ORTHOGRAPHIC VARIATIONS AND VISUAL INFORMATION PROCESSING*

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Abstract. Based upon an analysis of how graphemic symbols are mapped onto spoken languages, three distinctive writing systems with three different relations between script and speech relationships are identified. They are logography, syllabary, and alphabet, developed sequentially in the history of mankind. It is noted that this trend of development seems to coincide with the trend of cognitive development of children. This coincidence may imply that different cognitive processes are required for achieving reading proficiency in different writing systems. The studies reviewed include experiments on visual scanning, visual lateralization, perceptual demands, word recognition, speech recoding, and sentence comprehension. Results from such comparisons of reading behaviors across different orthographies suggest that human visual information processing is indeed affected by orthographic variation, but only at the lower levels (data-driven, or bottom-up processes). With respect to the higher-level processing (concept-driven, or top-down processes), reading behavior seems to be immune to orthographic variations. Further analyses of segmentation in script as well as in speech reveal that every orthography transcribes sentences at the level of words and that the transcription is achieved in a morphemic way.

INTRODUCTION

Ever since Rozin, Poritsky, and Sotsky (1971) successfully taught a group of second-grade nonreaders in Philadelphia to read Chinese, the question has been repeatedly raised: If Johnny can't read, does that mean Johnny really can't read in general or Johnny just can't read English in particular? To the

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reading specialists, educational psychologists, and cognitive psychologists who are interested in the visual information processing of printed materials such a question is of practical as well as theoretical importance with respect to the understanding of reading behavior. At the practical level, is it true that some writing systems are easier to learn than others, and to what degree can dyslexia be avoided given that a certain type of writing system happens to be used for a certain type of spoken language? At the theoretical level, one must start to untangle the relations between script and speech by uncovering strategic differences at various levels of information processing (feature extraction, letter identification, word recognition, etc.) in the reading of different writing systems. These analyses may result in a new form of linguistic determinism (cf. Scribner & Cole, 1978; Tzeng & Hung, 1980).

It is conceivable that reading different scripts entails different processing strategies. Paivio (1971) has gathered much evidence that meanings of words and of pictures are retrieved via different routes. Thus, one may speculate that, depending on how spoken languages are represented by printed symbols, readers have to develop different processing strategies in order to achieve proficiency in reading. Failure to develop these strategies may result in a certain type of dyslexia that may be avoided when learning to read another script. For example, because of the close grapheme-sound relation, alphabetic script may require beginning readers to pay special attention to phonetic structure. Children who have not developed the appropriate "linguistic awareness" (Mattingly, 1972) of such a phonetic structure may become nonreaders. The same children, who are classified as dyslexic under an alphabetic system, may encounter no problem in learning to read a sign script such as Chinese logographs.

The idea of teaching the dyslexic to read Chinese is by no means new. According to Hinshelwood (1917), Bishop Harmon suggested that the ideal therapy for this disorder was to teach dyslexic children Chinese characters, because Chinese is a sign script where each word was its own symbol. The success of Rozin et al. (1971), though it has not gone uncriticized (Ferguson, 1975; Tzeng & Hung, 1980), undoubtedly reinforces this idea and seems to point to the possibility that dyslexia may not characterize visual-verbal association in general. Hence, for a general understanding of reading behavior, cross-language comparisons of visual information processing strategies should provide valuable clues to the underlying mechanisms and processes involved in reading.

We will critically review some recent studies pertinent to the issue of comparative reading. We will begin by discussing different orthographic rules for mapping written scripts onto speech in various languages. Then we will examine results of experiments that were conducted to find out whether these orthographic variations have any effect on visual information processing. Finally, we will draw some tenable conclusions about the relations between orthography and reading.

RELATIONS BETWEEN SCRIPT AND SPEECH

The relation between written scripts and spoken languages seems so close that one would expect that anyone who is able to speak should be able to read.
But this is simply not the case. For all normal children, learning spoken
language seems to require no special effort. From the time the child is able
to emit his first sound, he is tuned to engage actively in the language
acquisition game, and the process seems to be spontaneous. Some psycholinguists (e.g., McNeill, 1970) even suggest that the language acquisition device
is prewired biologically in our genetic program and that the language
environment serves as a stimulus releaser to allow this program to unfold.
Learning to read, on the contrary, requires a relatively long period of
special training and depends heavily on intelligence, motivation, and other
social-cultural factors. And even with so much effort directed toward the
acquisition of reading skills, not every child is blessed with the ability to
read.

There is a general consensus that written languages evolve much later
than spoken languages and that in some way the former are attempts to record
the latter. Increasingly complicated and sophisticated living experience
renders oral communication an unsatisfactory mediator for cultural and social
transmission. If one is able to transcribe spoken language visually into some
kind of graphic representation, then communication can overcome the limita-
tions of space and time that are usually imposed on the spoken sound. Since
there are many levels of representation of spoken language, the transcription
of spoken language into visual symbols can be achieved in many different ways.
If we look back at the history of mankind, we soon discover that the evolution
of writing systems proceeds in a certain direction. In a sense, the
transcription starts at the deepest level, the conceptual gist, and gradually
shifts outward to the surface level, the sounds. At each step, unique and
concrete ways of representing meaning give way to a smaller but more general
set of written symbols. In other words, writing efficiency is achieved by
sacrificing the more direct link to the underlying meaning; consequently, the
grapheme-meaning relation becomes more abstract.

Primitive men wrote (or more precisely, carved) on rocks, tortoise shell,
cave walls, and so on, to achieve some form of communication. These drawings
were usually pictures of objects that immediately evoked meaningful interpre-
tations. A general idea (sememe), rather than a sequence of words in a
sentence, was expressed via object drawing. Thus, semasiography writes
concepts directly without the mediation of spoken language. Archaeologists
have discovered these rock paintings and carved inscriptions in many parts of
the world (Asia, Europe, Africa, America, Australia Oceania). From them they
are able to reconstruct and speculate about the life styles of these early men
(Gelb, 1952). However, picture drawing as a communication tool has many
obvious difficulties. First of all, not everyone is capable of good drawing.
Second, it is difficult to draw pictures that express abstract concepts.
Third, different ways of arranging objects within a picture result in
different interpretations. Finally, an unambiguous picture (e.g., a map
telling the location of food resources) can be disadvantageous. Thus, new
systems had to be invented.

The next step is important and insightful and should be regarded as one
of the most important achievements in the history of mankind. Instead of
expressing a general idea by drawing a picture, symbols were then invented to
represent the spoken language directly. First, there were pictograms,
(e.g., 木 for tree), which were carried over from the previous stage of
picture drawing. Then, there were ideograms, which are frequently formed by putting several pictograms together to suggest an idea: for instance, putting two trees together side by side to mean GROVE ( 林 ) and stacking three trees together to mean FOREST ( 林 ). Thus, by the principle of metonymy, many ideograms were invented to represent ideas and feelings of various kinds.1

But even with this new invention, there were still difficulties in forming characters to represent abstract concepts. This need led to the invention of phonograms, which were typically made up of two or more components, one of which was used not for its semantic content but for its phonetic value. The reader gets a hint as to the character's meaning from the semantic component (called the signific) and to its sound from the phonetic component. With these three methods and the combination of them, a large number of characters may be created to represent all words used in the spoken language. This is exactly how the Chinese logographic system was formed (Wang, 1973). Some examples of the formation of pictograms and of phonograms in Chinese are illustrated in Figure 1. Similar principles were also used in ancient Egyptian hieroglyphics and hieratics (Gelb, 1952). For example, the cartouche (an oval or oblong figure) was used as a signific to enclose the syllabic spelling of a monarch's name. It should be noted at this point that once the concept of sound writing was conceived and appreciated, it immediately became a powerful tool for inventing new characters; it was so powerful that nowadays a majority of Chinese characters are phonograms (Wang, in press).

Chinese logographs actually map onto spoken language at the morphemic level. Such a one-to-one grapheme-morpheme relation in the logographic system requires that there must be distinctive characters corresponding to each morpheme. The inevitable consequence is that one has to memorize thousands of these distinctive characters before one is able to read. Furthermore, writing is tedious and slow. Printing and typing demand too much effort and time, and in an era of mechanization and computerization cries for change are echoed at every level of the Chinese scientific community. This is not the place to enter the debate for or against the character reform currently taking place in the People's Republic of China. Suffice it to say that the logographic script, with so close a grapheme-meaning relation, has its difficulties and is under a great deal of technological pressure. However, one should bear in mind that this does not mean that logographic scripts are in any sense less advanced than alphabetic scripts. Evolutionary fitness should be defined in terms of the particular environment. The intrinsic virtue of Chinese logographs cannot be outweighed by technological difficulties that may easily be overcome by further technological advancements. What we need to find out is how the logographic scripts affect reading behaviors.

We have already noted the power of representing sound. It takes only a small step to go from the rebus2 system to the syllabic system, in which every written symbol denotes a syllable in the spoken language. As we can see from cuneiform syllabaries, west Semitic syllabaries, Aegean syllabaries, and Japanese syllabaries, the design feature is a close symbol-sound relation. Thus, with a relatively small set of syllable-based symbols one can transcribe an infinite number of spoken sentences. An economy of writing is accomplished and the unit of written language coincides with that of the spoken language. However, there immediately arises the problem of homophones, which are indeed
Figure 1. (a) Examples of Chinese phonograms. In the upper panel, the character on the left-hand side is the base character and is pronounced as /wang/ (meaning KING). The three characters on the right are derivatives that contain the base character as a clue to their pronunciations. In fact, they are pronounced as /wäng/, /wäng/, and /wang/ from top to bottom, meaning THE BARKING SOUND OF DOGS (or alternatively, DEEP AND WIDE), NOT STRAIGHT, and PROSPERITY for the three characters, respectively. In the lower panel, the base character on the left is pronounced as /m̄a/. It means HORSE, and it is a pictogram by itself (see Wang, 1973). Similarly, the three derivative characters on the right are pronounced as /m̄a/, /m̄a/, and /m̄a/, meaning MOTHER, ANT, and TO SCOLD, respectively. Thus, if a reader knows how to pronounce the base characters, he can guess at the pronunciations of the derived phonograms that contain the base character as a partial component. However, one should be cautious in making generalizations because in many cases the base character only gives a clue to the sound of a particular phonogram (sometimes the clue refers only to the vowel ending) and the tonal patterns (,—,/,✓,/ ) are not included. (b) Examples of pictograms and their transformation through hundreds of years.
a nuisance even with the contextual cues provided in reading (Suzuki, 1963). This problem is best exemplified by the Japanese writing system, in which three different types of scripts, namely, kanji, katakana, and hiragana (four if we also count the Roman letters used in many modern Japanese texts, i.e., romaji), are concurrently used in order to overcome the difficulty of homophones. In the Japanese syllabary, the problem was resolved by retaining Chinese logographs, generally referred to as kanji, to be used as the content words. The kana script is a set of symbols representing the syllable sounds of the spoken language; thus, in principle, it can be used to write any word in the Japanese language. The kana script is subdivided into two types, hiragana script and katakana script. The former, a more cursive style, is the script used for writing the grammatical particles and function words; the latter is mainly used to write loan words (foreign words such as television). These three different scripts, kanji, hiragana, and katakana, are used concurrently in a text. Because they have different writing styles and serve different linguistic purposes, reading is probably facilitated by these distinctive visual cues. On the other hand, all the difficulties associated with the logographic script arise once again. It is no wonder that over the last 30 years, the Japanese government has been making every effort to eliminate Chinese characters in their writing system. However, the close grapheme-morpheme relation represented in a Chinese character has enough intrinsic value in facilitating visual reading that these attempts to abandon the Chinese characters have not been successful. Ironically, instead of reducing the number of characters, the Ministry of Education was recently forced to add five more characters to their allowable list.

For most of the Indo-European languages, the writing system patterned after the Greek system, and further evolved to an alphabetic system, with the number of written symbols further reduced. A full alphabet, marking vowel as well as consonant phonemes, developed over a period of about 200 years during the first millennium B.C. in Greece (Kroeber, 1948). The transition from the syllabic to the alphabetic system marks another gigantic jump with respect to the script-speech relation. The discovery of vowel letters, which form the basis of the analytical principle of an alphabetic system, has been characterized as something of an accident rather than a conscious insight (Gleitman & Rozin, 1977). As a sound-writing script, an alphabetic system maps onto speech at the level of the phoneme, a linguistic unit smaller than the syllable but larger than an articulatory feature. The problem of homophones was solved in some languages (e.g., English) by simultaneously taking into account the lexical root of each word. The consequence is that the grapheme-sound relation becomes somewhat opaque. As C. Chomsky points out, "English orthography represents linguistic knowledge on different levels. In particular, there is a phonological level and a morphological level. The same sound can often be represented by different letters. Which letters are chosen is then decided on a morphological basis; e.g., 'sign' could be spelled sign, syne, cyne, etc. If it relates to 'signature' in meaning, then its spelling must be sign" (1970). Thus, the grapheme-speech relation embedded in the English alphabetic system is characterized as a morphophonemic representation. As a consequence, English orthography is a phonologically deep writing system and the opaqueness of the link between English script and phonology has been seen by many as a barrier to acquisition. Not all alphabetic scripts have such a deep grapheme-phonology relation. For example, Serbo-Croatian, the major language of Yugoslavia, is written in a phonologically shallow
orthography with the simple rule: "Write as you speak and speak as it is written" (Lukatela, Popadic, Ognjenovic, & Turvey, 1980, p. 124).

