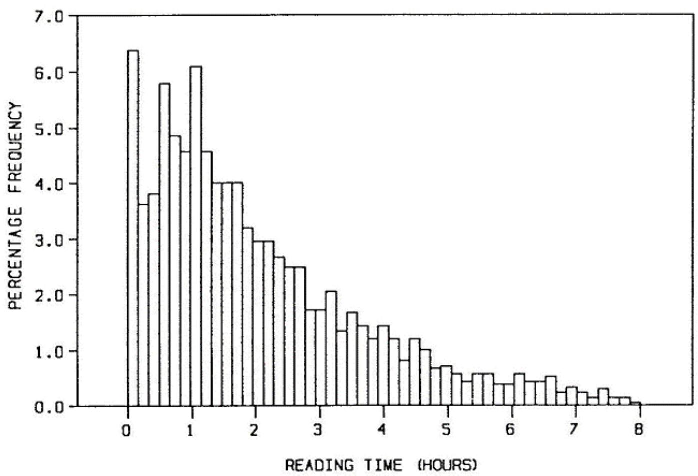


Figure 1. A frequency distribution of reading times for a sample of five thousand readers (after Sharon, 1973/74).

Some change in reading habits is also noticeable (Robinson, 1980). Young people are reading less, but those who do read are more committed. In one study, 85% of the youngsters who appeared in juvenile court were disabled readers (Kvaraceus, 1974). With more education, there is a shift from newspapers to magazines and books. There is also a well-known decline in literacy (Copperman, 1980). The upward trend in academic achievement reversed in the mid-sixties. Scores on the Scholastic Aptitude Test (SAT) also declined throughout the seventies. The verbal score declined about 4% per year; the math score declined about 2.5% a year. It seems also the case that these declines cannot be attributed to an increased number of lower ability students taking the test. In addition to scholastic achievement, the quality of instruction may have declined. Public schools no longer require a prescribed curriculum for students and teachers. Encouragingly, the scores have shown consistent improvement in the eighties. .

## WRITTEN LANGUAGE

One of the earliest known uses of written language is the cuneiform writing of the Sumerians. Short, straight lines were impressed by a broad-based stylus. This writing system, like hieroglyphic writing, included word-signs or sound pictures, phonograms which expressed phonetic sounds, and determinatives (which was the context to eliminate ambiguities). Linear A and Linear B differed from earlier writing systems in that the written form was directly tied to the spoken form of writing. Linear B was a syllabary with open consonant-vowel syllables. A syllabary was also developed by the Japanese, who had difficulty using Chinese characters as the bases for their script. The alphabet was invented in about 1600 B.C., although its development is not well known. The unique feature of the alphabet was that each unique sound was denoted by only one symbol.

We can imagine that significant changes in reading occurred in parallel with the changes in writing. Unfortunately, we know even less about the historical development of reading and learning to read than we do about the history of writing. Written messages (especially those on clay tablets) remain to be found and studied; the historical readings of these messages do not. We might guess that most early reading was oral reading or at least was closely tied to speaking. St. Augustine was amazed by his mentor when he discovered St. Ambrose reading without moving his lips. In the future, we might expect to read even more, given the electronic communications revolution. Electronic mail is an important medium for communication, and we will be asked to read not just black letters on white paper but luminous dots on a TV screen.

## A SHORT HISTORY OF READING RESEARCH

Reading research has had a short but lively history. Many of the issues being addressed today in research on reading were also studied during the early period of experimental psychology, shortly after the invention of the tachistoscope and Emile Javal's discovery of saccadic eye movements in the 1870s. Until then, it had been assumed that the eye moved continuously across the page, identifying each letter as it appeared. Now it was revealed that the eye moved in a series of discrete steps across the page. This finding generated the question of how much could be read in a single fixation between steps. James M. Cattell (1888), the first American to write a dissertation directed by Wundt, did a tachistoscopic study of letter, word, and phrase recognition showing that subjects could read out words, or even phrases and short sentences, from a display presented for so short a time that an eye movement was not possible.

In the 1890s, Erdmann and Dodge found that subjects could read words at distances too great to permit the identification of the component letters when they were presented alone. Since acuity breaks down with increasing distance, this is another experimental technique which can be used to obtain errors; it does not limit the amount of processing time but decreases the S/N (signal to noise) ratio. This method should produce the same qualitative results as a method which manipulates processing time to obtain errors. Erdmann and Dodge also found that subjects could read sentences at a distance too great to permit the recognition of the words presented alone.

Further insights into reading were provided by the work of Pillsbury, a disciple of Wundt, who in 1897 devised an experiment to test Wundt's theory of apperception. Wundt, influenced by the philosophy of Kant, argued that what one perceives is dependent upon a pre-existent structure of knowledge. Pillsbury's demonstration of apperception in reading involved presenting subjects with visually distorted words. For instance, the word word might be presented with a slash drawn through the o. Other stimulus words might simply be missing a letter. These displays were presented very briefly to subjects, who were then asked to report what they had seen. Subjects were able to identify the distorted words correctly, and sometimes they failed to perceive anything unusual in the display. The apperceptive process enabled them to perceive the words as accurately as if they were complete and undistorted.

