To readers—those who read well and those who struggle to read, in one language or many languages, in alphabetic or nonalphabetic orthographies

僅將此本書獻給所有的閱讀人：閱讀能力佳者或是閱讀有困難者，不管是在單一語言或是多語的狀況，也不管是在拼音文字或是非拼音文字的狀況

INTRODUCTION

The Alphabet and the Sinogram

Setting the Stage for a Look Across Orthographies

William S-Y. Wang and Yaching Tsai[1]

LANGUAGE: SPOKEN AND WRITTEN

Although we share a common ancestry with the chimpanzee, our closest living relative, there is a huge chasm between how chimpanzees communicate and how we communicate. The differences started accumulating after our lines diverged some six million years ago. When, exactly, early *Homo sapiens* acquired language is a question that is often asked. The answer of course depends on how we define *language.* Human communication focused on the increasingly differentiated sounds we made with our mouths. Some of the vocal sounds we inherited from our ancestors, building upon the cyclic movements of our jaw used in chewing food, gradually became articulated as syllables constructed from vowels and consonants. When these early syllables were uttered with meanings shared in a community, the first words were born together with an infrastructure of phonology. When our ancestors varied these words slightly for different but related meanings, such as *lion* versus *lioness,* they invented morphology. When they associated different orders of the same words with different meanings, such as *lion saw monkey* versus *monkey saw lion,* they invented syntax.

The emergence of human language crossed several such phase transitions, and it is impossible at present to know the details of this trajectory, which may have been quite different for the many communities scattered in the ancient world; compare Freedman and Wang (1996) for a polygenetic scenario. However, whatever the scenario for

[1]This chapter is based on remarks presented by the first author at the Extraordinary Brain Symposium (January 16–22, 2010, Taiwan). Due to space limitation, much of the symposium presentation cannot be included here. The symposium was indeed extraordinary and highly successful because it was organized with contributions from many disciplines and from many distinct languages. We thank the organizers of the Symposium and The Dyslexia Foundation for their invitation and colleagues at the symposium for their many helpful discussions. Our work at the Language Engineering Laboratory (LEL) is supported in part by the Shun Hing Institute of Advanced Engineering of the Chinese University of Hong Kong, and the Research Grants Council of Hong Kong SAR. We thank members of the LEL for their collaboration, especially Manson Fong, James Minett, Yang Ruoxiao, and Zhang Caicai for helping us improve this paper in various ways. Special thanks to Peggy McCardle for her invaluable contributions to the symposium and for her excellent editorial suggestions on this chapter.

the prehistoric interactions, it is reasonable to infer from archeological evidence that by some 40,000 years ago, human communication had evolved to something like the languages we speak today, at least in some communities; see Davidson (2010). That is, they had phonology, morphology, and syntax, as well as hundreds if not thousands or tens of thousands of words.

We must not take such dates too seriously, of course, though they are useful as rough guidelines. Language did not suddenly materialize out of thin air. It is grafted on many of the sensory-motor, cognitive, and social skills that had been evolving for millions of years and that we share to varying extents with our chimpanzee relatives today. In recent years, writers have been using terms like *overlaid* (Sapir, 1921), *tinker* (Jacob, 1977), *mosaic* (Wang, 1982, 2007), *exaptation* (Gould, 1991; Gould & Vrba, 1982), *recycle* (Dehaene, 2005), and *reuse* to express this idea. Anderson (2010) discusses *reuse* and compares its various interpretations. Darwin was studying orchids and writing the following words a century and a half ago, but they apply to both spoken language and written language:

> Thus throughout nature almost every part of each living being has probably served, in a slightly modified condition, for diverse purposes, and has acted in the living machinery of many ancient and distinct specific forms. (Darwin, 1862, p. 348)

Written language came much later than spoken language; indeed, the majority of the world's languages do not have writing systems even today. Speech sounds can be heard only in an immediate area, and they disappear as soon as they are uttered. Written texts overcome these limitations in space and time—they can be carried to distant lands and passed on from generation to generation. It has been said of our species that our humanity came with spoken language and our civilization came with written language. Not all visual symbols qualify as writing or orthography, even if they have well-defined meanings. Traffic signs on roads, gender figures on washroom doors, icons on the computer screen, symbols for numbers—these all bear clear messages, but they are not part of a complete system that maps directly to a corresponding spoken language. Unlike orthography, they are pronounced differently in different languages.

The correspondence between a spoken language and a written language is not complete. For instance, intonations express a variety of attitudes, such as doubt, irritation, joy, or sadness, most of which are not indicated in writing. In English, for example, some of these intonations can be approximated by punctuation marks. Moreover, the use of *space* to separate syllables or words on the printed page, as well as many ways of capitalization in various languages, provide information typically absent in spoken language. For example, words in the grammatical category of nouns are all capitalized in written German. In principle, however, a writing system should be able to represent anything that can be

said, even though the mapping between the spoken and the written may be quite complex.

Around 10,000 years ago, our ancestors gradually changed from roving tribes of hunter-gatherers to people with sedentary lives, built villages, and began agriculture. From clay, they made pottery as well as tablets that could be inscribed on. The earliest precursors of writing on clay represented numbers and domesticated animals, presumably for keeping records and for trading. These were excavated in West Asia and dated to some 9,000 years ago. From such humble beginnings came the Western tradition of writing, including the early Sumerian cuneiform, the Egyptian hieroglyphics, the Phoenician script, and others, which evolved step by step to the various kinds of alphabetic writing we have in the world today.