There is an important contrast between logographic and alphabetic scripts with respect to how symbols are packed together to represent the spoken language graphically. For example, in English script, spaces are largely determined on the basis of words: "man," "gentleman," "gentlemanly," "ungentlemanly" and "ungentlemanliness" are each written as a single word even though the last contains five morphemes while the first contains only one. In Chinese script, on the other hand, the spacing is based on morphemes and each morpheme is in fact a syllable: a word like tricycle has three morphemes in Chinese (three-wheel-vehicle) and is therefore written with three characters and read with three distinctive syllables. Perceptually, the grapheme-sound mapping in Chinese is discrete (i.e., each character is also a syllable) while in English script the relation is continuous and at a more abstract level. This difference may have implications for the beginning readers of these two scripts. For Chinese children, the written array is dissected syllable by syllable and thus has a one-to-one correspondence with the syllables of the spoken language. On the other hand, because of the multilevel representation, a reader of English may have to go through a morphophonemic process in which words are first parsed into morphemes and then symbol-sound relations applied (Venezky, 1970). Furthermore, phonological rules are necessary in order to derive the phonetic form, e.g., to get /sain/ for sign. These processes seem very abstract and hence may be quite difficult for a beginning reader.

As we look back at these historical changes, we see that the evolution of writing seems to take a single direction: At every advance, the number of symbols in the script decreases and as a direct consequence the abstractness of the relation between script and speech increases. This pattern of development seems to parallel the general trend of cognitive development in children. Results from two independent lines of research are of particular interest. First, anthropological studies (Laboratory of Comparative Human Cognition, 1979) have shown that children's conceptualization of the printed arrays in a text proceeds from pictures, to ideas, to syllables, and finally, to WORDNESS. Second, according to E. Gibson (1977), one of the major trends in children's perceptual development is the increasing specificity of correspondence between what is perceived and the information in the stimuli. Similarly, a beginning reader progresses from the whole to the differentiation of the whole, and then to the synthesis of the parts to a more meaningful whole. In a sense, the ontogeny of cognitive behavior seems to recapitulate the evolutionary history of orthographies. This cannot be simply a biological coincidence (Gleitman & Rozin, 1977). Such parallelism implicates the importance of a match between the cognitive ability of the reader and the task demand imposed by the specific orthographic structure of the scripts. One is almost tempted to suggest that orthographic structure in a writing system must somehow mold the cognitive processes of its readers. In fact, it has been claimed that the processes involved in extracting meaning from a printed array depend to some degree on how the information is represented graphically (Besner & Coltheart, 1979; Brooks, 1977; Tzeng & Hung, in press). It is therefore conceivable that different cognitive strategies are required to achieve reading efficiency in various writing systems. One particular concern is whether these different cognitive requirements imposed by various script-
speech relations impose a permanent constraint on our visual information processing strategies, such that readers of different scripts learn to organize the visual world in radically different ways. Evidence for such a new "linguistic relativity" hypothesis can be found in papers discussing the "weak" version of the so-called Whorfian hypothesis (Tzeng & Hung, in press) and in recent ethnographic studies on the behavioral consequences of becoming literate in various types of Vai writing systems (Scribner & Cole, 1978). Cross-language and cross-writing system comparisons are certainly needed to help us answer this and other questions.

Curiously, there has never been a systematic attempt to investigate the effects of orthographic variations on visual information processing. Venezky (1980) characterizes such an absence of studies on orthographic structure as an unfortunate oversight in reading research. He attributes this absence of interest by psychologists in orthography in part to the lack of a linguistic base for describing different orthographic systems and in part to the fact that experimental psychologists in the past were not really interested in the problem of reading. Now the situation has been drastically changed. In 1979 and 1980, three big volumes of theoretical and experimental work on visual language (Kolers, Wrolstad, & Bouma, 1979), spelling (Frith, 1980), and orthography (Kavanagh & Venezky, 1980) were published. In addition, an anthology of experimental work on the perception of print is forthcoming (Tzeng & Singer, in press). It is time to have a critical look at the relation between orthography and visual information processing.

**EMPIRICAL DATA**

Several points should be clarified. First, although there are many types of alphabetic scripts (English, French, German, Russian, etc.), we will limit our discussion to the English alphabet, mainly because most of the comparative reading studies use English as the representative case. Occasionally, we may discuss other alphabetic scripts when they provide important contrasts to English orthography with respect to certain experimental paradigms. Second, and not unrelated to the first point, most comparative studies have employed the following research strategy: Data and models of processing English orthography are the basic reference points for evaluating data collected with analogous experimental paradigms in non-alphabetic orthographies. Third, the non-alphabetic orthographies here refer to Japanese syllabaries (i.e., kanji and kana) and Chinese logography unless otherwise specified. And finally, in the review itself we assume an information processing approach. That is to say, we first look at studies comparing visual scanning patterns, then at visual lateralization, at some perceptual phenomena such as the Stroop effect, at the issue of speech recoding, at word recognition, and finally, at sentence comprehension. The review is in no way exhaustive and is concerned only with empirical data rather than linguistic speculations.

**Visual Scanning**

On the surface, the most obvious difference between an English text and a Japanese or Chinese text is that the former is written from left to right and then line by line from top to bottom whereas the latter is usually written from top to bottom and then column by column from right to left. Considering
the fact that most people are right-handed (this is especially true in both China and Japan because of the social-cultural factor that stigmatizes left-handers) and that for right-handed people it is easier to write continuously from left to right, the development of a vertical and right-to-left text arrangement is certainly an unforgivable mistake. The inconvenience can be felt immediately if one attempts to write with a brush and ink. As soon as one moves to the next line, the finished but still wet characters on the right hand side tend to interfere with the current writing unless one consciously lifts the elbow and keeps it in the air all the time. (The ancient Chinese had a special way of training their scholars to be patient and poised.)

Putting aside this inconvenience in writing, is a vertical and right-to-left text easier to read? That is, do we have a natural tendency to scan downward during visual information processing? The anatomical arrangement and physiological structure of our eyes seem to suggest the opposite. Studies in perceptual development have generally found that infants engage in more horizontal than vertical scan (Salapatek, 1968). Moreover, with an equal number of nonsense geometrical figures arranged vertically or horizontally, it has been found that horizontal scanning is quicker than vertical scanning, and this result is observed for both American and Chinese elementary school children. One investigator attributes this difference to the possibility that vertical scanning may result in greater muscular strain as well as quicker fatigue (Tu, 1930). Similar results have also been obtained in Japan with tachistoscopic presentation and with reaction times as the dependent measure (Sakamoto & Makita, 1973). Thus, with respect to reading, there is no evidence suggesting any biological advantage to arranging written text vertically and leftward.3 The Chinese style has influenced Japanese and Korean text arrangement for centuries, and it is clear that such an arrangement is more a cultural convention than a biological consequence. It is not surprising that a shift toward left-to-right and downward printing has been made in many science texts in order to accommodate Arabic numerals and names of western authors, whose works are usually indexed in the original alphabetic script beside their translations. The readability of such texts seems not to be affected in any systematic way (Chang, 1942; Chen & Carr, 1926; Chou, 1929; Shen, 1927). Our eyes are really very versatile.

It should be pointed out that not all alphabetic scripts are written from left to right. For instance, Hebrew is usually written horizontally from right to left. In fact, in about A.D. 1500 as many scripts were written and read from right to left as from left to right (Corballis & Beale, 1971). Only with the expansion of European culture in later years did left-to-right scripts become predominant. Again, there is no evidence to suggest a biological predisposition for scanning in either direction. Bannatyne (1976) found that eye movement is generally random for 6-year-old or younger French children. However, with older subjects, the left-right eye movements become more or less regular and the regularity increases with the age of the subjects. Apparently, this regularity is a result of reading habit. The following example given by Dreyfuss and Fuller (1972) illustrates this point.

In South Africa, most of the men who work in the mines are illiterate. The miners, therefore, are given instructions and warning in the form of symbols rather than words. In an effort to enlist the miner's help in keeping mine tracks clear of rock, the
South African Chamber of Mines posted this pictorial message [See Figure 2]. But the campaign failed miserably, more and more rocks blocked the tracks. The reason was soon discovered. Miners were indeed reading the message, but from right to left. They obligingly dumped their rocks on the tracks. (1972, p. 79).

The title of this little example explains the notion very well—"LEFT AND RIGHT ARE IN THE EYES OF THE BEHOLDER."

Although reading direction is merely a learned habit, it seems to have a tremendous effect on the reader's perceptual performance. For example, in one type of speech perception experiment, a subject hears a click while listening to a recorded sentence and is asked to estimate the part of the sentence with which the click was simultaneously presented. With such an experimental paradigm, Fodor and Bever (1965) found incidentally that when the click location task was administered dichotically, the click was judged as coming earlier when it was delivered to the left ear and the speech to the right ear than with the opposite arrangement. Bertelson and Tisseyre (1975) replicated this finding. They conjecture that from the perspective of the subjects, the click is in fact perceived to the left of the sentence, which is presumably transformed into a left-to-right written array. Hence, when the subjects are asked to mark the location of the click on a response sheet, they tend to displace the mark toward the beginning of the sentence, owing to the spatial relation between the click and the sentence. Bertelson and Tisseyre further speculated that the opposite result should be found for Hebrew, which is written from right to left. Indeed, they found that Israeli students, when listening to Hebrew sentences in a similar click experiment, pre-posed the click when the speech was in the left ear and the click in the right ear more than in the opposite arrangement. Hence, the direction of the effect is inverted when a language that is written from right to left, namely Hebrew, is used in the test. A similar impact of learning to read materials written in different directions (i.e., right-to-left or left-to-right) was also demonstrated on children's visual exploratory patterns. Arrays of pictures of common objects were presented to children who were instructed to name all objects in each array. The exact order of the naming was recorded. While Elkind and Weiss (1967) found a developmental trend of left-to-right directionality in American children, Kugelmass and Lieblich (1979) showed a systematic appearance of a right-to-left directionality in Israeli and Arabic children. These findings are corroborated by Goodnow, Friedman, Bernbaum, and Lehman's (1973) demonstration of the effect of learning to write in English and Hebrew on the direction and sequence in copying geometric shapes.

There also has been some suggestion that the habit of reading direction (i.e., right-to-left vs. left-to-right) affects the pattern of the visual lateralization effect in a visual half-field experiment (Orbach, 1966). We will discuss this issue in more detail in the next section. We mention it here simply as a note on the effect of reading habit on subsequent visual information processing strategies.

We have seen that different arrangements of text in various scripts have a definite effect on reading behavior. In general, horizontal arrangement seems to be more natural from the viewpoint of anatomical arrangement of our eyes and more efficient for writing itself. However, since our eyes are so
Figure 2. LEFT AND RIGHT ARE IN THE EYES OF THE BEHOLDER (adopted from Dreyfuss & Fuller, 1972).
versatile and flexible, the issue of horizontal versus vertical arrangement may not be too critical. One thing is clear: Once children learn to read the standard style, the pattern of their eye movements becomes stabilized as a result of reading habit.

An important issue has been neglected in all these earlier studies of visual scanning. Very little information is available about the on-line processes during the reading of different orthographic scripts. Since the logographic, syllabic, and alphabetic scripts map onto their respective spoken languages at different levels (i.e., morphemes, syllables, and morphophonemes, respectively), it is important to know whether these orthographic variations affect eye fixation and eye scanning patterns during reading. Such cross-orthography studies of eye movements during reading will no doubt help to resolve one of the key controversies among contemporary investigators of eye movements, namely, the nature and degree of control of individual movements (Levy-Schoen & O'Regan, 1979). For instance, does a Japanese reader tend to skip hiragana symbols based on the knowledge that these cursive scripts usually represent functors in a sentence (as English readers tend to skip THE during reading)? How do Chinese readers compute successive saccadic jumps when word boundaries are not clearly specified in the logographic scripts? Immunity to the effect of such orthographic variations would lend support to the notion of autonomy—that the eyes move to their own rhythm, more or less inflexibly, and with little concern for local variation in the nature of the text. Hence, further research should be directed to basic questions such as the size of perceptual span in each fixation (Rayner, 1978), the number of eye fixations per line given an equivalent amount of information in different orthographies, the length of each fixation as a function of orthographic variations, developmental changes in the eye scanning patterns, and so on.