A great deal of excitement in psychological and educational circles was generated by this work. The research results convinced many people that word recognition was not dependent upon the recognition of individual letters. Many educators, convinced that the basic unit of recognition in reading was not the letter--as had always been assumed-- but the word and even the phrase, began to advocate the whole-word method of teaching. Thus began the controversies that have raged ever since around the proper method for teaching children to read. If skilled readers perceive entire words and phrases, it was reasoned, the method of teaching children spelling patterns and spelling-to-sound correspondences (phonics) could only interfere with their developing the optimal technique for deriving meaning from the text.

Psychologists meanwhile intensified their study of reading, convinced that it held the key to a great many crucial psychological issues. Edmund Huey wrote in 1908:

> to completely analyze what we do when we read would almost be the acme of a psychologist's achievements, for it would be to describe very many of the most intricate workings of the human mind, as well as to unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history.

In spite of such grand expectations, most of the work done on reading in this period concerned the measurements of eye movements. A great deal of time was spent on devising apparatus of varying degrees of ingenuity to record the flight of the eye from one fixation to the next.

In 1900, Wilhelm Wundt objected. To understand reading, he pointed out, one would have to understand far more than the duration of eye fixations and the speed of eye movements. Crucial psychological processes, such as attention and expectancy, were being ignored by the reading psychologists in their study of how the reader derives meaning from printed text. For instance, the reader brings to the reading task a variety of sources of knowledge. When reading, the skilled reader is able to predict the next word or words to some extent. This could result from either of two causes. (1) The information is available in the reader's peripheral vision; although focused on one point on the page, the reader can actually see words that occur further on in the text. (2) Knowledge enables the reader to guess at what is coming on the basis of what has already been read. It is possible, therefore, that reading efficiency is due not to an effect of the peripheral processing, but rather to the reader's ability to construct hypotheses about what lies ahead on the basis of what is already known.

Wundt's observations are highly relevant to the study of psychological processes in reading. It is important to know how much visual information is available to the reader at any moment and, secondly, to what extent readers utilize higher-order knowledge to impose meaning on the printed page. These two issues might be considered to be central to much of today's reading-related research (Gibson & Levin, 1975; Just & Carpenter, 1987).

**Supraletter Features in Words**

The early work on letter and word recognition led some researchers and educators to conclude that words are learned as patterns of unique shapes rather than as sequences of unique letters. If words have unique shapes, readers would learn words in terms of relatively gross properties which define their shape. We call these properties supraletter features since they supposedly are composed of multiletter patterns and even whole word patterns. This belief was responsible for the whole-word method of teaching reading.

As appealing as the concept of supraletter features might be, there is no evidence for this idea (Anderson & Dearborn, 1952; Gibson & Levin, 1975; Huey, 1968). One of the strongest arguments against the idea of supraletter features is the small potential contribution of supraletter features to reading. Overall word shape, for example, does not sufficiently differentiate among the words of a language. Groff (1975) examined the shapes of high-frequency words taken from schoolbook sources. The shape was defined by drawing a contour around the letters so that elephant would be elephant. Only 20% of the 283 words were represented by a unique shape. The author rightly concludes that the small number of words that can be represented by a unique shape precludes the utilization of this cue for accurate word recognition.

There is also experimental evidence against the idea of word recognition based on supraletter features. The role of supraletter features has been evaluated in a number of studies by determining whether mixing the type fonts of letters eliminates the tachistoscopic identification advantage of word over nonword letter strings. Adams (1979) studied the tachistoscopic recognition of words, pseudowords very high in orthographic structure, and nonwords very low in structure. The items were presented in a single type font or the items were constructed from a variety of fonts. Table 1 presents examples of the words, pseudowords, and nonwords in single and mixed type fonts. Performance was more accurate for words than pseudowords and poorest for nonwords. Most importantly, the size of the differences among the three types of items did not change when the letters of the items were presented in a variety of type fonts. If supraletter features or whole-word cues contribute to the perceptual advantage of well-structured strings, the advantage of the word and pseudoword strings should have been drastically attenuated in the mixed-case presentation.

| Word | Pseudoword | Nonword _ |
|---|---|---|
| rEAd | tHaP | yIbv |
| bACk | SuCE | gTsI |
| wEak | BleT | MbIa |

Table 1. Words, pseudowords, and nonwords printed in mixed uppercase and lowercase.

In reading, our eyes make short ballistic movements about four or five times a second. Each movement covers between four and eight characters. The movement time is very short and accounts for only about 10% of the time spent reading. We derive visual information only during the pauses between eye movements. Hold your fixation on the black dot in the center of the following sentence.

Pev au lbc kmrw dmr zfl jsrb wcm svf•uxrwa fc esrh br htc ozh wl hfuws cnvmhwp.

How many letters can you identify without moving your fixation? Now do the same for the next sentence.

Now is the time for all good men and•women to come to the aid of their country.

This one is easier, since it conforms to English writing, whereas the top sentence does not. However, not more than about four or five words can be seen in a given fixation. Letters and words outside of this range seem blurred or fuzzy.