THE ALPHABETIC TRADITION

The word *alphabet* was formed by joining the names of the first two letters of the Greek alphabet, *alpha* (α) and *beta* (β). The Latin alphabet is the Roman adaptation of the Greek alphabet and is the most widespread among modern languages today. The idea of the alphabet deeply impressed no less a scholar than Galileo, who considered it the crowning glory of all human inventions:

> But of all other stupendous inventions, what sublimity of mind must have been his who conceived how to communicate his most secret thoughts to any other person, though very far distant, either in time or place? And with no greater difficulty than the various arrangements of two dozen little signs upon paper? Let this be the seal of all the admirable inventions of man. (Galileo, 1632)

As writing systems were transmitted from culture to culture, they took on different forms. One parameter that varies among alphabetic systems is how vowels are written. The distinction between vowels and consonants is universal among all spoken languages, which typically include many more consonants than vowels (Wang, 1971); there is even the possibility that these two classes of sounds are processed separately in the brain (see Caramazza, Chialant, Capasso, & Miceli, 2000). However, languages differ in how vowels are written. In one type of alphabetic writing, of which Arabic is an example, vowels are optional: they may not be written at all. In another type of alphabet, such as is used in many Indic orthographies, vowels are obligatory: they are always written, but as diacritic marks appended to the consonants. These two types have been named *abjad* and *abugida*, respectively (Daniels, 1992; Daniels & Bright, 1996). In contrast to these two types of alphabetic writing—vowel-optional and vowel-diacritic, respectively—vowels are written as full letters, as consonants are, in the Latin alphabet; thus, it may be considered a third type of alphabet: full alphabet.

Table I.1. Vowel sounds in American English

Front	Central	Back	Diphthong
he		who	
hid		hood	
hay	hud	hoe	
head		hod	
had	hard		hi, how, hoy

For example, in English vowels are written on the line much as consonants are. But the mapping between vowel sounds and vowel letters is quite complex. Whereas there are only five vowel letters that English adopted from the Latin alphabet, there are many more distinct vowel sounds. We can easily verify this by considering a set of words such as shown in Table I.1.

Such a complex relationship between the 5 vowel letters of the written language with the 14 vowel sounds of the spoken language is obviously a burden for readers who need to establish a GPC (grapheme–phoneme correspondence) as they try to retrieve the meaning of what is being read. The burden is all the heavier for learners of the English language, whether as native tongue or as a foreign language.

From the viewpoint of GPC, the burden is heavier still when we note that the vowels in most words alter their phonetic values according to their morphology. Thus the stressed vowels in words such as "tut *o* rial" and "manag *e* rial" are reduced to an indistinct schwa sound [ə] when the stress moves away; that is, "tutor" and "manager." But note that the vowel letter in *tutor* tells us how the second vowel should be pronounced when it does carry the stress.

Alternations affect many vowels in a different way in the following set of words, even when the stress does not move:

sanity > *sane*	*shepherd* > *sheep*	*fifth* > *five*
gratitude > *grateful*	*kept* > *keep*	*Christmas* > *Christ*
opacity > *opaque*	*serenity* > *serene*	*divinity* > *divine*
tabular > *table*	*obscenity* > *obscene*	*linear* > *line*
chastity > *chaste*	*left* > *leave*	*hid* > *hide*

English spelling was largely fixed around 1475, when Caxton first introduced printing to England. Spoken language is always changing, and English is no exception. More than five centuries have passed since Caxton, and Modern English is very different from the Middle English of Chaucer.

The vowels in words illustrated in the previous example, such as *sane, sheep,* and *five,* changed their pronunciations several hundred years ago in a systemwide sound change that has been called the Great Vowel Shift; see Wang (1968) for an analysis of this shift. (It is also due to this shift that the name "China" is pronounced with a diphthong $[a^i]$ in English, yet it is pronounced with a high front vowel [i] in other European languages, in agreement with the name of the first Chinese empire which is its probable source, "Qin"; compare French "Chine.") On the other hand, these same vowels were shortened but preserved their vowel height when these words took on certain suffixes, namely *-ity* in *sanity, -itic* in *Sinitic, -herd* in *shepherd,* and *-th* in *fifth.*

Many people have complained about English orthography, and various attempts have been made to reform it, perhaps the best known being that of the writer George Bernard Shaw. Abercrombie (1981) gives a brief historical review of these efforts. Also noteworthy in this regard is the progress that has been made in the science of speech sounds. Our understanding of the speech chain has deepened on several fronts—how the sounds are produced, their acoustic structure, how they are perceived, and the neuropsychology underlying both the production and the perception. We realize now that the goal set by Alexander Melville Bell (1867)—for his universal alphabet to teach the sounds of all languages—is much more ambitious than he realized. Speech sounds are continuous along many different acoustic dimensions, and different languages slice up these continua in different ways. A phonetic feature that is lexically distinctive in one language may not be distinctive in another. For example, the phonetic feature that distinguishes "peel" from "pill" in English is not distinctive in Spanish.

In any case, because a desired end product of the reading process is the words and their combined meanings, it is not clear that attention to all the phonetic details is helpful. English spells the plural suffix in *cats* and *dogs* the same way: *-s*. A more faithful GPC would require us to spell them as *cats* and *dogz,* thereby obscuring the identity of the suffix. Similarly, a "shallower" orthography with high GPC would require us to spell the pairs of words with different vowels: *sanity* and *seyn, shepherd* and *shiyp, hid* and *hayd.* Phonetic fidelity, in the sense of GPC, is only part of the story, but it is surely less important than the preservation of morpheme identity. After all, it is the morphemes that will lead us to the meaning, not the phonetics per se.