Neuroanatomical Localization

The human cerebral cortex is divided into left and right hemispheres, and presumably the two hemispheres function cooperatively in normal cognitive activities. However, the idea that these two hemispheres may assume different types of functions was suggested more than 100 years ago (Broca, 1861). Now it is common knowledge that the hemispheres are indeed not equivalent. Sperry, Gazzaniga, and Bogen's (1969) research on split-brain patients provides direct evidence of hemispheric specialization of cognitive function. In these patients, after cutting the corpus callosum (the communication channel between the two hemispheres), the two hemispheres are able to function separately and independently. Sperry et al. (1969) found that written and spoken English are processed in the left hemisphere, while the right hemisphere is superior in performing various visual and spatial tasks. The second line of evidence for this lateralization comes from studies of injuries to the left hemisphere caused by accidents, strokes, tumors, and certain illnesses. These injuries usually impair some language ability, with the kind and degree of the impairment depending on the site and severity of the injury (Lenneberg, 1967; Geschwind, 1970). Evidence for asymmetrically represented functions has also been found in behavioral research with normal subjects. Kimura (1973), for example, found in dichotic listening experiments that subjects were quicker and more accurate in identifying speech sounds transmitted directly (from the right ear via the crossed auditory pathways) to the left hemisphere. Similarly, in visual half-field experiments in which
words were tachistoscopically presented to either the left or the right of a central fixation point, Mishkin and Forgays (1952) found a differential accuracy of recognition, favoring words presented to the right of the fixation point. The last finding has been termed the "visual lateralization effect." It is interesting to note that under certain conditions the visual lateralization effect can also be demonstrated with Chinese-English bilinguals in cross-language testing situations (Hardyck, Tzeng, & Wang, 1977, 1978).

The general pattern that emerges from the results of the above research is the following. In nearly all right-handed individuals and many left-handers as well (Hardyck & Petrinovich, 1977) the left hemisphere is specialized for verbal cognition and memory, including language and most areas of mathematics. The right hemisphere is specialized for nonverbal cognition and memory, including spatial relations and imagery, but also music and other nonverbal sounds. Our concern here is not to review the findings and controversies concerning specialization. Rather, we want to point out that most of these findings came mainly from studies with English or other alphabetic systems. The question is whether orthographic variations make a difference, particularly with respect to data pertinent to reading rather than speech. Evidence has been presented that the nature of the reading impairment depends, in part, on the specific structure of the written language in question (Asayama, 1914). So, our review will focus on the cross-writing-system comparisons of brain-damaged patients and of the visual lateralization effect in normal subjects.

**Aphasic Studies in Japan.** The major work on the effects of brain lesions on reading Japanese syllabaries has been done by Sasanuma and her associates (Sasanuma, 1972, 1974a, 1974b, 1974c; Sasanuma & Fujimura, 1971). In an earlier review of the literature on reading disorders due to brain lesions in Japan, Beasly (cited in Geschwind, 1971) observed that comprehension of kana scripts is usually more severely affected than that of the kanji script, although the reverse occasionally occurs. Following the implications of this article, Sasanuma has carefully examined the characteristics of the aphasic's speech production and reception and their abilities in reading kana and kanji scripts during and after speech recovery. She reports some evidence for the selective impairment of reading kana and kanji scripts, as suggested by Beasly. Rather than postulating a right and left hemispheric specialization for processing kanji and kana (this dichotomy seems to be implied in Beasly's review), Sasanuma argues for differential disruption of language due to localized lesions in the left hemisphere. The primary difference between reading kana and kanji writings is the necessity of a phonological processor for kana, which is needed to mediate the grapheme-sound-meaning correspondence. It is interesting to note that a similar processor has been postulated for the reading of alphabetic scripts (Rozin et al., 1971). Therefore, Sasanuma's argument has potential for explaining characteristics of language processing beyond Japanese and deserves more careful examination.

Sasanuma has found that most of her patients can be categorized into one of four diagnostic patterns. About half of them had equal impairment for kana and kanji. Another 25% showed the overall symptomatology of Broca's aphasia. On a task that involved writing high-frequency words in kana and kanji, these patients made almost twice as many kana errors as kanji. When asked to write a sentence, they used only kanji characters and the sentence form was similar.
to the agrammatical speech of Broca's aphasia. This led Sasanuma to conclude that there was probably a correlation between the impairment of kana processing and an agrammatical tendency. A third group of patients (about 10%) also showed disruption of kana processing, but they differed from the last group in several important respects. In language ability, they were similar to patients with Wernicke's aphasia. A few were diagnosed as having conduction aphasia. These were fluent aphasics as opposed to the nonfluent aphasics with lesions in Broca's area. Their speech was fluently articulated but meaningless. It is also important to note that all patients with selective impairment of kana processing made errors that were phonological in nature. When writing kanji symbols, however, these patients made the same kind of errors as normal subjects—graphemic confusions (Sasanuma & Fujimura, 1971).

The converse was found in the final group of patients who performed better on tasks using kana than kanji. Unfortunately, Sasanuma (1974a) collected in-depth data on only one patient and gave no indication of the prevalence of the disorder. It is apparently a much less common form of aphasia. In writing high-frequency words in kana and kanji, this patient reproduced kana symbols perfectly while missing 80% of the kanji symbols. If he happened to write a kanji character, he used it as if it were a phonetic symbol, without regard for its meaning. Sasanuma classified this patient as belonging to the type of aphasia that has been labeled Gogi aphasia or semantic form aphasia (Imura, 1943) and is similar to the mixed form of transcortical aphasia. This type of patient often can read aloud and dictate in Kana symbols but without any comprehension.

Taken together, these findings would seem to indicate that kana and kanji processing represent distinctively different modes of operation in linguistic behavior. These clinical observations by Sasanuma and her associates are important and provide insights into the mechanisms underlying visual information processing of linguistic materials. Let us summarize these results with some cautious remarks.

1. Most of the aphasic cases reported by Sasanuma and her associates were caused by cerebrovascular accidents. Whenever possible, Sasanuma incorporated reports on neuroanatomical localization into the data. However, it is usually unclear just how precise the localization data are and how secure we can feel about the areas postulated in the aphasic syndromes found in these Japanese patients. Nevertheless, careful examinations of these syndromes and their related reading impairments suggest that these data are consistent with a general pattern of language-specific dyslexic effects reported in other languages (Vaid & Genesee, in press). In general, lesions in the temporal cortex are associated with greater impairment of reading and/or writing of scripts that are phonetically based (de Agostini, 1977; Hinshelwood, 1917; Luria, 1960; Peuser & Leischner, 1974/1980); lesions in the posterior, occipito-parietal cortical areas are associated with greater impairment in reading and/or writing of scripts with a logographic or irregular phonetic basis (Lyman, Kwan, & Chao, 1938; Newcombe, mentioned in Critchley, 1974).

2. There is an odd distribution of the aphasic syndromes, with only one patient with impaired use of kanji and many with impaired kana, which corroborates the disproportional pattern noted by Beasly (see Geschwind, 1971). Thus, the statement of "selective impairment of kana and kanji" may be
misleading. This extremely skewed distribution suggests a totally different interpretation. Rather than hypothesizing differentially localized structures for processing kana and kanji, it might be useful to look at differences in acquisition. One possibility is that kanji characters are difficult to learn and perhaps the long years of practice and special attention spent in learning these characters make them more resistant to loss after brain trauma. This interpretation is interesting but hard to verify empirically. A more attractive interpretation can be offered as follows. The two different pattern-analyzing skills (i.e., recognizing kanji vs. kana scripts) may be viewed as reflecting two different types of acquired knowledge, namely, knowing that versus knowing how. The former represents information that is data-based or declarative, whereas the latter represents information that is based on rules or procedures such as grapheme-sound correspondences (Kolers, 1979).

According to Mattingly (1972), operations with these two types of knowledge require two different levels of linguistic awareness. Whereas the realization of knowing that requires only a primary linguistic activity (or Level I ability in terms of Jensen's [1973] classification), the realization of knowing how requires a more abstract secondary linguistic activity (or Jensen's Level II ability). The imbalance between kanji and kana impairments observed in Japanese aphasics may be the result of differential difficulties related to the performance of these two levels of linguistic activities. The dissociation of knowing how from knowing that has recently been demonstrated in amnesic patients (Cohen & Squire, 1980).

3. When discussing the patients that approximate Broca's aphasia, Sasanuma observed a close relation between an agrammatical tendency in speech and an impairment in kana processing. Based upon this observation, she proposed a special phonetic processor and a syntactic processor and further assumed that these two processors were localized close to each other in the left hemisphere. Such a view of dual processors with differential cerebral localizations is suggestive but may be objected to on several grounds. First, that the majority of Sasanuma's aphasic patients were kana-dyslexic. No evidence was provided to show that the kanji-impaired patient was free from the agrammatical tendency. Thus, it is unfair to single out a kana processor. Second, linguistic variations such as kana and kanji scripts do not by themselves justify neurological differentiation unless evidence is provided that rules out other possible interpretations. Third, and more important, there is a more parsimonious explanation that requires no complication of neurological structure. Since the cursive hiragana scripts are used in Japanese writings mainly to represent grammatical morphemes, failure to read hiragana symbols leads directly to the disruption of syntactic structure. Therefore, the close relation between kana impairment and agrammatical tendency should be interpreted as the result of the special function served by kana scripts in Japanese writings.

4. Sasanuma and Fujimura (1971) have reported that Japanese aphasics with apraxia (an impairment of voluntary movement without obvious sensorimotor deficits) of speech perform less well certain tasks requiring visual recognition and writing of kana than do aphasics without apraxia, while the two groups perform comparable tasks with kanji about equally well. The finding that aphasics with apraxia of speech have special difficulty with kana but not kanji is important. Sasanuma and Fujimura (1971) offer the interpretation that apraxic patients have difficulty with the kana script because they cannot
bypass their damaged phonetics and phonology, as they can with kanji. But if the neurological mechanism that is responsible for phonetics and phonology is damaged, then these patients should also show deficiency in analyzing speech. Since these patients did not show any more difficulty in speech perception than the other patients, it is not very plausible to suggest that phonological impairment is responsible for their inability to read kana. Erickson, Mattingly, and Turvey (1977) provide an alternative interpretation. Suppose that it requires more subvocalization to read kana than to read kanji. The apraxic patients would have difficulty in reading kana because of the noise feedback resulting from the imperfect subvocalization. Evidence for more speech recoding activity in reading sound-based scripts such as alphabetic or syllabary scripts has recently been provided by Treiman, Baron, and Luk (1981).

Clinical observations are always very suggestive and should be regarded as a major part of scientific research. However, two apparent shortcomings cannot be avoided in this type of research and were not avoided in Sasanuma's. First of all, the number of cases involved in most clinical studies is usually small; thus, statistical evaluation is difficult. Second, the results are difficult to generalize to normal people. Most clinical observations are collected after the patient recovers from surgical operations. However, little is known about the plasticity of the brain except that reorganization and compensation do seem to occur (Hecaen & Albert, 1978, pp. 394-399). There is also evidence showing that a linguistic task can be accomplished by non-linguistic strategies (Hung, Tzeng, & Warren, in press). Hence, caution should be exercised in making inferences from the recovery patterns of the aphasic patients.

With these comments in mind, let us now turn to the experimental results on visual lateralization effects with normal subjects.

Visual Lateralization Effects. The rationale behind the visual half-field experiment is as follows. When a subject looks at a fixation point in the center of a lighted square within a tachistoscope, each visual half-field projects to the contralateral hemisphere. For example, stimuli presented to the right visual field (RVF) are first processed in the left hemisphere. If language is indeed processed in the left hemisphere, then verbal stimuli presented to the RVF should take less time to respond to than when the same materials are presented to the left visual field (LVF). The delay in reaction time is attributed to the need to transfer information from the right to the left hemisphere. The experimenter can also shorten the exposure duration so that subjects make identification errors. Depending upon the pattern of such an accuracy measure (i.e., RVF or LVF superiority) and upon the materials used, specific functions of the left and right hemispheres can be inferred. With these experimental procedures, most studies have found a RVF advantage for the recognition of English words. This finding is generally referred to as a visual lateralization effect.