The knowledge of the perceiver is critical in reading, since the sensory information available to the reader is imperfect. With respect to the visual system, the letters on a page are highly fuzzy. Readers utilize their knowledge of the content of the passage and their knowledge of the language to make the written word less fuzzy. There are many knowledge sources available to the reader such as the sentential constraints given by well-formed English sentences. Consider the passage, the actress was praised for an outstanding. Most of you probably thought of the word performance. Consider an early experiment in psychology. Subjects were given 0, 4, or 8 words of a context sentence, and this was followed by a test word presented for a short duration in a tachistoscope. As might be expected, subjects were more accurate when the duration of the test word was increased. In addition, the context improved performance so that words were more likely to be recognized when more of the context sentence was present. Readers appear to utilize the sentential context to facilitate their perception of a test word when the visual information alone is insufficient. We now turn to a more detailed study of how the reader utilizes the visual information and knowledge in imposing meaning on written text

**VISUAL INFORMATION AND REDUNDANCY**

Wundt's criticism of the reading experimentalists of his time brought to light the crucial requirement of a valid study of reading: the separation of the effects of two different contributions to the process. The first contribution is that of the stimulus--the visual symbols on the page of text. The second is nonvisual information possessed by the sophisticated reader and stored in memory.

There are three sources of nonvisual information that can aid the reader in decoding the written message. These sources are the orthographic, syntactic, and semantic structures that exist in English prose. The orthographic constraints define the valid spelling patterns in English. We know that words are separated by blank spaces and must have at least one vowel. Syntactic rules establish the permissible sequences of different parts of speech. For example, The boy down fell the hill is grammatically incorrect. Finally, semantic rules allow the reader to predict the word or words that make sense in a given sentence context. The hill fell down the boy is syntactically correct but semantically anomalous. All of these rules allow us to agree on the missing word in Please clean the dirt from your s---s before walking inside.

In terms of the information-processing approach, the visual stimulus is transformed by the visual system, and a list of features is recorded in preperceptual visual storage. Recognition, or the readout of this information, depends on the features of the information in preperceptual store and on the information possessed by the reader about the occurrences of spelling patterns in English. Figure 2 demonstrates how two identical visual patterns can be interpreted as different letters because of meaningful context. Thus, although the visual information available about the last letter of the first word is the same as the first letter of the second word, the contribution of what one knows about the valid spelling patterns in English text demands that they be interpreted as different letters. (This knowledge is sometimes referred to as redundancy, since it reduces the number of valid alternatives a particular visual configuration can possess.) In reading, we would expect that this knowledge of English spelling would enable us to extract meaning from a page of text without analyzing all the visual information present or to identify words even when some of the visual information is incomplete or fuzzy.

It should be stressed that knowledge of orthographic constraints involves more than simply a knowledge of the spelling of each word in our vocabulary. For example, we know that cht does not

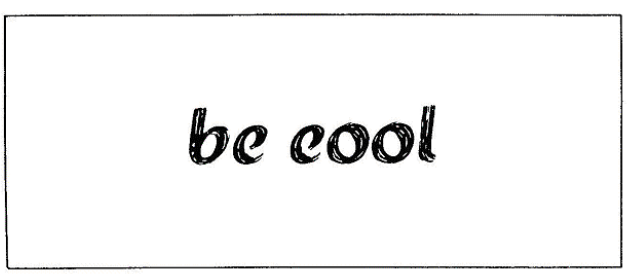


Figure 2. The same visual configuration can be interpreted as two different letters, depending on the meaningful context.

spell a word, not because the meaning of cht is unknown, but because we know that cht is an invalid spelling sequence for a three-letter word. To illustrate, consider the spelling configuration cit. Even though one may not have this word in his or her vocabulary, it would be incorrect to conclude that this configuration could not spell a word.

Given that the reader may utilize orthographic, syntactic, or semantic context, two interpretations emerge from the early experiments of Erdmann and Dodge, and Pillsbury. In the Erdmann and Dodge study, subjects were able to read words and sentences better than they could read isolated letters and words, respectively. One interpretation is that words are easier to read because they are easier to perceive. For example, words may have unique visual characteristics which make them easier to perceive than individual letters. The alternative interpretation is that subjects were able to guess correctly more often when the impoverished letters formed word sequences than when they did not. Consider the example in Figure 2. If the subject is presented the letter c at a very great distance, she may be unsure if it is a c or an e and may have to guess randomly between the two. On the other hand, if she is presented with cool, the c may be just as ambiguous visually, but if ool is interpreted as such, she can guess correctly with the word cool. In this case, the results would show better recognition for words than for isolated letters. We can also develop an analogous explanation for the result that sentences are better recognized than isolated words.

Similarly, we do not know why the subjects in the Pillsbury experiment were able to identify words when a letter was missing or distorted. It is possible that they actually perceived the intact word, and that they did not need each letter to be present and intact in order to perceive the word. On the other hand, it is possible that they did not perceive it as complete and intact, but that their knowledge of English spelling enabled them to make a good guess at the word after perception was complete. This interpretation weakens the relevance of these results to natural reading. Readers may not be able to utilize nonvisual information in rapid reading when their eyes move across the page at a rate of four or five fixations a second. However, given a short tachistoscopic exposure with a relatively long time to respond, the subject might be able to utilize nonvisual information. In this case, subjects need not perceive every letter before they can correctly identify the word.

**Orthographic Structure**

Orthographic structure refers to the fact that a written language, such as English, follows certain rules of spelling. These rules prohibit certain letter combinations and make some letters and combinations much more likely in certain positions of words than others. Readers might utilize these constraints in the written language in letter and word perception. Concern for orthographic structure in reading has occurred only recently.

One of the first studies of the utilization of orthographic constraints in reading was carried out by Miller, Bruner, and Postman (1954). These authors had subjects reproduce letter sequences flashed in a tachistoscope. The eight-letter strings corresponded to different approximations to English based on Shannon's (1948, 1951) algorithms. The authors found that performance improved with increases in the degree to which the letter strings approximated English. By correcting for the statistical redundancy in the strings, the amount of information transmitted (Chapter 1) was shown to be equal for the various approximations.

