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# 20 Reading Chinese characters: orthography, phonology, meaning, and the Lexical Constituency Model

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## The implications of Chinese for models of word reading

Models of word reading have come primarily from studies of English word identification, supplemented by studies of alphabetic writing systems for European languages. This is true both for symbolic models that postulate an internal lexicon and multiple pathways to pronunciation (Coltheart, 1978; Coltheart et al., 1993; Besner & Smith, 1992; Paap & Noel, 1991) and non-symbolic models that assume a single mechanism without a lexicon (Harm & Seidenberg, 1999; Seidenberg & McClelland, 1989; Plaut et al., 1996; Van Orden, Pennington & Stone, 1990). Models that may extend beyond English (Berent & Perfetti, 1995; Grainger & Jacobs, 1994; Grainger & Jacobs, 1996; Jacobs et al., 1998) remain largely focused on alphabetic writing systems.

Research on reading in nonalphabetic writing systems, however, has accumulated sufficiently to invite comparisons with alphabetic reading. Both Japanese Kana, a syllabic system, and Chinese have been the focus of research. Because the Chinese system, as used in China and derivatively elsewhere in Southeast Asia (e.g. Japanese Kanji), presents the highest contrast to alphabetic systems, it provides an especially interesting comparison with alphabetic reading.

A focus on Chinese brings to light an important property of reading that may have been partially submerged by alphabetic research and its focus on routes to the lexicon and phonological mediation of meaning: that phonology is automatically activated in reading words, whether it is "before" or "after" some moment of lexical access and whether it is instrumental in retrieving the meaning of a word. This conclusion in fact became visible following research comparing Chinese and English and led to the Universal Phonological Principle (UPP) described by Perfetti, Zhang, and Berent (1992). The principle is that, in any writing system, the pronunciations are activated during reading at the earliest moment allowed by the units of the writing system. In alphabetic systems, pronunciations of phonemes and phoneme sequences are activated by letters. In Chinese, the UPP means that pronunciations will at least be activated by characters, even when meaning is the goal of the reader. That Chinese should work this way was not obvious on the traditional understanding of the writing system.

### *Semantics and phonology in the Chinese writing system*

Historically, the Chinese writing system has been viewed as meaning based rather than speech based (e.g. Baron & Strawson, 1976; Wang, 1973). Accordingly, the traditional assumption about reading has been that Chinese reading works as a visual form-to-meaning system. However, research has forced a new understanding of Chinese reading: as summarized in a review by Tan and Perfetti (1998), the evidence is that Chinese reading involves phonology at the word level as well as at the text level. The explanation for these discoveries seems to require highly general, perhaps universal processes, constrained by the UPP.

A very brief review of the Chinese writing system helps explain why this conclusion is important. Although it is often classified as a logographic system, written Chinese also can be considered morphemic (e.g. Leong, 1973) or morphosyllabic (e.g. DeFrancis, 1989; Mattingly, 1992). A character, as a basic writing unit, maps onto a single-syllable morpheme rather than a phoneme in the spoken language. A single character can be considered a word and also can join with other characters to form a multicharacter (and hence multisyllable) word.

Characters consist of smaller components or radicals, which may themselves have a pronunciation or meaning. A compound character has two or more radicals. For example, the character 惊 [/jing/1, "frighten"] contains the radical 忄 on the left and the radical 京 on the right. Such compound characters make up the majority of characters in Chinese. Although some of these compound characters have two semantic components, about 85 percent are phonetic compounds, composed of one semantic and one phonetic component (Perfetti and Tan, 1998; Zhu, 1988). Although most compounds have a degree of semantic validity, i.e. some aspect of their meaning is suggested by a semantic radical (Fan, 1986; Jin, 1985), semantic validity is frequency dependent, increasing with decreasing printed frequency of the compound character (Perfetti, Zhang & Berent, 1992). The same frequency–validity relationship holds for the phonetic component. The phonetic radical, when it stands alone as a character, is more likely to have the same pronunciation as the whole character for a low-frequency character. This general frequency–validity function is adaptive for reading. Less familiar characters are more likely to be correctly identified based on their components. Nevertheless, the validity of a phonetic radical is not high, as low as 38 percent (Zhou, 1978), although higher with alternative statistical procedures. Thus neither semantic nor phonetic information in characters is highly reliable, but both are useful. For pronunciation, the components are probably not reliable enough to support a systematic component approach to reading.