Under the influence of Sasanuma's work, investigators have begun to study visual lateralization effects with kanji and kana scripts. When kana symbols are presented first to the LVF and then to the RVF, more errors in a recognition matching task are observed than when they are presented in the reverse order, indicating a left hemisphere superiority for processing kana
script (Hatta, 1976; Hirata & Osaka, 1967). This result is similar to those obtained with alphabetic writings. More recently, Hatta (1977) reported an experiment measuring recognition accuracy of kanji characters and found a LVF superiority for both high and low familiarity kanji characters, suggesting that kanji characters are processed in the right hemisphere. Using a similar experimental procedure, Sasanuma, Itoh, Mori, and Kobayashi (1977) presented kana and kanji words to normal subjects and found a significant RVF superiority for the recognition of kana words but a nonsignificant trend toward LVF superiority for kanji characters. Thus, it seems that for sound-based scripts such as English words and Japanese kana, a RVF-LH superiority effect is to be expected in a tachistoscopic recognition task, whereas a LVF-RH superiority effect is to be expected for the processing of logographic symbols.

The implication underlying this orthography-specific localization hypothesis is that a special phonemic processor is required for the grapheme-sound-meaning mapping in the lexical access of alphabetic and kana words. Although there is indeed evidence for the hemispheric specialization of speech perception (Cutting, 1974; Wood, Goff, & Day, 1971), generalization of such findings to explain the differences between reading logographic symbols and reading alphabetic/syllabic symbols may be misleading. There is now much evidence showing that reading logographic symbols also requires speech recoding under certain circumstances (Erickson et al., 1977; Tzeng, Hung, & Wang, 1977). Thus, the hemispheric difference found in the tachistoscopic recognition of kanji and kana (or alphabetic) symbols reflects, not an orthography-specific localization property but a task-specific property of cerebral hemispheric functioning. To support this claim, Tzeng, Hung, Cotton, and Wang (1979) asked Chinese subjects (all right-handed) to name tachistoscopically presented characters. In the first experiment, Chinese subjects were exposed to brief presentations of single characters in either the RVF or the LVF, and their task was to name the character as quickly as possible. The accuracy data reflected a LVF-RH superiority, replicating previous findings (Hatta, 1977; Sasanuma et al., 1977). Although the results of RH processing are clear cut, its implication for reading is less clear. Modern Chinese tends to be multiple-syllable, and so the perceptual unit in reading may be larger than single characters. Thus, a major task in reading is to generate meaning by putting together several characters to form meaningful terms. Recognition of single characters can be accomplished by non-linguistic strategies such as pattern match. Only in combining several morphemes to comprise a meaningful whole does reading require an analytic (linguistic) strategy.

In the second experiment of Tzeng et al. (1979), the stimuli were two characters arranged vertically, and the subjects were asked to name the stimuli (all meaningful terms) as quickly as possible. The procedure of the third experiment was similar to that of the second experiment except that the subjects' task was to decide whether these character strings as a whole were correct semantic terms. (This is a common lexical decision task, and the dependent measure was the reaction time required to make the decision.) A RVF-LH superiority effect was found in both the second and the third experiments. These differential visual lateralization results were difficult to reconcile with the location-specific hypothesis. However, these data are consistent with the view expressed by Patterson and Bradshaw (1975), who assume that the left hemisphere is specialized for sequential-analytic skills, whereas the
right hemisphere performs holistic-gestalt pattern matches. Thus, all these results should be interpreted as reflecting the function-specific properties of the two hemispheres (Patterson & Bradshaw, 1975); they cast doubt on the orthography-specific localization hypothesis proposed by previous investigators. Such a shift of visual lateralization is by no means a unique finding. In fact, Elman (Note 1) reports that even with single kanji characters, a shift from LVF-RH superiority to RVF-LH superiority was observed when the experimental task was changed from simple naming to syntactic categorization (i.e., deciding whether the presented character is a noun, verb, or adjective). A similar shift, though not very pronounced, was also observed in deaf subjects' perception of ASL (American Sign Language) signs (Poizner, Battison, & Lane, 1979). With statically presented signs, a LVF-RH superiority was found; whereas with moving signs, the deaf showed no lateral asymmetry. These latter stimuli included movements of the hands in straight lines; bending, opening, closing, wiggling, converging, linking, divergent, and others. These movements capture much of the significant variation of movement in ASL at the lexical level. Recognition of these movements depends on the ability to put several discrete signs together into a coherent moving sequence. Therefore, the shift from right dominance to a more balanced hemispheric involvement with the change from static to moving signs is consistent with the position that the left hemisphere predominates in the analysis of skilled motor sequencing (Kimura, 1976). It is worthwhile to point out that single ASL signs, like single Chinese characters, sometimes represent morphemes rather than words. In natural signing or in spoken Chinese a meaningful word frequently consists of two or more signs (or characters). The similarity between perceiving ASL signing and reading Chinese characters (despite other differences, cf. Klima & Bellugi, 1979) with respect to the visual lateralization effect strongly suggests that the idea of a left-hemisphere phonetic processor is not viable.

This argument against the orthography-specific localization hypothesis is further reinforced by the observation that procedural differences in a visual half-field experiment may result in either a RVF or LVF superiority effect in the tachistoscopic recognition of Hebrew words (note that Hebrew is an alphabetic script), depending on whether the stimulus words are presented successively in either visual field or simultaneously in both visual fields (Orbach, 1966). Habit of reading direction (right to left for Hebrew) becomes an important factor in this case (Heron, 1957). In fact, all these results are compatible with the substrata-factor theory of reading (Singer, 1962), which asserts that when a task cannot be solved at one level of cognitive operation, a reader may have to fall back on a more analytical mode, perhaps by switching from the right to the left hemisphere. Under this conceptualization, the interaction between orthography and information processing strategy as demonstrated here enables us to identify various subskills at different stages of information processing. The visual lateralization experiment may prove to be a useful technique for untangling this complexity (see Tzeng & Hung, 1980, for a demonstration).

So far, we have reviewed research on effects of orthographic variations on cerebral lateralization using two different approaches, namely, the brain lesion approach and the visual half-field experimental approach. The clinical and experimental studies found differences resulting from reading different scripts, and we have been critical of these findings. However, we do not wish...
to deny the existence of these differences. We only argue that these
differences can be explained by proposing two types of knowledge (knowing how
vs. knowing that) and by the general properties of cerebral organization,
without inventing special processors or proposing special locations.

**Stroop Interference Experiments**

In studies of the Stroop effect (Stroop, 1935), color names are written
in an ink of a different color (e.g., GREEN in red ink) and subjects are
required to name the color of the ink in which the word is written. In the
control condition, subjects name a series of different color patches. It is
an established fact that the time it takes to name a series of colors in the
test condition is much longer than the time it takes to name a series of color
patches in the control condition. Since the Stroop interference effect is
very robust and easy to demonstrate, the Stroop task and its variants have
been employed by researchers in various fields to investigate different
psychological processes, such as the parallel processing of verbal and
nonverbal materials (Keele, 1972), the nature of stimulus encoding in short­
term memory (Warren, 1972), the properties of bilingual processing (Dyer,
1971; Preston & Lambert, 1969), the automaticity of word recognition in
beginning reading (Samuels, 1976), and so on.

A recent study by Biederman and Tsao (1979) with an ingenious application
of the Stroop interference paradigm has shed light on the issue of
orthographic differences. They observed a greater interference effect for
Chinese subjects in a Chinese-version Stroop color-naming task than for
American subjects in an English version. They attributed this difference to
the possibility that there may be fundamental differences in the perceptual
demands of reading Chinese and English. Since, for Chinese characters, the
direct accessing of meaning from a pattern's configuration is a function that
has been assigned to the right hemisphere, which is also responsible for the
perception of color, the increased perceptual load would result in greater
interference. For English words, on the other hand, the word processing is
mainly a left hemisphere activity; less interference is expected. This study,
although intriguing, suffers from several methodological weaknesses. First,
there were tremendous subject differences in the reaction times required to
name the colors of simple color patches (for some unknown reason, the mean
reaction times of the Chinese subjects were relatively slow overall) and
differences in verbal ability (i.e., the Chinese subjects happened to be all
highly selected graduate students). Second, Chinese color terms are all
monosyllabic characters, but this was not true in the case of the English
version. Third, all Chinese subjects in the study should be considered semi­
bilingual whereas the American subjects were monolinguals. Although Biederman
and Tsao did try to rule out the first confounding factor by certain post­hoc
statistical analyses and the third confounding factor of bilingualism by
citing other bilingual Stroop data, we think that their results should be
replicated with a more general subject population.

Shimamura and Hunt (Note 2) and Biederman (personal communication)
independently ran the Stroop experiments with Japanese subjects naming the
color terms written either in kana or kanji (a within-subject factor). They
both found that the kanji version produced more interference than the kana
version. Since the same subjects took both the kanji and kana version, the
subject difference was avoided. The result is still consistent with that of Biederman and Tsao (1979). However, a possible flaw may exist in both studies. For fluent readers of Japanese, the color terms they read in everyday life are usually expressed in kanji script and rarely in kana. The greater interference observed for the kanji script may be attributable to this familiarity factor. To counter such an argument, both studies presented further evidence showing that in a simple word-naming experiment (naming words printed in black), color terms written in kana were actually named much faster than color terms written in kanji. Similar findings were reported by Feldman and Turvey (1980). So, although colors are more frequently written in the kanji form and although kanji are more compact graphic representations of words in general, naming time was consistently less for the kana. So far, so good. However, whether one may use naming latency data to resolve the controversy generated by the Stroop task is a question by itself. Since Stroop interference can be obtained in cases where no naming is required (Dyer, 1971), naming speed is hardly an important factor. Thus, although studies of both Biederman and Tsao (1979) and Shimamura and Hunt (Note 2) showed the effect of orthographic variation on the magnitude of Stroop interference, other uncontrolled factors made their data less convincing. Furthermore, with a pictorial variation of the Stroop task, in which subjects were asked to name the pictures as rapidly as possible and ignore the non-congruent words presented simultaneously with the pictures, Smith (Note 3) found no difference in the magnitude of interference between a Chinese version and an English version. This result is opposite to those from studies with colors. One thing that should be noted is that Smith employed multiple-character words, which are linguistically different from the morpheme-based single characters used in the color studies. With these ambiguities in mind, let us look at another set of Stroop studies.

In discussing their original finding, Biederman and Tsao (1979) further speculated that there may be some fundamental differences in the obligatory processing of Chinese and English print. They suggested that a reader of alphabetic writing cannot refrain from applying an abstract rule system to the word whereas a reader of Chinese may not be able to refrain from configurational processing of the logograph. Such a conceptualization—that reading different types of scripts may automatically activate different types of perceptual strategies—is intriguing. It leads to a unique prediction concerning bilingual processing in a modified Stroop task. Suppose a Spanish-English bilingual subject is asked to name the color in an English-version Stroop task either in English, the same language as the printed color terms (intra-language condition), or in Spanish, the language different from the printed color terms (inter-language condition). Based on previous empirical findings (Dyer, 1971; Preston & Lambert, 1969), one can predict that the Stroop interference effect should be reduced in the inter-language condition as compared with the intra-language condition. Suppose further that another group of Chinese-English bilinguals are asked to perform a similarly modified Stroop task either in an inter-language or an intra-language condition. Once again one would predict that the Stroop interference should be reduced in the inter-language as compared with the intra-language condition. Of particular interest is the comparison between the Spanish-English and the Chinese-English bilingual subjects with respect to the magnitude of the reduction of the Stroop interference from the intra-language to the inter-language condition. According to Biederman and Tsao's (1979) conjecture that reading alphabetic
and logographic scripts make different perceptual demands, one would predict that the magnitude of reduction should be greater for the Chinese-English bilinguals than for the Spanish-English bilinguals, because English and Spanish are both alphabetic scripts and presumably compete for the same perceptual mechanism (i.e., both would activate obligatorily the same perceptual mechanism for deciphering the alphabetic script). Fang, Tzeng, and Alva (in press) carried out exactly such a modified version of the bilingual Stroop experiment, and the results of their study showed that indeed the magnitude of reduction of the Stroop interference from the intra-language to the inter-language was much greater for the Chinese-English bilinguals than for the Spanish-English bilinguals. This seems to support Biederman and Tsoo's contention that reading alphabetic and logographic scripts make different perceptual demands.