**Measures of Orthographic Structure**

Given that readers are sensitive to orthographic structure, an important question is the nature of a reader's knowledge about orthographic structure. It is possible to distinguish between two broad categories of orthographic structures: statistical redundancy and rule-governed regularity (Venezky & Massaro, 1987). The first category includes all descriptions derived solely from the frequency of letters and letter sequences in written texts. The second category includes all descriptions derived from the phonological constraints in English and scribal conventions for the sequences of letters in English words. Although these two descriptions are highly correlated in written English, it is possible to create letter strings that allow the descriptions to be orthogonally varied. Given these strings as test items, perceptual recognition tasks have been carried out to decide which general category seems to reflect the manner in which readers store and utilize knowledge of orthographic structure.

Massaro et al. (1980) contrasted specific statistical-redundancy descriptions with specific rule-governed descriptions by comparing letter strings that varied orthogonally with respect to these descriptions. The statistical redundancy measures were summed token single-letter frequency, bigram frequency, and log bigram frequency. The rule-governed regularity measures were various sets of rules based on phonological and scribal constraints. In a typical experiment, six-letter words and anagrams of these words were used as test items. The anagrams were selected to give letter strings which represented the four combinations formed by a factorial arrangement of high or low frequency and regular or irregular orthographic structure. In a series of experiments utilizing a target-search task, subjects were asked to indicate whether or not a target letter was present in these letter strings. Both accuracy and reaction-time measures indicated some psychological reality for both frequency and the regularity description of orthographic structure.

Consider an experiment carried out by Massaro et al. (1981). Some examples of the words and their respective anagrams are presented in Figure 3. Period has a high word frequency, while coined has a low word frequency. The letter string rodipe is a regular-high anagram of the word period, and nidcoe is a regular-low anagram of coined. The number in each cell gives the average summed-positional log bigram frequency for the items of that class. For example, the irregular-high anagrams of high-frequency words have an average count of 11.625. Forty high-frequency and 40 low-frequency words were selected along with four anagrams of each word. The anagrams were selected so that they formed a factorial arrangement of high and low summed-positional log bigram frequency crossed with regular and irregular orthographic structure.

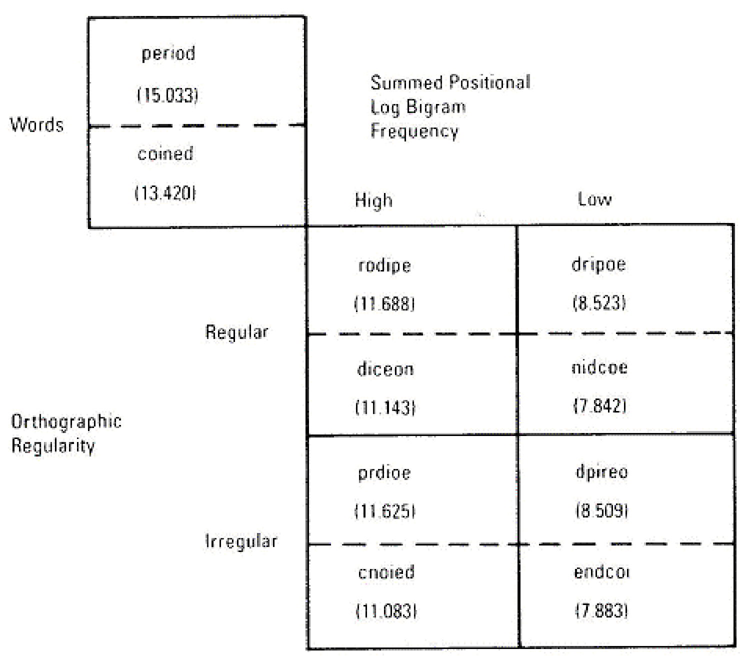


Figure 3. Examples of the words and anagrams used in the Massaro et al. (1981) task.

These six-letter words and their anagrams were used as test stimuli in a target-search task. The test string was presented for a short duration, followed by a masking stimulus and the target letter. Subjects responded yes or no whether the target letter was present in the test string. There was an advantage of words over regular-high anagrams and an advantage of regular over irregular anagrams. There was also an advantage of high-frequency words over low-frequency words. Word frequency of the items from which the anagrams were derived did not have a significant effect on perceptual recognition of the anagrams. Post hoc correlations with performance accuracy on each of the test strings gave significant effects of position-sensitive log bigram frequency and regularity. The results of these studies provided evidence for the utilization of higher-order knowledge in the perceptual processing of letter strings. Lexical status, orthographic regularity, and frequency appear to be important components of the higher-order knowledge that is used.

**Perceptual versus Memory Contributions**

Although Miller et al. (1954) and, later, Eleanor Gibson and her colleagues (Gibson, Pick, Osser, & Hammond, 1962) found positive effects of orthographic structure in tachistoscopic tasks, the results do not necessarily implicate a perceptual effect. Memory is a critical component in the tachistoscopic task. In a similar vein, Baddeley (1964) questioned the perceptual contribution to the original psychological study of orthography carried out by Miller et al. (1954). Recall that the authors had subjects reproduce letter sequences, eight letters in length, corresponding to different approximations to English based on Shannon's (1948) algorithms. The displays were exposed for durations of 10 to 500 msec, and the number of letters reported increased with display duration. Also, performance was a systematic function of the order of approximation to English. By correcting for redundancy of the string, the amount of information transmitted was shown to be equivalent for the four different approximations.