An interesting new phenomenon that has arisen in writing English, and in alphabetic writing in general, has to do with numerous innovations found among casual communications on the Internet: abbreviations such as "ruok" for "are you ok?" or emoticons such as ":-)" for a happy face (Crystal, 2001). The phenomenon is too recent for us to assess its ultimate effect on the evolution of written language; much depends on future technological developments.

THE WORLD OF THE SINOGRAM

In contrast to the Western tradition and its various alphabetic writings, the Chinese tradition developed along a different route. The earliest specimens are inscriptions preserved on bronzeware, pieces of pottery (potsherds), and shells and bones. The inscriptions on turtle shells and ox scapulae were discovered only around the beginning of the

20th century, and systematic excavations were begun by archeologists only in the 1920s. Previous to this discovery, countless pieces were ground up for medicinal purposes in the superstitious belief that these inscriptions marked them as bones of the dragon.

Many decades of dedicated scholarly research have enabled us to read most of these inscriptions. Like the habits of many ancient peoples who practiced divination in many parts of the world—most famously at Delphi in ancient Greece—these inscriptions were mostly questions addressed to God, and records were kept of the divinations. Hence they are also called *oracle bone inscriptions*. Heat was applied to processed parts of these oracle bones, and the cracks thus produced were divine responses interpreted by the royal shaman (Chang, 1980; Keightley, 1978). Typically, the inscriptions dealt with prospects of winning a war, appropriate weather for planting crops, likelihood of a successful childbirth, and so forth.

Such inscriptions date to more than 3,000 years ago during the Shang Dynasty and extend a little into the succeeding Zhou Dynasty, several millennia later than the earliest extant writing in West Asia. However, judging by the maturity of these inscriptions and the number of distinct symbols used, experts agree that this orthographic tradition must have started considerably earlier (Cheung, 1983). Nonetheless, no evidence is available so far that is fully convincing of an earlier date than these oracle bone inscriptions, even though occasionally archeologists report likely precursors on potsherds, especially those found in well-known Neolithic sites such as Banpo (半坡) and Dawenkou (大汶口). One such recent report is that of Li X-Q, Harbottle, Zhang, and Wang (2003), who titled their paper "The Earliest Writing? Sign Use in the Seventh Millennium BC at Jiahu." This report has particular significance because the signs were inscribed on tortoise shells, rather than on potsherds.

Because reading is a relatively new function for the brain in evolutionary time, it has been hypothesized that the cortical circuits of this region have been exapted from their earlier function of tracking or "reading" natural trails—a skill that doubtless was highly adaptive for prehistoric hunters. Skills developed from tracking patterns of animal footprints on the ground have been transferred to reading graphic patterns on a printed page (Dehaene, 2009; Dehaene, chapter 6 in this volume).

This line of reasoning is reminiscent of the speculation advanced by China's first lexicographer, Xu Shen (許慎), some 2,000 years ago when he described how the legendary Cang Jie (倉頡) "examined the tracks made by birds and beasts . . . and created writing."[2] Xu also went

[2]Here is a fuller quote from the original text from Xu's preface to his great dictionary: 「倉頡之初作書也，蓋依類象形，故謂之文。其後形聲相益，即謂之字。文者，物象之本；字者，言孳乳而寖多也。著於竹帛謂之書。」 We see from this quote that before paper and printing, writing was mainly done on bamboo and silk. This ancient work has been reproduced numerous times over the past two millennia. The quote here is taken from p. 761 of the 1965 version of 說文解字段注, published by 藝文印書館 in Taiwan.

on to say that "the first graphs Cang Jie created imitated the shapes of the categories; these graphs were called *wen* (文). Later, shapes and sounds were combined to form *zi* (字)." In modern Chinese, the first graphs and all the later combinations have been lumped together and called *wenzi* (文字), or simply *writing*.

The unit of Chinese writing—a set of strokes assembled in a square architecture—is popularly known as the Chinese *character*. A more precise term that we use here is *sinogram*. Similarly, although popular descriptions frequently characterize Chinese writing as ideographic or pictographic, a more precise term is *logosyllabic*, as the majority of sinograms are actually phonograms, as we discuss shortly. Due to the early emergence of the sinogram and the broad reach of the Chinese civilization, the sinogram has exerted a profound influence over much of East Asia and parts of Southeast Asia. For two millennia, Vietnamese was written in sinograms, either directly imported from China or in locally created variants, until 1910, when the French colonialists decreed that all public documents be transcribed into *quốc ngữ* (literally, *national language*) based on the Latin alphabet. A lesser known case is that of the Dungan (東干), who emigrated to Kirghistan in the 19th century and replaced their sinograms with a Cyrillic script (Husmann & Wang, 1991).