Fang et al. (in press) also made an interesting observation. They recalculated from Dyer's (1971) and Preston and Lambert's (1969) bilingual data the magnitude of reduction of the Stroop interference from the intra- to the inter-language condition. All together, there were five types of bilingual subjects: Chinese-English, French-English, German-English, Hungarian-English, and Spanish-English. Fang et al. ranked these bilingual data according to the magnitude of reduction from the intra- to the inter-language condition. The result is as follows: Chinese-English (a reduction of 213 msec), Hungarian-English (112 msec), Spanish-English (68 msec), German-English (36 msec), French-English (33 msec). The ordering of the last three categories is particularly revealing. Why should switching between Spanish and English produce a greater reduction of interference than that between French and English or that between German and English? It is certainly not intuitively obvious why Spanish and English are more orthographically dissimilar than French and English (or German and English). However, if we examine the spellings of color terms across these languages, then the deviation of Spanish becomes immediately clear. For example, red, blue, green, and brown (these colors were used in all these experiments) are translated and spelled as rot, blau, grün, and braun in German; as rouge, bleu, vert, and brun in French; but as rojo, azul, verde, and cafe, respectively, in Spanish. Clearly, with respect to the color terms used in all these studies, Spanish color terms are orthographically more dissimilar to English color terms than both French and German. Correspondingly, the data showed a greater reduction of Stroop interference. The pattern suggests that the magnitude of reduction is a negative function of the orthographic similarity between the two languages involved in the task.

However, since orthographic similarity is highly correlated with phonetic similarity, an alternative explanation for the data is to attribute the effect of switching language to the phonetic factor instead of the orthographic factor. Even though these two explanations are not necessarily mutually exclusive, it is important to determine which factor (orthographic vs. phonetic) contributes more to the reduction of the Stroop interference. To answer this question, Fang et al. ran a similar language-switching experiment with Japanese-English bilinguals. In this case, the pronunciation of the color terms was the same for kanji and kana symbols. If the phonetic factor is responsible for the reduction, then little difference in the magnitude of reduction should be observed between the kanji-English switching condition and the kana-English switching condition. On the other hand, if the orthographic
factor alone can effectively account for the differential reduction, then the magnitude of reduction should be significantly greater for the kanji-English condition than for the kana-English condition. The results of Fang et al. showed that, even with the phonetic factor controlled, the reduction was still greater in the kanji-English switching than in the kana-English switching. Thus, we may conclude that orthographic structure does play an important role, independent of phonological factors, in the lexical access of a bilingual subject.

From the viewpoint of cross-language research, the demonstration of differential perceptual demands in processing different orthographies is an important step toward a general theory of visual information processing. It leads to a host of more intricate questions to be answered. For example, what are these perceptual demands? Do they represent the activation of different knowledge structures (procedural vs. declarative), as speculated in the previous section? Do these differences result in different types of dyslexia? Do they necessitate different instructional strategies for teaching different scripts to beginning readers? To readers learning a second language? Furthermore, does the difference in orthographies (e.g., Chinese-English vs. Spanish-English) also result in different lexical organization? These questions can be answered only by reading research with rigorous experimentation and sophisticated statistical-analytical procedures. Ultimately, we would like to be able to relate the depth of the orthographic structure to the formation of the lexicon in a literate person (either monolingual or bilingual).

Phonetic Recoding in Reading Different Orthographies

Fluent readers can read faster than they can talk, but the opposite is usually true for a child who has just started to learn to read, because the child has to sound out every word in order to get at the meaning. At what point during the process of acquiring reading skills does the transformation of visual code into speech code (a process generally referred to as phonetic recoding) become automatic or even unnecessary (the latter view has been generally referred to as the direct access hypothesis)? The choice between the phonetic recoding hypothesis and the direct access hypothesis has been and still is one of the most controversial subjects of debate in reading research. Experimental data in orthographies other than English are particularly relevant here because of their unique grapheme-meaning mapping rules. For example, the possibility of reading Chinese, in which the logograms do not specify the sound of the word, has been taken as evidence to support the direct access hypothesis. However, a growing number of recent experiments has cast doubt on this general impression of reading Chinese (e.g., Tzeng & Hung, 1980). Let us examine this issue of phonetic recoding versus direct access more carefully with respect to available comparative data.

The idea that readers convert the graphemic representation of printed words into a speech-related code can be traced to the proposal of the subvocalization hypothesis. In its extreme form, this hypothesis asserts that readers must convert the written form into subvocal speech and that, in a sense, reading is no more than listening to oneself. Although there is evidence supporting this hypothesis (Hardyck & Petrinovich, 1970), a moment's reflection suggests it can easily be refuted on both logical and empirical
grounds. For one thing, it asserts that a fluent reader can never read faster than he can talk. This we already know is not true. Second, Rohrman and Gough (1967) and Sabol and DeRosa (1976) have shown that subjects can gain access to a word in the mental lexicon in less than 200 msec, whereas naming a three-letter word requires approximately 525 msec (Cosky, 1975). Thus, it is absurd to assert that readers have to wait to receive subvocal information before they gain access to the lexical memory of words.

The phonetic recoding hypothesis differs from the subvocalization hypothesis in that the grapheme–speech conversion is at a more abstract level, thus avoiding the tedious motor process of vocalization. There is a great deal of evidence that phonetic information is often used during the decoding of written English. In the early 60's, researchers on memory accumulated much evidence suggesting that phonetic recoding occurs in processing verbal materials even if they are presented visually (Conrad, 1964). These experiments generally found that confusion in short-term memory is more often due to phonetic similarity between the to-be-remembered and the interpolated items than to visual or semantic similarity. Analysis of the kinds of errors the subjects make suggests that a grapheme–speech code conversion occurs and that this speech code is phonetic in nature (Baddeley & Hitch, 1974).

Another source of evidence for the phonetic recoding hypothesis is work by Corcoran (1967) and others who have demonstrated that spelling errors resulting in a letter string that is pronounced like a word go undetected more often than errors leading to letter strings that do not sound like words. Similar results were obtained by MacKay (1972) with a different experimental paradigm. These investigators have taken these data to suggest that the reader has translated the printed words into a phonetic representation that corresponds to an entry in his mental lexicon such that the spelling errors go undetected.

Considerable evidence has been accumulated that shows a syllable effect in reading-related tasks: disyllabic or multisyllabic words are named more slowly than monosyllabic words; same/different judgments are slower for multiple-syllable than single syllable items, and letter detection is more accurate in monosyllabic than disyllabic words (see Massaro, 1975, for a general review). Since the syllable effect is obtained for words equated for visual length, the effect can be taken to indicate translation into a phonetic form during the visual recognition process. However, one should take extreme caution in interpreting results of a naming task. At least two processes should be distinguished: (1) visual recognition and (2) articulating the response. A syllable effect can be localized in either process, but our theoretical interest is in only the first, since our concern is really with how speech is used to gain access to meaning during the initial contact with print. An experiment that demonstrated the syllable effect without the contamination of the naming process (Pynte, 1974) is particularly revealing in this connection. Pynte found that French people gazed longer at two-digit numbers whose names contained more syllables (e.g., 82 is pronounced as quatre-vingt deux, with four syllables) than at those whose names contained fewer syllables (e.g., 28 is pronounced as vingt huit, with only two syllables). The syllable effect observed in reading numbers is important because Arabic numerals are logographic symbols and it has been assumed that reading logographic scripts does not engage any phonetic recoding. Apparently, this assumption is not valid.
Experiments using lexical decision tasks provide a fourth source of evidence in favor of the phonetic recoding hypothesis. Rubenstein, Lewis, and Rubenstein (1971) presented letter strings to their subjects and simply asked whether or not each letter string was an English word. They found that subjects took considerably longer to reject pseudowords that are homophonous with (sound like) real English words (e.g., brane) and that nonpronounceable items (e.g., saam) were rejected most rapidly. In another experiment, these investigators also found slower positive responses for words that are homophonous in nature, such as yoke-yolk and sale-sail than for control words such as moth. Meyer and his associates (Meyer & Ruddy, Note 4; Meyer, Schvaneveldt, & Ruddy, 1974) have replicated and extended these findings to experimental situations involving lexical judgments of pairs of letter strings.

In summary, a number of experiments using a variety of techniques have produced evidence that the phonological structure of a word affects its visual processing. This evidence is consistent with a phonetic recoding hypothesis. However, the seemingly clear picture becomes muddied when we begin to examine other sets of experimental results, which support the direct access hypothesis, that readers are able to go directly from the graphemic representation of the printed word to the lexical representation in their mental dictionary.

First, Baron (1973) demonstrated that subjects had no more difficulty in deciding that a phrase was nonsense when it sounded sensible than when it did not. For example, they could classify the phrase, TIE THE NOT, as nonsense, as quickly as the phrase, I AM KILL. According to the phonetic recoding hypothesis, one would have expected the phonemic correctness of the first phrase to slow down rejection time if phonetic translation had indeed occurred. But this expectation was clearly not confirmed. Second, Bower (1970) asked speakers of Greek to read passages containing misspellings that were pronounced exactly the same as the correct spellings. This was accomplished by interchanging vowels that were pronounced identically but spelled differently. The Greek readers were considerably slowed down by this visual distortion, suggesting that their normal reading must be via some route disrupted by the visual change. Obviously, the grapheme to phoneme route was still available and undistorted (though it was less familiar), indicating that it was not the only route used during rapid reading. Third, Davelaar, Coltheart, Besner, and Jonasson (1978) have shown a dependence of the homophone effect on the exact items used in the lexical decision judgments. In their experiment, Davelaar et al. included one comparison (MOTH vs. YOKE) under Rubenstein et al. conditions, with nonwords like SLINT. The result showed a reliable slower response time for YOKE than that for MOTH (628 vs. 606 msec). When the experiment was changed slightly by including nonwords (like BRANE) that were homophonous with real words, the previous difference in response time between YOKE and MOTH (600 vs. 596 msec, respectively) went away. The conclusion seems clear: an optional, not compulsory, speech-based process is involved in lexical access and the subjects can bypass it when the task demands make it a poor strategy.

A final but perhaps the strongest set of evidence against the phonetic recoding hypothesis comes from an experiment conducted by Kleiman (1975). Kleiman presented subjects with a pair of words and asked them to make one of three types of judgments: (a) graphemic similarity, (b) phonemic similarity, and (c) semantic similarity (synonymity). On some trials the subjects were
also required to "shadow" a series of digits heard through an earphone while performing the judgment task. On other trials they performed only the judgment task. Kleiman found that prevention of phonemic translation had little effect on graphemic and semantic judgments as compared with performance on phonemic judgment. Since semantic judgment required access to meaning, this result suggests that meaning access does not depend on grapheme-phoneme conversion.

We have seen evidence for and against the phonetic recoding hypothesis with respect to the reading of alphabetic materials. What about parallel lines of research in reading logographic materials? In fact, supporters of the direct access hypothesis have always used the example of reading Chinese logographs to reinforce their argument. The argument goes like this: Since Chinese logographs do not contain information about pronunciation, people must be able to read without speech recoding. This statement is not exactly correct. First of all, the majority of Chinese logographs are phonograms that at times do give clues to the pronunciation of the character (the efficiency coefficient for correctly predicting pronunciation of a phonogram from its constituent sound component is estimated to be .36, see Tzeng & Hung, 1980). Second, reading should not be equated with lexical access of a single word; rather, it should be regarded as a more general linguistic activity that involves all sorts of subcomponent activities such as iconic scanning and storage, lexical retrieval, short-term memory, syntactic parsing at both the macro- and micro-levels (Kintsch & Van Dijk, 1978), and semantic integration (Bransford & Franks, 1971). This kind of conceptualization immediately questions the validity of the view that reading logographic script such as Chinese involves no grapheme-phoneme translation. Such translation may not be necessary at the entry of the lexicon, but it may very well occur during the short-term memory stage or the syntactic parsing stage.

Tzeng et al. (1977) carried out two experiments to investigate whether phonemic similarity affects the visual information processing of Chinese characters. The first experiment employed a retroactive interference paradigm introduced by Wickelgren (1965). Chinese subjects were asked to memorize a list of four unrelated characters presented visually followed by the shadowing of a series of aurally presented characters that were phonemically similar or dissimilar to the target characters. The results showed a tremendous amount of intralist and interlist interference due to phonemic similarity. This is consistent with the experimental results in English (Conrad, 1964; Kintsch & Buschke, 1969; Wickelgren, 1965). Furthermore, vowel similarity produced more interference than did consonant similarity. This finding is consistent with previous experiments by Crowder (1971) with alphabetic materials and a very different experimental procedure. In their second experiment, Tzeng et al. extended the finding of such a phonemic similarity effect to a sentence judgment task. The experimental task required subjects to judge whether a singly presented sentence was a normal sentence or an anomalous sentence. Normal sentences were both grammatical and meaningful whereas anomalous sentences were both ungrammatical and relatively meaningless. The major independent variable was the degree of phonemic similarity among the characters that made up the sentences; the dependent measure was the reaction time required for making a correct judgment. The results clearly showed that performance in such a sentence judgment task was impaired by the introduction of phonemic similarity into the test material. Erickson et al. (1977) also
demonstrated the effect of phonemic similarity with Japanese subjects memorizing a list of kanji characters.