Baddeley (1964) observed that performance in the task was unlikely to be a direct index of how well the letter sequences were perceived. Given that performance improved at a negatively accelerated function of log exposure duration, one or two hours would be required for correct report of all eight letters. Baddeley argued that Miller et al.'s results may have reflected differences in the memory for the sequences rather than differences in their perception. To test this idea, he presented the eight-letter sequences of Miller et al. at a duration that was sufficient for that subject to name each of the eight letters. Presentation times ranged between one and two seconds. The contribution of orthographic redundancy to performance in this task was essentially identical to that reported by Miller et al. (1954). Baddeley concluded that both interletter redundancy and exposure time allow a more effective coding and, therefore, better memory and recall of the letter sequence.

We have seen that, in addition to perception, post hoc guessing and memory are critical contributions to performance in tachistoscopic experiments. In order to assess how some variable influences perception, the experiments must account for both post hoc guessing and memory contributions to performance. This might be seen as an insurmountable obstacle, but some good solutions have been proposed. The most influential solution was invented by Gerald Reicher for his dissertation research at the University of Michigan in the late sixties. His goal was to control for both post hoc guessing and memory in the tachistoscopic report of letter strings.

**REICHER PARADIGM**

In Reicher's task, subjects saw a short display of letters in a tachistoscope. Reicher presented either single letters, words, or random letter strings (nonwords) for a short duration, followed by a masking stimulus (see Figure 4). For example, on one trial, the subject might be presented with the word WORD for a very brief time, followed immediately by a visual noise mask made up of overlapping X's and O's. The masking stimulus also contained a cue to report one of the four letters. When the task was to name the fourth letter in the word, two alternatives would be presented at the time of the cue, D and K. The subject would have to choose one of these alternatives. In this task, then, the subject must make a choice only on the basis of the information obtained from the visual display. Knowledge of the rules of English spelling will not help this decision: both alternatives D and K form words given the information WOR-. Of course, a different word was presented on each trial, and the subject did not know which letter position would be tested until the cue appeared.

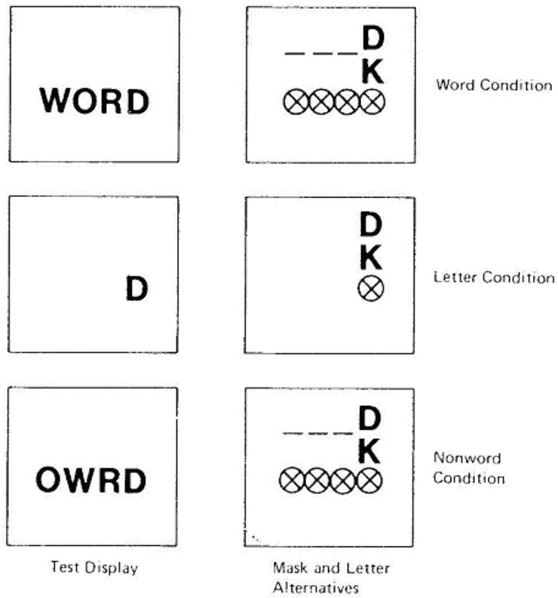


Figure 4. The visual displays used in the Reicher (1969) study.

Performance in this word condition was compared with performance when the subject was presented with a single letter at any of the four serial positions defined by the word. For example, the subject could be presented with D alone and asked whether it was D or K.

The third condition allowed Reicher to compare word versus nonword recognition. On some trials, the subject was presented with a nonsense word that did not conform to the spelling rules of English: for example, OWRD or OWRK. This procedure appears to control for both post hoc guessing and memory in the task. To control for the contribution of English orthography, Reicher and Wheeler limited the subject to two response alternatives, both of which spelled words. features from the other letters in the word. The results of their studies showed an accuracy advantage of words over nonwords and single letters, and indicate that information about how letters make up words supplements the visual information in the letters to give an advantage of words over nonwords and single letters.

**Words versus Rules**

There are two fundamentally different accounts of the word advantage. These two accounts parallel summary-description and exemplar-based accounts of categorization. Similar to our conclusions with respect to these two alternatives, we might expect that both explanations are correct to some degree. The reader probably uses both rule-like knowledge and specific word knowledge in perceiving letters and words in reading. The traditional one that we have discussed is that the reader has rule-like information that makes a contribution to word recognition. These rules do not have to be consciously known or applied, and they do not have to be perfect. That is, a rule can still make a positive contribution to word recognition even if it provides only partial information. Analogous to the use of cues to depth or the use of top-down constraints in speech perception, several pieces of partial information can yield an unambiguous situation.

A more recent account of the word advantage dispenses with the idea of rules entirely, and explains the word advantage in terms of the contribution of the specific words in the reader's lexicon (Brooks, 1978; Glushko, 1979). The most complete model within this class is the interactive activation model. The model was designed to account for context effects in word perception (McClelland & Rumelhart, 1981) and was extended to account for other phenomena (Rumelhart & McClelland, 1982). The model postulates three levels of units: features, letters, and words. Features activate letters that are consistent with the features and inhibit letters that are inconsistent; letters activate consistent words and inhibit inconsistent words; and most importantly, words activate consistent letters. A letter is more accurately recognized in the context of a word than in context of random letters. Interactive activation explains this word advantage in terms of interactive activation from the word level to the letter level. Definitive tests between rule-based and word-based accounts of the word advantage have not been developed. A safe bet is that both rule-based and word-based information is brought to bear in reading.