Korea began to replace the sinogram in the middle of the 15th century, when they invented an ingenious writing system called *Hankul*[3] (literally, *Han writing*). This system is remarkable and unique in that each syllable is represented by the square architecture of the sinogram, and the component graphs actually represent consonants, vowels, and sometimes distinctive features of the language as well. So the system is simultaneously alphabetic and syllabic. The name of the script, Hankul, is written as 한 글. In the left syllable, the circle and the two horizontal lines above it, ㅎ, is the consonant *h;* the short horizontal line together with the vertical line ㅏ is the vowel *a;* and the bent line at the bottom of the square, ㄴ, is the consonant *n.* The right syllable is written vertically downward. The bent line on top, ㄱ, is *k;* the horizontal line, ㅡ, in the middle is *u;* and the remainder below, ㄹ, is *l.*

Japanese and Korean are both Altaic languages; their grammars differ from that of Chinese in fundamental ways in both morphology and syntax, despite much shared vocabulary. Altaic languages are typically rife with sequences of suffixes that cannot be easily written in sinograms, which function primarily as content words. Rather than abandoning sinograms altogether, Japanese adopted a hybrid approach

[3]A potential source of confusion lies in the first syllable of these words: *hanzi* in Chinese, *kanji* in Japanese, and *hankul* in Korean. In the first two cases, the *han-* and the *kan-* are two pronunciations of the same morpheme, 漢, the name of one of China's great dynasties, which was roughly a contemporary of the Roman Empire. 漢 is also the name of China's major ethnic group. The Korean *han-*, on the other hand, though homophonous, is a different morpheme, 韓, and refers to the Republic of Korea. This same morpheme is also the name of various kingdoms of ancient China.

for its script. On the one hand, some 2,000 sinograms are kept for daily use in Japan, a few with minor modifications on the original ones imported from China. These are called *kanji*, or Han writing. For instance, the sinogram for Buddha in Chinese is 佛, based on an ancient phonetic transcription of the word imported from India. But in Japanese, the corresponding kanji is written as 仏. More important, based on the square architecture of the sinogram, the Japanese have invented a syllabary of some 50 symbols, most of which represent syllables of the CV type; that is, a consonant followed by a vowel. The Japanese syllabary is called *kana*, a common form of which is called *hiragana*.

The word *hiragana* is written ひらがな, and the four symbols correspond to the four syllables. Note that for the third symbol there are two little dots in the upper right corner; these are diacritics for phonetic voicing. These dots indicate that the *k* in *kana* should be pronounced [g] because of its phonetic environment, much as the *s* in English *dogs* should be pronounced [z], though it is not marked as such. The two scripts, kanji and kana, are used simultaneously in Japanese writing in complementary ways, with kana mostly representing various grammatical morphemes to glue the sentences together and kanji representing most of the content words. It is of great theoretical interest that these two coexisting scripts can be selectively impaired in Japanese aphasics (Sasanuma, 1974).

Consider once again ancient China and the Han dynasty. Xu Shen pioneered a classification of the 9,000 or so sinograms that he compiled in his dictionary by introducing a system of 540 radicals called *bushou* (部首) in Chinese. The idea is that every sinogram belongs to a unique radical and can be found under its radical in the dictionary and by counting the number of residual strokes. The system of radicals has great philosophical interest because it is an orthographic representation of the knowledge of the world, insofar as the totality of sinograms is a representation of the world one can write about. By the time the authoritative *Kangxi Dictionary* was compiled in the 18th century, the system had been reduced to 214 radicals. And with the wholesale simplification of sinograms in the 1950s, which was officially sponsored by the government, the system of radicals was further reduced. The influential dictionary *Xinhua Dictionary*, in its 1992 edition, has reduced the system further to 189 radicals. Although the great majority of the radicals are also independent sinograms with their own sound and sense, a handful are not.

The simplification of the 1950s has an effect on the how phonetics represent the pronunciations of their host sinograms. As examples, the traditional sinograms for *factory* and *large* are 廠 (*chang3*) and 廣 (*guang3*);[4]

[4]The numerals at the end of pinyin spellings of Putonghua (common speech, also known as Mandarin in mainland China, Hong Kong, and Macau) words indicate their tones.

their simplified counterparts are 厂 and 广, thereby removing their phonetic clues, which are 敞 (*chang3*) and 黄 (*huang2*), making them no longer phonograms. As a contrast, the simplified sinograms for *protect* and *Chinese* are 护 (*hu4*) and 华 (*hua2*), with the phonetics 户 (*hu4*) and 化 (*hua4*); these are phonetically more transparent than their traditional counterparts, 護 and 華. The simplification also altered the relations of some sinograms to their original radicals and thereby their semantic associations. In the previous two examples, the radicals are different between the respective traditional and simplified forms.

In Figure I.1, 12 radicals are illustrated in gray because they occur in different host sinograms. Each radical has an approximate or fuzzy meaning: the three dots on the left side of the left top sinogram indicate *water*, and the standing cross in the sinogram to the right indicates *wood*. Because the world of meanings is vast and nondiscrete, each radical can offer only a vague hint for the meaning of its host sinogram. For this reason, for most cases we also refer to the radical as the semantic of the host sinogram.

These sinograms are selected because they are all phonograms, in the sense that in each the remaining partial is a phonetic—an independent sinogram with its own pronunciation (except for the two in the bottom row). The phonetic in the left top sonogram, 羊, for instance, is an independent sinogram pronounced *yang2*, meaning *sheep*—the two horns are still visible from its earlier iconic form. But here the partial is serving as a phonetic, so its meaning is irrelevant. The total sinogram is therefore pronounced *yang2;* it means *ocean*. Coincidentally, like the word *logosyllabic*, the approximate meaning of this sinogram is indicated by its radical on the left side, and its syllabic pronunciation is indicated by its phonetic on its right side. Phonograms are the most prevalent type of sinogram; according to various estimates, as much as 80% of the sinograms in Putonghua are phonograms, even though in

Left	洋	water	松	wood
Right	切	knife	頂	head
Top	草	grass	竿	bamboo
Bottom	煮	fire	盟	vessel
Outside	圓	encircle	裹	clothing
Inside	斑	graph	瓣	melon

Figure I.1. Radical positions.

many cases the phonetic can only approximate the pronunciation of its host sinogram. (However, because the definition of *phonogram* varies among reports, a rigorously collected and publicly accessible database would be very helpful for future research.)