In another experiment, Tzeng and Hung (1980) asked Chinese subjects to read a section of prose containing about 1500 characters and concurrently circle all characters containing certain graphemic components such as  \( \hat{\sigma} \) or  \( \vec{\sigma} \). These two graphemic components sometimes are used to construct phonograms but sometimes they have nothing to do with the pronunciation of the entire character. For example, the pronunciation of  \( \hat{\sigma} \), /tai/ is based on the sound of  \( \hat{\sigma} \), /tai/ while that of  \( \vec{\sigma} \), /\i/ is not, even though both characters contain the same graphemic component  \( \hat{\sigma} \) on the right-hand side. It was found that subjects detected more characters in which the designated graphemic component carried a phonetic clue. This result is similar to Corcoran and Weening's (1968) finding that when English-reading subjects are asked to perform a similar task, they detect the embedded letter more often when it is sounded than when it is silent. One may argue that since the findings reported by Tzeng and his associates were obtained with Chinese students who are to some extent bilinguals, the results may be attributed to their having been exposed to alphabetic materials. This argument was weakened by a recent study with Chinese children who had just started to learn Chinese characters. Chu-Chang and Loritz (1977) found that in a Chinese character recognition task, where a tachistoscopically presented character list was followed by a list consisting of corresponding phonological, visual, and semantic distracting characters, the children responded predominantly to phonological distractors.

To explore further the contrast between processing logographic and alphabetic scripts with respect to the issue of phonetic recoding, Tzeng and Hung (1980) ran an experiment similar to that of Kleiman (1975). They asked Chinese subjects to make one of four types of judgments about two simultaneously presented characters that were flashed very briefly in the tachistoscope: (a) graphemic similarity (share an identical radical), (b) phonemic similarity (rhyme with each other), (c) semantic similarity (synonymity), and (d) sentence anomaly (grammaticality of a sentence). Again, on some trials subjects were concurrently engaged in a digit shadowing task while performing the decision task and on other trials they were not. Tzeng and Hung found that the phonemic decision was seriously affected by the shadowing task, whereas both the graphemic and semantic decisions seemed to suffer only from general disruption caused by the shadowing task. The authors concluded, like Kleiman with his data on English, that lexical retrieval of single characters does not require any grapheme-phoneme translation. Of particular interest was the result of the sentence-judgment condition. It was found that sentence judgment was also affected greatly by the shadowing task, suggesting a performance impairment caused by the prevention of the grapheme-phoneme conversion.

One implication to be drawn from all these findings is that phonetic mediation is just one of the strategies for obtaining access to meaning, rather than an obligatory stage. The use of phonetic recoding may depend on such factors as the difficulty of the materials and the reader's purpose (e.g., whether he wishes to commit the material to memory). Hence, Tzeng et al. (1977) concluded: "There are at least two major ways in which phonetic recoding is claimed as an important process in reading. First, in blending
the individual letters of words, the phonetic recoding of the individual letter sound can plausibly be argued as an important intervening stage, at least for children learning to read. A second way in which phonetic recoding may be involved in reading is concerned with the question of whether fluent adult readers need to phonetically recode printed material or are assisted by doing so. In this latter view the phonetic recoding is viewed as a general strategy of human information processing, and thus the orthographic difference in the printed materials becomes less important" (p. 629). The view that the role of speech in lexical access changes with increasing experience in reading was confirmed in a developmental study by Barron and Baron (1977). They reasoned that at the beginning stage of reading, children may need to sound out words in order to match them with the only lexical system they have at the time, a lexical system organized by speech; however, as fluency develops, direct connections emerge between the printed words and their meaning, resulting in a visually-organized lexicon. Barron and Baron's experimental results were consistent with such a dual-lexicon hypothesis. This tendency of shifting from a speech-based lexicon to a visually based lexicon seems to be a universal phenomenon of fluent reading behavior. Based upon clinical observations of Japanese aphasic patients, Asayama (1914) suggested that the "sensory-acoustic" center of the cerebral cortex plays a major role in the initial learning of kanji because it is not acquired ostensively but rather by way of the oral Japanese translation. With practice and experience, the significance of this center diminishes until, finally, associations between the "optic center" and the "concept center" can take place directly without involvement of the sensory-acoustic center. Thus, a general principle seems to hold for fluent readers regardless of whether the scripts contain sound-based symbols or morpheme-based logographs—a speech code may not be necessary for lexical access, but it is certainly useful for short-term memory. This conclusion is similar to the one reached by Liberman, Liberman, Mattingly, and Shankweiler (1980), that the requirement of a phonetically based working memory for linguistic comprehension should be a universal phenomenon.

Before we leave the debate on the phonetic recoding hypothesis versus the direct access hypothesis, let us remember Campbell and Stanley's (1963) admonition about opposing theories. "When one finds...that competent observers advocate strongly divergent points of view, it seems likely on a priori grounds that both have observed something valid about the natural situation. The stronger the controversy, the more likely this is" (p. 3). Campbell and Stanley's observation certainly applies to the phonetic recoding versus direct access issue in reading.

Given the possibility of two different paths leading from the print to the two lexicons (speech-based or visually based), the existence of some speech recoding activities is no longer in doubt. The question now facing us is when they are used. What factors encourage their use and what factors discourage it? Undoubtedly, study of the different forms of script-speech relation—Chinese logographs, Japanese syllabaries, vowel-free Hebrew, and so on—should reveal further constraints upon possible patterns of speech recoding during reading. For example, English and Chinese writings differ along an important dimension: the extent to which one can predict sound from the printed array. It is quite possible that differences in orthographies along this dimension affect the use of speech recoding in silent reading. If the written forms on the page stand in a regular relation to the sounds of
language, readers may use the grapheme-sound rules to help them derive the meanings of words. Such a path would be largely unavailable to the readers of Chinese but would be highly available to English readers. Therefore, one may expect readers of English to engage in speech recoding more than would Chinese readers. A recent experiment comparing the degrees of speech recoding between Chinese and English readers confirmed this expectation (Treiman et al., 1981).

One can push the argument even further and make the claim that in an alphabetic script where the prediction of sound from letters alone is always valid (i.e., a perfect spelling-to-sound regularity), readers may automatically activate the phonological route to the lexicon. Experiments with a phonologically shallow orthography such as Serbo-Croatian (the major language of Yugoslavia, which can be written in either Roman or Cyrillic) have consistently demonstrated that lexical decision proceeds with reference to the phonology (Lukatela et al., 1980). Most important, these investigators found that even when matters were arranged so as to make the use of a phonological code punitive in accessing the lexicon, readers of Serbo-Croatian were unable to suppress the phonological code. This result is directly opposite to that obtained with English. Davelaar et al. (1978) found that under similar arrangements, readers of English abandoned the phonological route and opted for direct visual access to the lexicon. Thus, in a less shallow orthography such as English, reading may proceed simultaneously at several levels of linguistic analysis. The concept of depth with respect to the orthographic structure seems to be a useful construct in evaluating the issue of speech recoding.

From the above discussions, there is an interesting speculation to be made. In between Serbo-Croatian orthographies, which have excellent letter-sound correspondences, and Chinese logography, which has only very fuzzy sound clues, we have other orthographies such as English, which are phonologically deep and thus are graphemically and phonemically opaque. According to Baron and Strawson's (1976) classification of Phoenician (those who attend to the phonetic aspects) and Chinese (those who attend to the visual aspect) readers, one should expect that fluent readers of Serbo-Croatian are disproportionately Phoenician and fluent readers of logography are disproportionately Chinese. For fluent readers of English the proportions of Phoenician and Chinese should be roughly equal with a tendency of being skewing toward becoming more and more Phoenician (Lukatela et al., 1980). It seems that the development of coding options and the development of meta-cognitive ability in order to optimize certain coding strategies relative to appropriate linguistic contexts are essential for becoming skilled readers of a phonologically deeper orthography such as English. Here is an area in which comparative reading studies across different orthographies can yield important information.

Word Recognition

The processes by which words are recognized in isolation have occupied the attention of many experimental psychologists over the last hundred years. Research in this area has made significant contributions to our understanding of pattern recognition, memory structure, the relation between speech and reading, and cognitive functioning in general. However, cross-language studies, especially cross-writing-system comparisons of word recognition processes, are very much needed. The reason is simple and straightforward.
Different orthographic structures exhibit different script-speech relationships, and perceptual pathways leading from print to meaning seem to be constrained by these differences, as shown by different degrees of speech recoding activity and different patterns of Stroop interference. It should also be pointed out that current models of word recognition such as Morton's (1969) logogen model and the spreading activation model of Collins and Loftus (1975) make the assumption that orthographic information is contained in semantic memory. This assumption was verified in a recent study by Seidenberg and Tanenhaus (1979) by the demonstration that the orthographic code is readily available even in an auditory word recognition task. They showed that in a listening experiment, subjects were markedly slower in deciding that "rye" and "tie" rhyme than that "pie" and "tie" do. Thus, by examining factors that affect word recognition in different writing systems we should be in a better position to specify the nature of logogens in our semantic memory.

In general, it seems that similar factors affect recognition of logographic characters and of alphabetic words. Solomon and Postman (1952) demonstrated that in English the recognition threshold for high-frequency words is lower than for low-frequency words. Other variables that also influence word recognition include meaningfulness (Broadbent, 1967), imagery, and concreteness (Paivio, 1971), with higher value in these dimensions being associated with lower thresholds. In Chinese, these same variables also show similar effects on character recognition. Yeh and Liu (1972) demonstrated the effects of frequency and meaningfulness on the recognition threshold. The effectiveness of imagery and concreteness were substantiated by the experimental work of Huang and Liu (1978). One interesting observation should be noted here. In English, word length has been found to be a negative function of frequency of usage and this has been referred to as one type of Zipf's law. The same observation seems to hold in the case of Chinese characters. Thus, whereas the average word length in English is about five to six letters, the average number of strokes in common Chinese characters is about six (Wang, 1973). In both cases, the graphemic development seems to favor the direction of perceptual ease and production economy. In another interesting study, Nelson and Ladar (1976) selected randomly a list of characters from norms of scaled meaningfulness in Taiwan (Liu & Chuang, 1970) and asked Canadian college students who had no experience with Chinese to rate these characters for their visual meaningfulness. The result showed that the amount of perceptual information in these characters as conveyed to those English-speaking observers correlated significantly with the index of associative meaningfulness for Chinese-speaking individuals. Similar studies were also carried out by Koriat and Levy (1979) who showed that Israeli students noncognate of Chinese were able to correctly guess the meanings of Chinese logographs with better than chance success.

Psychological studies such as these can yield insights as to how characters evolve through the years. In order for such a correlation to hold, one has to assume that, on the one hand, high frequency of usage has forced simplification of the characters and, on the other hand, the graphemic simplification and formalization process is constrained by universal perceptual-motor factors. The first assumption is easy to defend, but the second assumption deserves critical analysis. In a recent study, Tzeng, Malley, Hung, and Dreher (Note 5) demonstrated that even in simple drawings of common objects, such as a coffee cup, people tend to exhibit the history of their
interaction with the object. For example, most people draw a coffee cup with a handle on the right-hand side because that is the way they usually hold the cup. The argument advanced by Tzeng et al. is that graphemic information is subject to certain perceptual-motor constraints. If such is the case, then visual recognition of Chinese characters may be aided by such constraints, just as the Canadian and Israeli students are able to gather some meaningful information from the graphemic information alone. All these results suggest that choice of orthographic code to designate concepts is not arbitrary but is rather governed by lawful, cross-culturally consistent, figural-semantic associations (Koriat & Levy, 1979).

Another important research topic in current word recognition studies concerns the issue of the so-called word superiority effect (WSE). Almost a hundred years ago, Cattell (1886) discovered that with very brief exposures a letter can be reported more accurately when it is embedded in a word than when it is presented alone. Since then, this WSE has been repeated and confirmed. Reicher (1969) performed an experiment that rules out a simple guessing theory. Immediately after exposure of a stimulus word, Reicher tested one critical letter position with a forced choice between two alternative letters (e.g., a choice between "D" and "K" after the word "WORD"). The key to the experiment is that both critical letter alternatives always made a word in the context of the other stimulus letters (e.g., "WORD" and "WORK"); in fact, each letter alternative was equally likely to appear in the presented context. To measure the WSE, the same critical letter was presented in an unrelated letter string (e.g., "RWOD") again, followed by a forced choice between "D" and "K" as alternative last letters. Reicher (1969) found that performance for a letter in a word was substantially higher than for a letter in an unrelated letter string, and indeed higher than for a single letter presented alone.