**PHONOLOGICAL MEDIATION**

A very old question in reading-related research, one that is probably as old as reading itself, is whether the reader must translate print into some form of speech before meaning is accessed. This question can be formalized in terms of two different models in which speech mediation either does or does not occur in a derivation of meaning. Figure 5 presents a schematic diagram of both models. The top model assumes that phonological mediation must occur in order for the meaning of a message to be determined. In this model a letter string is presented, and the letters are identified by evaluating the visual information against feature lists of letters in long-term memory. The letters then are translated into a speech-like or a sound-like medium by the spelling-to-sound correspondences of the language. We call this kind of mediated word recognition phonological

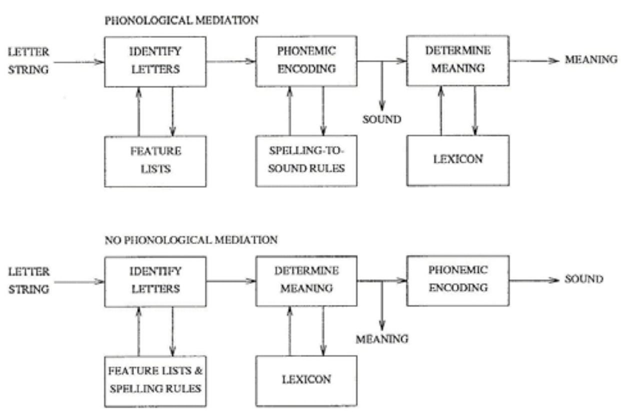


Figure 5. Two models of word recognition with and without phonological mediation.

mediation. One example of a spelling-to-sound rule is that a medial vowel is usually pronounced as short unless it is followed by a consonant and a final e. Thus, we have fin and fine or fat and fate. The speech code derived from spelling-to-sound rules is then used to access the lexicon in order to recognize the meaning of the word. The critical assumption of this model is that lexical access is achieved only by way of a speech code.

The bottom model in Figure 5 assumes that a speech code becomes available only after lexical access is achieved. The letters are identified in the same way as in the speech mediation model.

However, the meaning of the letter string is determined by utilizing a visual code to achieve lexical access. The important assumption in this model is that the reader has information about what letter sequences represent what words. In this model the speech code becomes available only after lexical access is achieved. Given these two formal models, one would expect that it would be relatively easy to distinguish between them.

**Experimental Tests**

Experiments have been done utilizing the time needed for lexical access in order to test between the models. Consider an experiment carried out by Gough and Cosky (1977). Subjects were asked to read aloud words that either obeyed or violated spelling-to-sound rules. One example of a word that violates a spelling-to-sound rule would be the word give; the vowel is not pronounced as long as it should be as, for example, in the word hive. If subjects recognize words via speech mediation and utilize spelling-to-sound rules to achieve the speech code, then recognition of the word give should take longer than recognition of the word hive. Utilizing spelling-to-sound rules, the reader would first interpret the letters give as [gaiv] (rhymes with hive). Failing to achieve lexical access, a backup strategy would be initiated, and the short form of the vowel would be inserted, giving the correct pronunciation [gIv]. In this case, lexical access would be achieved on the second try. Given the word hive, recognition would occur directly from the speech code [haIv] produced by spelling-to-sound rules. The obvious hypothesis is that the pronunciation time for exception words, such as give, should be longer than the pronunciation time for regular words, such as hive. Gough and Cosky found that the pronunciation times for the exception words were in fact 27 msec longer than the pronunciation times for regular words. This result would seem to provide evidence for the speech mediation model.

Before these results can be interpreted as supporting the speech mediation model, however, it is necessary for the investigator to locate the differences in reaction time at the word-recognition stage of processing. The naming task requires a number of processing stages, and it is necessary to perform a stage analysis of the naming task. Naming a written pattern includes word-recognition and speech-production operations. In terms of this analysis, the RT between the onset of the written pattern and the onset of the spoken response is a composite of these two component times plus the times for other processes. It could be that lexical access time did not differ for exception and regular words but that the time for the subjects to program the naming response did differ. It could be that exception words are more difficult to pronounce once they are recognized and therefore require more time in the pronunciation task. One possible control would have been to present the words auditorily and see if naming times differ in this situation. If they do not, this result would provide some evidence that the original differences with visual presentation are due to differences in time to achieve lexical access.

Another test for differences between exception and regular words is a category judgment task. Subjects are asked to categorize the words, such as whether they are nouns or verbs. The differences in the times to complete the categorization task would not be confounded with response processes because the response of categorization is identical for the exception and regular words. Following this logic, Bias (cited by McCusker, Hillinger, & Bias, 1981) tested for differences between exception and regular words using animal/nonanimal judgments.

Even if lexical access is slower for exception than for regular words, phonological mediation may not be responsible. Differences between exception and regular words could be the result of differences in the times to process the letters of the words. There is good evidence that readers utilize orthographic structure to facilitate letter processing in word strings (see previous section). It could be that exception words have less orthographic structure than regular words, and letter recognition is therefore faster for regular than for exception words. Controlling for orthographic structure differences is difficult because an exact description of structure has not been validated.