In the top right sinogram, the radical (or semantic) on the left means *wood*. The phonetic on the right is pronounced *gong1*, but the host sinogram is pronounced *song1*, with a different initial consonant, and means *pine*. A perfect match in pronunciation between the phonetic and its host sinogram occurs in only about a third of the phonograms in Putonghua (Zhou, 1978). This low rate is perhaps to be expected because a lot of sound changes have occurred over the centuries, which could take a phonetic and its host sinogram along divergent paths of phonetic development. For similar reasons, dialects vary in the degree to which the pronunciations of the phonetic and its host sinogram agree. Indeed, vibrant dialects like Cantonese often create new sinograms based on regional need (Cheung & Bauer, 2002).

Using S for semantic/radical and P for phonetic, the top two sinograms may be described geometrically as SP. But the semantics may appear on the right, as in the two sinograms 刀 and 頁 in the second row of the figure, meaning *knife* and *head*. These sinograms therefore have the geometric description of PS. Similarly, the semantics may appear at top or bottom, outside or inside, as illustrated in the figure. Of all the geometric types illustrated here, SP sinograms by far constitute the majority.

It used to be thought that reading Chinese was a straightforward process going directly from the graphs on paper to the meanings represented by these graphs. Tzeng, Hung, and Wang (1977) disabused us of this overly simplistic misconception with a series of experiments that conclusively demonstrated "speech recoding" in reading Chinese, regardless of whether the sinograms being read are phonograms. Their paper was a turning point in helping launch many studies of the Chinese and Japanese scripts from an experimental perspective (see Hardyck, Tzeng, & Wang, 1977, 1978, and many others).

With the recent technological breakthroughs in computer graphics and brain imaging, we are now in a new era of research on questions of reading. The studies of Lee and colleagues (2007) and Hsu, Tsai, Lee, and Tzeng (2009) have been particularly effective in using the temporal resolution of electroencephalography (EEG) to examine effects of combinability, consistency, and regularity in recognizing sinograms. Also using EEG, Hsiao, Shillcock, and Lee (2007) explore whether the left and right halves of a sinogram—of either the SP or PS structure—may actually fall differently on a split fovea and project to different brain hemispheres. (See also Ellis & Brysbaert, 2010.) These EEG studies have yielded a great deal of information on sublexical processing of the sinogram. We now know that both the radical and the phonetic and their frequencies of occurrence play significant roles in how the brain accesses their host sinograms.

The studies of Kuo and colleagues (2001), Siok, Perfetti, Jin, and Tan (2004), and Lee, Huang, Kuo, Tsai, and Tzeng (2010) have discovered important information regarding which parts of the cortex are more involved in processing sinograms by capitalizing on the spatial resolution of functional magnetic resonance imaging (fMRI). Comparing the brain scans of normal and dyslexic readers, Siok and colleagues (Siok et al., 2009) discovered a region in the left middle frontal gyrus (LMFG) that may be of special significance for reading Chinese. It is intriguing that this region is close to various cortical areas involved with motor control, hinting at a closer connection between reading and writing for sinograms than for alphabetic writing. Because the sinograms are graphically much more complex than letters of the alphabet, Chinese school children typically spend a great deal of time in learning to write them correctly, if not elegantly, thus involving extensive practice of motor skills. Indeed, it is not unusual for a Chinese person to try to recall a forgotten sinogram by tracing its shape with a finger on his or her palm. (This habit sometimes even generalizes to Chinese bilinguals who might trace difficult English words on their palms.)

These studies harnessing the new technology of brain imaging are the leading edge of many ongoing and future waves of research, which will surely bring deeper understanding of the ability to read sinograms. This new understanding will in turn lead to a more balanced knowledge of reading and writing in our species.

READING AND WRITING

Ultimately, our knowledge of reading and writing, normal as well as impaired, must come from the convergence of results from at least three disciplines: linguistics, neuroscience, and psychology. Marcus Raichle (2010), a pioneer in the technology of brain imaging, gives us a current appreciation of the complexity of visual cognition in informational–theoretic terms, of which reading is a special instance:

> Of the virtually unlimited information available in the world around us, the equivalent of 10 billion bits per second arrives on the retina at the back of the eye. Because the optic nerve attached to the retina has only a million output connections, just six million bits per second can leave the retina, and only 10,000 bits per second make it to the visual cortex.
>
> After further processing, visual information feeds into the brain regions responsible for forming our conscious perception. Surprisingly, the amount of information constituting that conscious perception is less than 100 bits per second. Such a thin stream of data probably could not produce a perception if that were all the brain took into account; the intrinsic activity must play a role.
>
> Yet another indication of the brain's intrinsic processing power comes from counting the number of synapses, the contact points between neurons. In the visual cortex, the number of synapses devoted

> to incoming visual information is less than 10 percent of those present. Thus, the vast majority must represent internal connections among neurons in that brain region. (Raichle, 2010, p. 47)

From the 10 billion bits per second (bits/sec) made available at the retina, the amount of information is dramatically pruned to a mere 100 bits/sec at the stage of conscious perception at the cortex—a reduction of 100 millionfold! There are many way stations along this route that participate in this information reduction or filtering, including the superior colliculi at the brain stem; the lateral geniculate nuclei at the thalamus; the visual areas at the occipital lobe, especially the Visual Word Form Area (VWFA) at the occipitotemporal area; among others—before the visual information reaches the frontotemporal areas of the cortex to arrive at a conscious perception.