A number of investigators soon pointed out that a modified version of the sophisticated guessing theory could be formulated to account for the WSE obtained with Reicher's paradigm (for a review, see Johnston, in press). Experiment after experiment was conducted to set up the parametric boundary of this effect. In fact, the WSE has become one of the most important experimental paradigms in evaluating theories of word recognition. It is not our intent to review all the theories and models constructed to explain this effect; but we would like to highlight two contrasting views of the WSE and review a study of this effect with kana symbols that helps to clarify these two contrasting views.

One important observation on the WSE is that the superiority effect is not restricted to meaningful words. It can readily be demonstrated with pseudowords that follow the orthographic regularities of English spelling. Since orthographic regularity is correlated highly with pronounceability, the observed superiority effect has usually been attributed either to the orthographical regularity of the letter groups (e.g., Massaro, 1975) or to their syllabic nature (Spoehr & Smith, 1975). The latter view is called the vocalic center group (VCG) hypothesis, according to which a syllable-like structure is the perceptual unit for word recognition. The reason for the superiority in the perception of words and pseudowords is that the perceived letter strings are readily parsed into VCGs.
The VCG hypothesis has recently been challenged by a study in Japan (Miura, 1978) that demonstrated a WSE with kana script using Reicher's experimental paradigm. Since each kana symbol has an invariant one-syllable pronunciation, the superiority effect obtained cannot be attributed to the advantage of parsing into a VCG. Actually, a VCG model would predict that word and nonword recognition accuracy should be the same and should be lower than for the single kana symbol. The results were just the opposite of these predictions. Miura therefore suggested that a model based upon orthographic regularities may be a better candidate for the interpretation of the WSE. Unfortunately, no corresponding experiment on the WSE has been run with Chinese logographs. It would be extremely interesting to make such a cross-orthography comparison. We mentioned that the WSE could be obtained with pseudowords. One could make counterfeit Chinese characters and see if the WSE still occurred for Chinese readers. Maybe the locus of the WSE lies neither in the speech pathway nor in the visual pathway to the lexicon but in the memorability of a more abstract and integrated code, as recently suggested by Johnston (in press).

In recent experimental work with English materials there is another interesting finding: For English-speaking subjects, written words are named markedly faster than pictures of common objects but are classified by meaning (semantic categorization task) more slowly than pictures (Potter & Faulconer, 1975). The difference cannot be readily explained by uncertainty as to the name of a pictured object or by features that allow pictures to be classified without full recognition. The general pattern of these results suggests that a picture of an object and its written English name ultimately activate in memory one and the same concept or meaning, accounting for the near equality for pictures and words in classification time. A word, however, appears to activate an articulatory mechanism before activating its concept, so that written words can be named rapidly. For a pictured object, access to the articulatory mechanism is apparently indirect; the object's concept must be activated first and then the associated name retrieved, so that naming is slow. Thus, the status of words and the status of pictures are experimentally differentiated.

One challenging question has always been raised with respect to the recognition of Chinese logograms: Is the recognition process more similar to picture perception or to word recognition? This distinction is similar to Huttenlocher's (1975) distinction between "reference-field schema" and "symbol schema" and has been shown to be linguistically meaningful in differentiating sign language from spoken language. Many linguists and reading specialists (Gibson & Levin, 1975) have speculated that Chinese logograms are similar to pictures and different from English words in three respects: They are graphically unified, they may represent features of their reference directly (e.g., the trunk and branches of a tree make up the character for wood, 木), and they do not represent the component sounds of their spoken names. On the other hand, logograms are also like written English words and different from pictures in that they, as symbol schemata, relate to the reference field only indirectly through encoding and decoding processes. Thus, a comparison with picture perception may indicate whether the pictorial properties of Chinese characters or their status as words determines how they are processed. If processing Chinese logograms is more like picture perception, then one would expect that Potter and Faulconer's (1975) experimental procedures would yield
smaller differences between logograms and pictures in naming and classification tasks for Chinese readers, compared with the pattern obtained with English readers.

Two experiments were carried out by So, Potter, and Friedman (Note 6) on the time it takes Chinese subjects to name logograms and to classify them according to meaning. For the purpose of cross-language comparison, they also reran the experiments with English subjects naming or classifying pictures and words. The results showed that in English as well as in Chinese, written words are named faster than pictures. The magnitude of the difference is almost identical in both languages. So, contrary to the speculation that written Chinese is harder to pronounce and easier to understand than written English, both languages are very similar in the processing of information. This finding for Chinese and English suggests that in any language there is a direct link between a written word and its spoken name, even when the writing system does not represent the component sounds of words.

The question of whether Chinese logographs are processed like pictures was also tested with a picture-word interference paradigm (Smith, Note 3). In a pictorial variation of the Stroop task, subjects are presented with a series of line drawings, each containing a noncongruent word. For example, a drawing of a chair may contain the word "hat." Subjects are asked to name the pictures as rapidly as possible, ignoring the words. Typically, the presence of an incongruent word results in considerably slower naming time compared with a control condition in which pictures are presented without words (Rosinski, Gollinkoff, & Kukish, 1975). Smith (Note 3) reasoned that if Chinese words are processed like pictures, then more interference should be observed with Chinese readers than with French readers in a similar picture-word interference task. Her results were negative, suggesting that words written with Chinese characters are no more processed like picture than words written with alphabetic scripts.

According to the logogen model (Morton, 1969) and the semantic-network model (Collins & Loftus, 1975) of word recognition, the linguistic unit with which the logogen or concept is concerned is, roughly, a word. We have mentioned that a single Chinese character should not always be equated with a word. For example, the English word library is written as a three-character compound, 学 檔, in Chinese. Thus, the word is a more abstract code, compared with a single character. It is no wonder that at the level of the word, the logogen should be independent of the orthographic factor. Factors such as frequency of usage, imagery, meaningfulness, and concreteness are concerned with the logogen itself. So these factors should have similar effects on words written in different orthographies. Only factors that specifically concern the connection between print and the logogen should show differential effects on word recognition in different orthographies. Besner and Coltheart (1979) asked their subjects to choose the larger number from a pair of digit numbers printed in different sizes, and found that subjects' choice reaction times were subject to the interference of size-incongruency (e.g., when the symbol for 6 was much larger than that for 9) only when the numbers were presented in Arabic numerals (i.e., logographic symbols) but not when they were presented as spelled-out English words (i.e., SIX vs. NINE). Apparently, different mechanisms are involved in making the connection between print and the logogen in these two cases. So, with respect to results of
different types of experiments on word recognition, the conclusion to be drawn is that at the level of the word, the orthographic variation does not seem to matter much. At the level of words, script and speech converge on an amodal linguistic entity.

Sentence Comprehension

We have reviewed so far the effects of orthographic variations on visual information processing from the most superficial level of eye scanning to the deeper level of word processing. We have found that processing differences for different writing systems seem to occur at the lower level, with little difference beyond the level of the word. Our attention will now shift to sentence processing. Ordinarily, real-life reading involves comprehension of individual sentences as well as integration of semantic contents across paragraphs within a text. We would not expect to find any processing difference due to different orthographies at such higher level processing. Although there have not been many studies on this issue, our general impression based on currently available data is that similarity seems to be the rule across different orthographies.

Just and Carpenter (1975) employed the picture-sentence verification paradigm to examine sentence comprehension in Chinese, Norwegian, and English. This experimental paradigm was first established by Clark and Chase (1972), who asked their subjects to decide whether a sentence was true or false according to an accompanying picture. For example, if a sentence is IT'S TRUE THAT THE DOTS ARE RED and the picture is of red dots, subjects' response should be "Yes," and this sentence is classified as a true affirmative (TA) sentence. If the picture shown is of black dots, then subjects would respond "no," and the sentence is a false affirmative (FA) sentence. There are also negative sentences. For instance, if the sentence is IT'S TRUE THAT THE DOTS ARE NOT RED and the picture is of black dots, then this is a true negative sentence (TN) and subjects' response should be "yes." Again, if the picture is red and the subjects' response should be "no," the sentence is a false negative (FN) sentence. Based upon an analysis of the verification process in each case, Clark and Chase (1972) were able to predict that the verification times for the four types of sentences should be ranked as TA<FA<FN<TN.

Carpenter and Just (1975) further elaborated and modified the Clark and Chase (1972) model and developed the so-called constituent model of sentence verification. This model assumes that all internal representations, whether of pictures or sentences, are propositional. The verification processes start at the most inward constituent propositions. For example, the TA sentence can be represented as \{AFF(RED,DOTS)\}. Since the picture is also represented as (RED,DOT), the time it takes to compare the sentence with the picture should be the quickest because of the direct match (the time required to do the comparison is called \(k\) units of time). Whenever corresponding constituents from the sentence and picture representations mismatch, the comparison process is reinitiated, so the total number of comparison operations, and consequently the total latency, increase with the number of mismatches. Accordingly, the time it takes for the verification of FA sentences will be \(k+1\) since an additional mismatch has been found. The FN sentence is represented as \{NEG(RED,DOTS)\}, which results in two additional mismatches; thus it should take \(k+2\) units time to verify. The propositional representation for a TN
sentence is \{NEG(RED,DOTS)\} but the picture is represented as (BLACK,DOTS). Therefore, three additional steps are required in this case in order to be able to verify the sentence; consequently it takes \(k+3\) units of time. (For detailed analysis of these verification times, see Carpenter & Just, 1975.) This model predicts beautifully the sentence verification times for these four types of sentences.

With this experimental paradigm, Carpenter and Just (1975) ran two cross-language experiments and fitted their model to the data. In their first experiment, they used Chinese subjects and all sentences were written in Chinese. They found a remarkable similarity between sentence verification processes in Chinese and English even though word boundaries are clearly defined by spacing in printed English sentences but not in printed Chinese sentences. The time per constituent comparison (i.e., \(k\)), 210 msec for Chinese sentences, is very close to the 200 msec for English. Thus, processing rates and modes of processing are similar even though these two languages come from very different language families and even though these two writing systems represent their respective spoken languages at very different levels.

In Carpenter and Just's second experiment, the same procedures were used to test Norwegian subjects with sentences written in Norwegian. One complication was added: a quantifier variable was included. For example, the sentence was IT'S TRUE THAT MANY (or A FEW) OF THE DOTS ARE RED. They found that mean latencies increased with the number of constituent comparisons for both kinds of quantifiers. The processing time per operation was slightly longer in Norwegian (322 msec in the first block of testing and 278 msec in the second and third blocks), compared with those of English and Chinese (200 msec and 210 msec, respectively). However, there were fewer practice trials and sentences and pictures were more complex in this experiment.

Overall, there seems to be considerable universality in the underlying mental operations across three languages. It is of particular interest that the time for each additional retrieval and comparison in this type of task is very close to the duration of the scanning and comparing operation (240 msec) found by Sternberg (1969) in a context recall experiment. This suggests that a common fundamental operation underlies different tasks, across different languages. It is worthwhile to mention that in a recent study with a similar sentence-picture verification paradigm, Hung, Tzeng, and Warren (in press) found that deaf subjects engaged identical schemes to process signed sentences. Such commonalities point toward an explanation of language universals through the discovery of processing universals.

The experiments just mentioned have monolingual subjects processing sentences written in their own languages. What would happen if bilinguals were to read materials written in mixed languages? Do they use a dual linguistic system or a single cognitive system but with specific linguistic information stored at some points? Tsao (1973) used Chinese-English bilingual subjects to study this issue. He employed Bransford and Franks' (1971) experimental paradigm to investigate the abstraction and integration of ideas across sentences when sentences were presented all in Chinese or all in English (the single-language condition), or half in Chinese and half in English (the mixed-language condition). Subjects were asked to remember
either the gist of the sentence or both the gist and the language in which the sentence was written. Tsao found that linguistic integration occurs across different languages. He also found that subjects could discriminate between old and new sentences in the single-language condition and between old and translated old sentences in the mixed-language conditions. So, he suggested that some information about language and about what idea occurred in what language was retained.

In his second experiment, Tsao employed Kintsch and Monk's (1972) paradigm to study the storage of sentence information presented in different languages. Again, Chinese-English bilinguals were the subjects. The results showed that it took longer for subjects to read mixed-language paragraphs than the single-language paragraphs. However, after the subjects comprehended the paragraph, the reaction time for answering inferential questions concerning the contents of the paragraph they had just read was the same for both mixed-language and single-language conditions. In other words, after the sentences are comprehended and the semantic contents are stored away in a core code or system, subjects have free access to this information and can convert the information into any form of language in which they are required to respond. Tsao concluded that the underlying representation of information from connected discourse is propositional; verbatim details may well be retained but they do not influence the process of reasoning and decision-making.