We have distinguished between orthographic structure and spelling-to-sound regularity in our description of written language. It would be of interest to assess the contribution of each of these in reading written words. Also of interest is word frequency--perhaps the most potent variable in naming and lexical decision tasks. Waters and Seidenberg (1985) assessed the contributions of these three variables in both naming and lexical decision tasks. Very similar results were found in both tasks. It is important in tasks such as these to look at performance on each test item rather than just on a class of items. One procedure is to compute an average RT for each word pooled across subjects, and to correlate the variables of interest with the RTs to the individual words. When this type of analysis was carried out on the Waters and Seidenberg (1985) results, there were significant effects of all three variables (Venezky & Massaro, 1987). This outcome has several implications. First, there must be some truth to both of the routes to the lexicon illustrated in Figure 7. Second, there is no single source of information responsible for written-word recognition. Finally, readers appear to evaluate and integrate multiple sources of information in reading, as they do in speech perception.

## THEORIES OF WORD RECOGNITION

Theories of visual-word recognition can be classified within the same scheme used for spoken-word recognition. For written words, the visual signal initiates a process that begins with the visual processing of the word and ends with access to a word or phrase in the mental lexicon. Three word recognition models will be discussed to highlight some important issues in understanding how written words are recognized. The same characteristics used to contrast and compare the models of spoken-word recognition will be used for written-word recognition. In fact, we will find that models of written-word recognition resemble analogous models of spoken-word recognition. One important question is whether word recognition is mediated or nonmediated. A second question is whether the perceiver has access to only categorical information in the word-recognition process, or whether continuous information is available. A third consideration is whether information from the continuously-varying signal is used on-line at the lexical stage of processing, or whether there is some delay in initiating processing of the signal at the lexical stage. A fourth characteristic involves parallel versus serial access to the lexical representations in memory. The final characteristic we will consider is whether the word-recognition process functions autonomously, or whether it is context-dependent. Figure 6 gives a graphical presentation of these characteristics.

### Logogen Model

Morton's logogen model (Morton, 1964, 1969) described for spoken-word recognition has also played an important role in the theoretical analysis of visual-word recognition. It is important to understand that the logogens could be activated by both auditory and visual words. Given that either auditory or visual words activate logogens, the description and evaluation of the model given in Chapter 19 applies directly to written-word recognition. (It might be worthwhile to review the section on word recognition at this time.)

The logogen model makes a strong prediction that once a logogen is activated, the consequences of that activation are independent of how the logogen was activated. Either stimulus information or context can push a logogen over the threshold, and the stimulus information could be auditory or visual. Winnick and Daniel (1970) tested this assumption in a test of visual-word recognition. Subjects were first primed with visual words, pictures, or definitions of the words, and asked to name each word. These same words were presented sometime later in a tachistoscopic

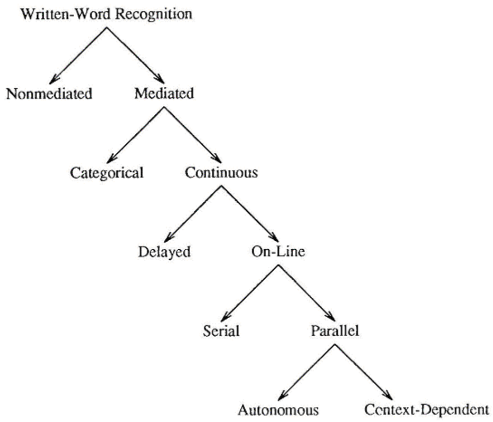


Figure 6. Tree of wisdom illustrating binary oppositions central to the differences among theories of written-word recognition.

identification task. Later identification of a written word was facilitated more when the word was presented in written form rather than in a picture or by a definition. These results parallel those discussed in Chapter 8, showing that the visual form of a word can contribute to its later identification. Morton (1979) replicated and extended these results, and now has revised the logogen model to include separate input logogens corresponding to the modality of the linguistic input.

**Cohort Model**

The cohort model might be extended to account for reading words. The most natural extension would assume that written words are recognized letter by letter in a left-to-right manner. In fact, Gough (1972) proposed exactly such a model, and this serial model is favored by Just and Carpenter (1987). For all of these models, a written word is recognized serially letter by letter from left to right during the word presentation. In addition, each of the models assumes that each letter of a word is recognized categorically. For the cohort model, word recognition occurs by way of the elimination of alternative word candidates (cohorts). Recognition of the first letter in the word eliminates all words that do not have that letter in initial position. Recognition of the second letter eliminates all of the remaining cohorts that do not have the second letter in second position. Recognition of letters and the elimination of alternative words continues in this fashion until only one word remains. It is at this point that the word is recognized.

**Activation-Verification Model**

A third model of word recognition is an activation-verification model (Becker, 1976; Paap, Newsome, McDonald, & Schvaneveldt, 1982). The model has three operations: encoding, verification, and decision. Figure 7 presents a schematic representation of the activation-verification model. Encoding refers to the initial processing of the visual information that activates letters and words. Verification is responsible for achieving a conscious recognition or a single lexical entry. The verification process is a serial-comparison between information made available by encoding and the set of candidate words generated during encoding. For each comparison, the output is positive or negative. If the match exceeds some criterion, then a word is recognized. Otherwise, the next word candidate is compared. The search is, therefore, self-terminating. Both semantic context and word frequency are assumed to contribute to the processing. Context constrains the candidate set that is verified, and word frequency influences the order of verification of the words in the candidate set.