By far, the bulk of the information from the retina is discarded along this journey. But how does the brain select the "thin stream of data" of 100 bits/sec at the end of the journey to make sure that it preserves the information the reader needs to recognize the word he or she is looking at? Clearly, these processes of selection and eventual perception and recognition are based in large part on what the brain has learned from the many years of training that culture has provided.

To be able to eventually answer this fundamental question about brain processes more fully, we need to pay special attention to aspects of various orthographies, perhaps not unlike the early efforts of Eden (1960) in his formalization of handwriting. For decades, linguists have made important use of the concept of "distinctive features" in analyzing the sound systems of the spoken languages of the world; see, for instance, Jakobson, Fant, and Halle (1951). A parallel approach for the written languages of the world, discovering their distinctive features, may prove to be equally essential for understanding reading. The recent work of Changizi and Shimojo (2005) seems to be a useful step pointing in this direction, as discussed in Dehaene (2009).

The Latin alphabet, for instance, inclines toward curvilinear (or circular) strokes in the construction of its letters. The first five letters—a, b, c, d, and e—are all based on modifications of the circle. In contrast, the strokes of the sinogram are mostly linear.

Compared with the couple dozen or so letters in the Latin alphabet, there are far more—thousands of—sinograms in use (Cheng, 1988). Consequently, their graphic complexity is much greater than that of alphabets, and their discrimination also requires a higher level of visual acuity. In Table I.2, we illustrate some of the distinctive features that are necessary for a Chinese reader.

The three sinograms in cell 1A in Table I.2 are each made with two downward strokes. However, the meeting of these two strokes at the top is distinctive. It is the same case for the three sinograms in cell 1B, in which the last stroke looks like a fishhook that starts on the left and proceeds downward. Where it actually starts is distinctive in three

Table I.2. Sinogram "distinctive features" necessary for a Chinese reader

	A	B
1	八 人 入	己 已 巳
2	日 曰	土 士 未 末
3	田 由 冑 胄	甲 申 （由 甲）
4	大 太 犬 王 玉 主	哀 衰 衷
5	戉 戊 戌 戍	丐 丏 宮 官
6	束 柬 東	兵 乒 乓

ways. The two sinograms in 2A are interesting because they are distinguished by their proportions: the taller one means "sun," and the wider one means "to speak." The two pairs of sinograms in 2B are distinguished by the relative lengths of the two horizontal strokes. In each pair, the upper stroke is longer in the right sinogram and the lower stroke is longer in the left sinogram. Similarly, we can discover more distinctive features used in written Chinese by examining the remaining four rows of sinograms given previously.

CLOSING REMARKS

We now close this brief overview of the two major writing traditions in the world today. The alphabet tradition is based on speech segments the size of phonemes. Sapir (1933) first raised the issue of the psychological reality of the phoneme almost a century ago; more recently, Read, Zhang, Nie, and Ding (1986) reexamined this question in the context of Chinese society. The study of Justeson and Stephens (1991) seems to suggest that the syllable has more cognitive saliency than the phoneme; systematic experimentation on this important question has only just begun (see Doignon-Camus, Bonnefond, Touzalin-Chretien, & Dufour, 2009). In any case, it is not clear that high GPC is always desirable for an efficient orthography, especially in languages that have extensive morphophonemic alternations, as illustrated previously with English vowels.

The logosyllabic tradition, as represented by the sinogram, has spawned various offshoot writing systems, such as the Japanese kana and the Korean Hankul, each in its own way successfully representing a national language. The sinogram is of special interest because it simultaneously presents semantic and phonetic information, albeit neither very precisely. Thus, the sinogram allows the brain to search for the word along both dimensions simultaneously from the outset, whereas the alphabet word enables only the phonetic dimension.

An optimal writing system depends on numerous factors both internal and external (Wang, 1981). The internal factors include how the system treats morphophonemic alternations; how it deals with stresses and tones; boundaries of syllables, words, and phrases; and other factors. The system must also respond effectively to problems of homonymy, which is present to varying extents in all languages. How successfully a writing system is learned often depends on many cultural intangibles. A history of literacy in China is reviewed in Wang, Tsai, and Wang (2009). The external factors include—among various cultural and sociopolitical considerations—the method by which the writing system is taught and maintained.

Peng, Minett, and Wang (2010) find that subjects differ in their brain responses to real and pseudosinograms, depending on whether they are from Hong Kong or the mainland. Currently, sinograms are taught on mainland China with the initial aid of an alphabetic system called the Hanyu Pinyin; they are taught in Taiwan with a quasi-syllabic system called Zhuyin Fuhao; they are taught in Hong Kong without any auxiliary phonetic system at all. Unfortunately, there does not seem to be any systematic planned curriculum anywhere to explain the structure of the sinogram to help with its instruction.