In sum, from both sentence verification and sentence integration experiments, we may conclude that higher level processing is not affected by variations in orthographies.

SUMMARY AND CONCLUSION

There is an inseparable relation between written language and spoken language—they both are essential communication tools in human societies and to some extent the former is parasitic on the latter. There are many writing systems for many different languages. Essentially, they can be divided into three categories based upon their various grapheme-meaning relations: logographic, syllabic, and alphabetic. We have reviewed most of the major experimental work done with these different types of orthographies and have compared the similarities and differences between them in terms of a visual information processing framework. We have found that indeed in lower level processing, different orthographic symbols were processed differently in terms of visual scanning, perceptual demands, involvement of different pathways between print and meaning, and cerebral lateralization functions. However, when we consider visual information processing at the higher levels, we find no difference with respect to word recognition, working memory strategies, inferences, and comprehension. This evidence suggests that reading is a universal phenomenon, a culture-free cognitive activity, once people in different language systems have acquired the ability to decipher the written symbols. Thus, Gibson and Levin (1975) aptly describe the state of affairs as follows:

The findings do not mean that the process of reading is not influenced by the nature of the different writing systems, but that the outcomes are alike. It seems reasonable that different writing
systems which relate to language at different levels will involve
attention to and abstraction of different aspects of the orthograph-
ic system. Readers of a syllabary must search for invariances at
one level, readers of an alphabetic system, at another level. But
the skilled readers of one system are able to read as efficiently as
skilled readers of another. (p. 165).

These statements have been supported by the present review, which has
indicated that while reading behavior at the macro level seems not to be
affected by orthographic variations, the information processing strategies at
the perceptual level are affected by how meaning is represented in the printed
symbols. Given such differences in the bottom-up processes required in
transforming the visual-spatial arrays into meaning units, beginning readers
of different writing systems apparently face different learning tasks when
they are taught how to decipher printed symbols. The match between the task
demands imposed by various writing systems and the developing cognitive
structure of the beginning reader is an essential factor for success in such
learning.

The three major writing systems reviewed assume three different types of
script-speech relations. Chinese logography represents speech at the level of
the morpheme rather than the word, so that each logogram stands for the smallest
type of meaningful unit and hence its form remains constant regardless of
syntactic structure. That is, grammatical marking elements, such as tense,
plural, gender, and so on, are introduced by adding other morpheme characters
rather than by modifying the form of a particular character. For example, in
Chinese logographs, go, went, and gone are expressed by exactly the same
character ( 
) and both ox and oxen are expressed by the single character
( 
). This perceptual constancy provides a certain advantage over those
writing systems, such as the English alphabet, that require the marking of
grammatical inflections at the word level. Thus, a reader learning a
logographic system may have initial success as long as the characters to be
learned are distinctively different; but as more characters are introduced,
there are bound to be similarities to the previously learned characters (after
all, the number of basic strokes in Chinese character formation is only
eight). Then, whatever cues the young reader was using tend to fail,
confusion sets in, and learning is disrupted until other memory strategies are
acquired (Samuels, 1976).

The syllabary represents speech at the level of the syllable, a much more
easily segmental unit than the phoneme, with a reduced set of symbols. For a
beginning reader, the match between symbol and perceived sound segment makes
the translation of visual arrays into speech code an easy task. The concept
of mapping the secondary linguistic activity (reading) onto the primary
linguistic activity (speech) can be acquired earlier through direct perceptual-
associative links. However, the initial success of learning a syllabary
starts to collapse as soon as more lexical items are learned and the problem
of homophones sets in, and confusions over segmentation (examples in English
would be to-get-her vs. to-get-her; a-muse vs. a-m-use) pile up during ordinary
reading (Suzuki, 1963). Special processing strategies are required, with
great demands on the reader for the linguistic parsing of a syllabary text
Finally, an alphabetic writing system represents speech at the morphophonemic level such that the grapheme-sound-meaning relation is more or less opaque, requiring a more analytical processing strategy to unpack the meaning encoded in words, which are composed of a further reduced set of symbols. The abstractness of such a multilevel representation may be optimal for fluent readers (Chomsky & Halle, 1968), but it poses a great deal of difficulty for those beginning readers whose cognitive ability has not achieved the level necessary for extracting the orthographic regularities embedded in the written words. Liberman, Shankweiler, Liberman, Fowler, and Fischer (1977) reported a high correlation between children's reading ability and phoneme segmentation performance. They carried out a longitudinal study with nursery-school, kindergarten, and first-grade children and found that when children of all ages were asked to identify the number of phonetic segments in spoken utterances, none of the 4-year olds could segment by phoneme whereas nearly half (46%) could segment by syllable. At age 6, 70% succeeded in phoneme segmentation while 90% were successful in syllable segmentation. They then tested the same children at the beginning of the second school year and found that half of the children in the lowest third of the class on a reading achievement test had failed the phoneme segmentation task the previous June. On the other hand, all the children who passed the phoneme segmentation task scored in the top third on the reading achievement test. They concluded that the ability to break down the spoken utterance into its components is crucial to reading acquisition. Mattingly (1972) proposed that development of competence in reading requires that the internal structure of one's language be made explicit. "Linguistic awareness" refers to the individual's conscious knowledge of the types and levels of linguistic structures that characterize the spoken utterance. A beginning reader has to know the spelling-to-sound rules of English in order to recognize an old word, and a mature reader uses these rules to assign a pronunciation to a printed word that he has not seen before. The critical role of Mattingly's "linguistic awareness" in learning to read has been supported by several recent reading studies in English, which has a phonologically deep orthographic structure (Liberman et al., 1977; Liberman & Shankweiler, 1979), and in Serbo-Croatian, which has a phonologically shallow orthography (Lukatela & Turvey, 1980).

A critical question that deals directly with the relation between orthography and reading should be raised at this point: What aspects of sentences in spoken language do different orthographies attempt to transcribe? The traditional classification of orthographies into logographic, syllabary, and alphabetic modes seems to imply that each mode transcribes sentences in radically different ways (but see Mattingly, Note 7). However, from our review of the literature, the generalization seems to be that all orthographies attempt to transcribe sentences at the level of words and, furthermore, the transcription of words is morphemic in nature. This point seems unnecessarily obvious in Chinese logography. The morphophonemic character of an alphabetic orthography is also obvious in the case of a language with a relatively "deep" phonology, such as English or French. An example of such representation can be seen in the transcription of the words heal, health, healthy (Chomsky & Halle, 1968). Mattingly (Note 7) has convincingly demonstrated that the same morphophonemic principle holds for orthographies with shallow phonology, such as Vietnamese and Serbo-Croatian, as well as for syllabary orthography, such as Japanese. This characterization of orthography suggests that in the actual process of reading, the analysis of a sentence
begins with its lexical content and not with its phonetic representation, since neither Chinese nor English transcribes words in phonetic forms. In fact, in sentence processing, regardless of the type of orthography, phonetic representation is used for the purpose of refreshing the information in short-term memory, especially when the material is difficult (Hardyck & Petrinovich, 1970; Tzeng et al., 1977). This conceptualization is consistent with the observation that differences due to orthographic variation in the visual processing of print occur only before but not after word recognition.

Given this argument that all orthographies attempt to transcribe sentences at the word level, the next question is whether different ways of achieving such a transcription also create different pathways between print and the lexicon. The answer is positive and at least two pathways can be readily identified. The phonologically based route represents a procedure or rule learning of knowing how and the visually based route represents an associative learning of knowing that. These two types of knowledge may have different neurological realizations (Cohen & Squire, 1980). In principle, different dyslexic patterns (Marshall & Newcombe, 1973) may result from the selective impairment of these two pathways or their combinations. However, experimental data together with clinical observations are very much needed to support all these arguments. Aphasic studies across different orthographies would certainly reveal important details about these different pathways.

Another question that needs to be answered is whether there is an optimal orthography for the purpose of reading. Anthropologists are generally sensitive to such a question, since it may imply a linguistic chauvinism—the belief that one's own orthography is the best of all possible orthographies. But the arguments advanced about written languages should be carefully distinguished from those concerning spoken language. In speech, moving our tongues and maneuvering air through our supralaryngeal tracts are no more foreign to us than programming our arms to move, wave, grasp, or make gestures. Using written languages, on the other hand, requires the utilization of something external to us: conventional notational systems invented by human beings. Changes in spoken language follow a more or less universal principle of biological evolution whereas maintenance or change in written languages is usually by sociocultural and cognitive factors, which may sometimes be as arbitrary as a dictator's decision. The apparent heterogeneity of orthographies may also imply inequality in the ease of achieving reading efficiency. It is therefore legitimate as well as important to raise the question about criteria of an optimal orthography, with or without respect to different spoken languages. No answer can be provided here. However, clues for a plausible answer may be obtained in Wang (in press).

One thing is sure: We cannot study a writing system without also considering the spoken language it attempts to transcribe. From history we learn that the development of a particular writing system is always constrained by the linguistic properties of its corresponding spoken language. The fact that the Chinese writing system adopts a logographic system and stops at the morphosyllabic level reflects the monosyllabic nature of its morphemes and the lack of morphological inflection. When the Japanese borrowed Chinese characters to transcribe their spoken language, additional symbols were required to represent grammatical inflections. Hence, Japanese scholars of those early days had to take some Chinese characters apart and derive from
them the sound symbols, namely, the kana syllable elements (Wang, in press). But due to the simplicity of the syllabic structure and the limited number of syllables in their spoken language (no more than 90 different syllables are used; hence, the problem of homophones), the Japanese adopted both syllabary and logographic scripts. For Koreans, who also borrowed Chinese characters to transcribe their spoken language, the writing system had to go one more step to the level of alphabet in order to meet the perceptual demands imposed by its much richer syllable structure (Martin, 1972).

From these examples, one can see that the relation between script and speech in any language exhibits a principle of mutual compatibility. That is, the relation suggests that through writing, properties of substance (meaning) and surface (script) enter into invariant combinations (at the level of words) to comprise a speech-relevant description of the semantic intents. In other words, when we read an array of graphemic symbols, we not only register the physical properties (shape, length, width, space, etc.) of the print, but also perceive the unique, abstract properties of speech that are afforded (supported or furnished) by this particular type of script. Such a complementarity of the script and the speech is best captured by the notion of affordance proposed by Gibson (1977). Thus, in this sense, no writing system should be claimed to be more advanced than others. The principle of mutual compatibility also implies that successful reading depends on the maturation and the awareness of one's own spoken language (Mattingly, 1972).

Man stands alone in history as the sole creature on earth who invents written symbols and who also benefits from these symbols. Since these new symbols are to some extent arbitrary inventions external to our organismic structure, both accommodation and assimilation processes must have worked at their extremes in order for us to achieve efficiency in manipulating them. It took a span of many thousand years for our ancestors to come up with a system that works for a particular language and it takes a great deal of effort on the part of a modern learner to become a fluent reader. The diversity of writing systems provides excellent opportunities for investigators of human cognition to examine how children of different languages adjust themselves to meet various task demands imposed by different orthographies. Once we understand something about the kind of advantage or disadvantage that a certain type of orthographic representation can bestow, we would be in a better position to understand how man can come to invent them. Once we are able to understand the script-speech relations in various writing systems and find out effects of such orthographic variations on our reading behaviors, we would be in a better position to "unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history" (Huey 1908/1968, p. 6).

REFERENCE NOTES

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FOOTNOTES

1 Examples of such ideograms during the early development of written scripts can be found in many different parts of the world. Huey (1908/1968), in his monumental book on reading, gives many excellent examples to illustrate the principle of metonymy. For those researchers who are interested in the issue of metaphor, these ancient ideograms and the rules behind their formations can be a very useful resource for discovering how people use metaphors.
A representation of word or phrase by pictures that suggest how it is said in the spoken language, e.g., 🌸 🍃 for idea. The rebus system is a hybrid of picture and sound representations.

There is, however, some experimental evidence suggesting that the rate of reading English may be limited by the reader's horizontal eye movements. With a method of RSVP (Rapid serial visual presentation), Potter, Kroll, and Harris (1980) demonstrate that when eye movements are not required, readers are able to comprehend text presented as rapidly as 12 wps (word per second), more than twice as fast as people normally read. Interestingly, reading in a RSVP manner is highly similar to the way a Chinese reader reads a vertically arranged text. Results of these RSVP studies suggest that there may be some yet-to-be-discovered advantages of the Chinese way, after all.

The term lateralization refers to the specialization of the left and right hemispheres of the brain for different functions. The rationale behind the visual hemi-field experiment and the actual experimental set-up will be discussed in a later section.

Strictly speaking, the proposition that Chinese characters do not specify sounds of the spoken language is not correct. We have already noted phonograms (see Figure 1) constitute a majority of modern day Chinese logograms.