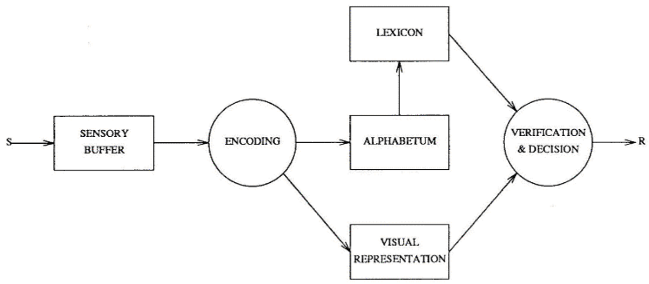


Figure 7. Illustration of the activation-verification model of written word recognition.

The activation-verification model can be described with respect to the five characteristics in Figure 8. The model is mediated, categorical, on-line, serial, and context-dependent. Written-word recognition is mediated by letter recognition, letters are recognized on-line categorically, final recognition of a word requires a serial search, and context can have an influence.

**Autonomous-Search Model**

An autonomous-search model of word recognition (Forster, 1979, 1981, 1985) is similar in many respects to the activation-verification model. Both models involve two stages--an initial access stage and a serial-search stage. In the autonomous-search model, the first stage in processing a written stimulus is in terms of recognizing the letters that make up a word. The abstract representation of this information serves as an access code to select some subset of the lexicon. The distinctive feature of this model is that words within this subset must be processed serially. The serial order of processing is determined by the frequency of occurrence of the words in the language. After making a match in the search stage of processing, a verification or post-search check is carried out against the full orthographic properties of the word. If a match is obtained at this stage, the relevant contents of the lexical entry are made available.

The autonomous-search model can be described with respect to the five characteristics in Figure 6. The model is mediated, categorical, on-line, serial, and is independent of context. Written-word recognition is mediated by letter recognition, letters are recognized on-line categorically, final recognition of a word requires a serial search. A critical feature of the autonomous-search model is that all of this processing occurs independently of context.

We limit the discussion to these four models because they differ from one another on the characteristics that we consider important to word recognition. Although these models have been studied and tested in a variety of tasks and domains, no definitive tests among the models has been carried out. We know, however, much about the answers to the questions illustrated in Figure 6. Readers have continuous information about written letters. Evidence presented in this chapter argues strongly in favor of letter information mediating word recognition; words are not recognized as unanalyzed wholes. Written words, as spoken words, are recognized on-line and alternative letter and word candidates appear to be accessed in parallel. With respect to the issue of context, we now discuss how sentential context and word information contribute to reading.

**Integrating Sentential Context**

Tulving, Mandler, and Baumal (1964) combined eight exposure durations with four sentential context lengths in a word-recognition task in which a tachistoscopic presentation of a word followed the reading of the sentence context. One of the 18 sentence contexts was Her closest relative was appointed as her legal ... The test word, which you may have guessed, was guardian. Subjects read either the last 0, 2, 4, or 8 words of the context part of the sentence, and the test word was presented at either 20, 40, 60, 80, 100, 120, or 140 msec. Subjects were instructed to write down the test word and to guess if they were not sure of their answer. They were told that the context words might be helpful in recognition of the test word.

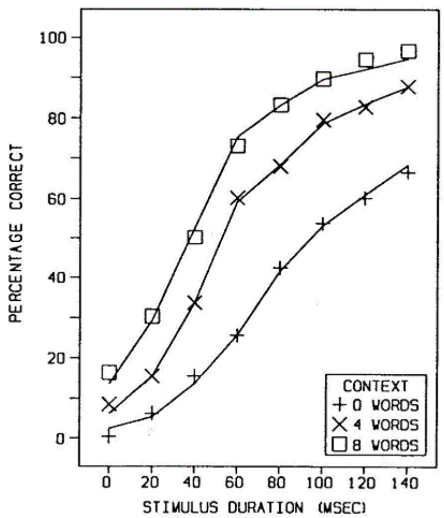


Figure 8. Observed (points) and predicted (lines) percentage correct identifications as a function of the stimulus duration of the test word and the number of context words (after Tulving et al., 1964).

Figure 8 presents the percentage of correct responses as a function of the duration of the test word; context length is the curve parameter. The context with two words is not presented since it produced results roughly identical to the context with four words. As expected, performance improved with increases in word duration and with increase in sentential context. The contribution of sentential context was larger when the exposure duration was intermediate and performance was neither very poor nor very good. This result indicates that context is most effective when subjects have some but not relatively complete stimulus information about the test word. This result is consistent with the FLMP in which the reader has partial information from both context and the stimulus. The reader has two sources of information about the test word: the visual information and the context. The reader evaluates both of these sources of information and integrates them to arrive at the amount of support for a particular word alternative. In fact, the FLMP gives a good quantitative description of the results as shown by the close match between the observations (points) and predictions (lines) in Figure 8.

Reading, like speech perception, is a form of pattern recognition. Visual features of the text and context contribute to the perception and comprehension of the passage. The information-processing framework allows us to break down these complex activities into component parts and to gain a better understanding how each part works. I hope the student has appreciated the value of the experimental method in the study of perception by taking seemingly intractable problems and opening them for objective analysis.