Hopefully, future research will help us sort out these many internal and external factors and thus enable us to understand the nature of reading and writing more deeply. Such new knowledge should in turn lead to significant improvements in reading education for both the normal and the dyslexic reader, as well as add to our basic understanding of how the brain works in one of the most distinctive of human activities.

REFERENCES

Abercrombie, D. (1981). Extending the Roman alphabet: Some orthographic experiments of the past four centuries. In R.E. Asher & E.J.A. Henderson (Eds.), *Toward a history of phonetics* (pp. 207–224). Edinburgh, Scotland: Edinburgh University Press.

Anderson, M.L. (2010). Neural re-use as a fundamental organizational principle of the brain. *Behavioral and Brain Sciences, 33*, 2245–2313.

Bell, A.M. (1867). *Visible speech: The science of universal alphabetics; or, Self-interpreting physiological letters, for the writing of all languages in one alphabet*. London: Simpkin, Marshall.

Caramazza, A., Chialant, D., Capasso, R., & Miceli, G. (2000). Separable processing of consonants and vowels. *Nature, 403*, 428–430.

Chang, K.C. (1980). *Shang civilization*. Princeton, NJ: Yale University Press.

Changizi, M.A., & Shimojo, S. (2005). Character complexity and redundancy in writing systems over human history. *Proceedings of the Royal Society B, 272*, 267–275.

Cheng, C.C. (1988). Quantification for understanding language cognition. In B.K. T'sou, T.B.Y. Lai, S.W.K. Chan & W.S.-Y. Wang (Eds.), *Quantitative and computational studies on the Chinese language* (pp. 15–30). Hong Kong: City University of Hong Kong Press.

Cheung, K.-H., & Bauer, R. (2002). *The representation of Cantonese with Chinese characters*. Journal of Chinese Linguistics Monograph Series (No. 18). Berkeley, CA: Project on Linguistic Analysis.

Cheung, K.-Y. (1983). Recent archeological evidence relating to the origin of Chinese characters. In D.N. Keightley (Ed.), *The origins of Chinese civilization* (pp. 323–391). Berkeley: University of California Press.

Cheung, Y.-S. 張日昇. (1968). 試論上古四聲 (A study of the tones in Archaic Chinese). *香港中文大學中國文化研究所學報, 1*, 113–170.

Crystal, D. (2001). *Language and the Internet*. Cambridge, England: Cambridge University Press.

Daniels, P.T. (1992). The syllabic origin of writing and the segmental origin of the alphabet. In P. Downing, S.D. Lima, & M. Noonan (Eds.), *The linguistics of literacy* (pp. 83–110). Amsterdam: John Benjamins.

Daniels, P.T., & W. Bright (Eds.). (1996). *The world's writing systems*. New York: Oxford University Press.

Darwin, C. (1862). *On the various contrivances by which British and foreign orchids are fertilised by insects, and on the good effects of intercrossing*. London: John Murray.

Davidson, I. (2010). The colonization of Australia and its adjacent islands and the evolution of modern cognition. *Current Anthropology, 51*(1), S177–S189.

DeFrancis, J. (1989). *Visible speech: The diverse oneness of writing systems*. Honolulu: University of Hawaii Press.

Dehaene, S. (2005). Evolution of human cortical circuits for reading and arithmetic: The "neuronal recycling" hypothesis. In S. Dehaene, J.-R. Duhamel, M.D. Hauser, & G. Rizzolatti (Eds.), *From monkey brain to human brain* (pp. 133–158). Cambridge, MA: The MIT Press.

Dehaene, S. (2009). *Reading in the brain*. New York: Penguin Viking.

Doignon-Camus, N., Bonnefond, A., Touzalin-Chretien, P., & Dufour, A. (2009). Early perception of written syllables in French: An event-related potential study. *Brain & Language, 111*, 55–60.

Eden, M. (1960). On the formalization of handwriting: Structure of language and its mathematical aspects. *Proceedings of the Twelfth Symposium in Applied Mathematics, XII*, 83–88.

Ellis, A.W., & Brysbaert, M. (2010). Split fovea theory and the role of the two cerebral hemispheres in reading: A review of the evidence. *Neuropsychologia, 48*, 353–365.

Freedman, D.A., & Wang, W.S.-Y. (1996). Language polygenesis: A probabilistic model. *Anthropological Science, 104*(2), 131–138.

Galilei, G. (1632). *Dialogo di Galileo Galilei* (*Galileo's Dialogue*).

Gould, S.J. (1991). Exaptation: A crucial tool for evolutionary psychology. *Journal of Social Issues, 47*, 43–65.

Gould, S.J., & Vrba, E.S. (1982). Exaptation: A missing term in the science of form. *Paleobiology, 8*, 4–15.

Hardyck, C., Tzeng, O.J.L., & Wang, W.S.-Y. (1977). Cerebral lateralization effects in visual half-field experiments. *Nature, 269*, 705–707.

Hardyck, C., Tzeng, O.J.L., & Wang, W.S.-Y. (1978). Lateralization of function and bilingual decision processes: Is thinking lateralized? *Brain and Language, 5*, 56–71.

Hsiao, J.H.-W., Shillcock, R., & Lee, C.-Y. (2007). Neural correlates of foveal splitting in reading: Evidence from an ERP study of Chinese character recognition. *Neuropsychologia, 45*, 1280–1292.

Hsu, C.-H., Tsai, J.-L., Lee, C.-Y., & Tzeng, O.J.L. (2009). Orthographic combinability and phonological consistency effects in reading Chinese phonograms: An event-related potential study. *Brain and Language, 108*, 56–66.

Husmann, L.E., & Wang, W.S.-Y. (1991). Ethnolinguistic notes on the Dungan. *Sino-Platonic Papers, 27*, 71–84. University of Pennsylvania: Department of Oriental Studies.

Jacob, F. (1977). "Evolution and Tinkering." *Science, 196*(4295), 1161–1166.

Jakobson, R., Fant, C.G.M., & Halle, M. (1951). *Preliminaries to speech analysis*. Cambridge, MA: MIT Press.

Justeson, J.S., & Stephens, L.D. (1991). The evolution of syllabaries from alphabet: Transmission, language contract, and script typology. *Die Sprache, 35*, 2–46.

Keightley, D.N. (1978). *Sources of Shang history*. Berkeley: University of California Press.

Kuo, W.-J., Yeh, T.-C., Duann, J.-R., Wu, Y.-T., Ho, L.-T., Hung, D.L., et al. (2001). A left-lateralized network for reading Chinese words: A 3T fMRI study. *NeuroReport, 12*, 3997–4001.

Lee, C.-Y., Huang, H.-W., Kuo, W.-J., Tsai, J.-L., & Tzeng, O.J.L. (2010). Cognitive and neural basis of the consistency and lexicality effects in reading Chinese. *Journal of Neurolinguistics, 23*(1), 10–27.

Lee, C.-Y., Tsai, J.-L., Chan, W.-H., Hsu, C.-H., Hung, D.L., & Tzeng, O.J.L. (2007). Temporal dynamics of the consistency effect in reading Chinese: An event-related potentials study. *NeuroReport, 18*, 147–151.

Li, X.-Q., Harbottle, G., Zhang, J., & Wang, C. (2003). The earliest writing? Sign use in the seventh millennium BC at Jiahu, Henan Province, China. *Antiquity, 77*(295), 31–45.

Peng, G., Minett, J.W., & Wang, W.S.-Y. (2010). Cultural background influences the liminal perception of Chinese characters: An ERP study. *Journal of Neurolinguistics, 23,* 416–426.

Raichle, M.E. (2010). The brain's dark energy. *Scientific American* (March), 44–49.

Read, C., Zhang, Y.-F., Nie, H.-Y., & Ding, B.-Q. (1986). The ability to manipulate speech sounds depends on knowing alphabetic writing. *Cognition, 24,* 31–44.

Sapir, E. (1921). *Language.* New York: Harcourt.

Sapir, E. (1933). "La réalité psychologique des phonèmes." *Journal de Psychologie Normale et Pathologique, 30,* 247–265.

Sasanuma, S. (1974). Impairment of written language in Japanese aphasics: Kana versus kanji processing. *Journal of Chinese Linguistics, 2,* 141–158.

Siok, W.T., Kay, P., Wang, W.S.-Y., Chan, A.H.D., Chen, L., Luke, K.-K., et al. (2009). Language regions of brain are operative in color perception. *Proceedings of the National Academy of Sciences, 106*(20), 8140–8145.

Siok, W.T., Perfetti, C.A., Jin, Z., & Tan, L.H. (2004). Biological abnormality of impaired reading is constrained by culture. *Nature, 431,* 71–76.

Tzeng, O.J.L., Hung, D.L., & Wang, W.S.-Y. (1977). Speech recoding in reading Chinese characters. *Journal of Experimental Psychology: Human Learning and Memory, 3,* 621–630.

Wang, F., Tsai, Y.-C., & Wang, W.S.-Y. (2009). Chinese literacy. In D. Olson & N. Torrance (Eds.), *Cambridge handbook on literacy* (pp. 386–417). Cambridge, UK: Cambridge University Press.

Wang, W.S.-Y. (1968). Vowel features, paired variables and the English vowel shift. *Language, 44,* 695–708.

Wang, W.S.-Y. (1971). The basis of speech. In C.E. Reed (Ed.), *The learning of language* (pp. 267–306). New York: National Council of Teachers of English.

Wang, W.S.-Y. (1981). Language structure and optimal orthography. In O.J.L. Tzeng & H. Singer (Eds.), *The perception of print: Reading research in experimental psychology* (pp. 223–236). Hillsdale, NJ: Lawrence Erlbaum Associates.

Wang, W.S.-Y. (1982). *Explorations in language evolution.* Hyderabad, India: Osmania University Press.

Wang, W.S.-Y. (2007). The language mosaic and its biological bases. *Journal of Bio-Education, 2*(1), 8–16.

Xu, S. 許慎. (1965). 說文解字段注 (Duan's annotation of *Shou Wen Jie Zi*). 台北: 藝文印書館.

Zhou, Y.-G. 周有光. (1978). 現代漢字中聲旁的表音功能問題 (The question of how well phonetic components in Chinese characters express sounds). *中國語文, 3,* 172–177.

PART I

Looking Across Orthographies

跨語言研究

PART I CONTENTS

1 Reading Processes and Reading Problems 18

2 Fundamentals of Chinese Reading Development and How They Might Affect Concepts of Dyslexia in Chinese 33

3 The Statistical Learning Perspective on Chinese Reading 44

4 Prevention of Reading Difficulties in Highly Transparent Finnish 62

5 Reading Akshara 76

INTEGRATIVE SUMMARY 1: Looking Across Orthographies 96