### *Identification with phonology in Chinese and English*

Experiments using various paradigms have produced evidence for phonology in Chinese reading at several levels from the character up through the sentence (e.g. Cheng & Shih, 1988; Hung, Tzeng & Tzeng, 1992; Lam, Perfetti & Bell, 1991; Perfetti & Zhang, 1991; Tzeng, Hung & Wang, 1977; Zhang & Perfetti, 1993). At the lexical level, the evidence is consistent with the identification-with-phonology hypothesis (Perfetti & Zhang, 1995; Perfetti and Tan, 1998, 1999; Tan & Perfetti, 1997), which places phonology as a constituent of word identification (rather than a by-product). The same constituent characterization has been applied to alphabetic writing (Perfetti, Bell & Delaney, 1988). Phonology is activated at the moment of *orthographic recognition* – the point at which the identification system distinguishes a given graphic representation from other (similar and partly activated) representations. Thus, although graphic information initiates identification, phonological activation does not lag much behind; rather it is part of a psychological moment of identification across writing systems. The difference between systems is that in an alphabetic system the elementary graphic units that initiate phonology correspond to phonemes. In a syllabic system, the elementary unit corresponds to a spoken syllable; in Chinese, the elementary unit (a character) is a spoken syllable that is also a morpheme.

The identification-with-phonology hypothesis has received considerable support. Xu, Pollatsek, and Potter (1999) and Chua (1999) independently reported evidence for phonological activation in a semantic categorization task. When asked to decide whether a character is a member of a prespecified semantic category, Chinese readers were slower and made more errors in rejecting a homophone of a category instance, a result parallel to what has been found in English (Van Orden, 1987). Although experiments with lexical decision tasks do not always produce phonological effects (Zhou & Marslen-Wilson, 1996), such effects have been found under some circumstances (Weekes, Chen & Lin, 1998). Other tasks have also exposed phonology in Chinese reading. For example, in brief (but slightly above threshold) exposure with backward masking, the target is better identified when the mask is a homophone (Tan, Hoosain & Peng, 1995), similar to results in English (Perfetti, Bell & Delaney, 1988). In semantic similarity judgments, two characters that are not similar in meaning but are homophones produce interference detectable in decision times, error rates, and event-related potentials (Perfetti & Zhang, 1995; Zhang, Perfetti & Yang, 1999; Perfetti, Liu & Tan, 2002).

Tasks that involve meaning judgments (semantic categories, meaning similarity) are especially important because they target the outcome of character identification – meaning – rather than phonology, which must show itself through interference. Their results support the conclusion that phonology is rapidly available as part of character identification, rapidly enough to interfere with an apparently slower semantic process. Results from these tasks cannot be taken to support the assumption that phonology mediates meaning, for which a different experimental logic is needed (Tan & Perfetti, 1997). Instead, they are critical in demonstrating the central idea that phonology is not by-passed in reading for meaning. However a different kind of experiment, the naming experiment, is helpful for exposing the time course of activation of lexical constituents when pronunciation rather than meaning is the outcome. We explain this further below in introducing the Lexical Constituency Model of word identification.

## The Lexical Constituency Model

We need to be clear about word identification, which may or may not be the same as "lexical access." Word identification *identifies* a word from the language of the reader, specifying a phonological object and its associated nonphonological components. This recovery of interlocked specifications of form and meaning, which we refer to as constituents, is the fundamental obligatory process of reading. In the Lexical Constituency Model, a word representation consists of three interlocking constituents: orthography (OR), phonology (PH), and semantics (SE). (For simplicity, the semantic constituent can be considered to include grammatical information as well.) A word's identity is the specification of the values of these constituent variables: the word $\{PH_i, OR_j, SE_k\}$ is the word such that it is pronounced $PH_i$, has orthographic form (spelling) $OR_j$, and has the meaning range $\{SE_k\}$. We say meaning "range," because we assume that, for a single word, meaning is not deterministic in the same sense that form is. The absence of any one of these {PH, OR, SE} values results in an underspecified identity, which can lead to identification failures of various types depending on the extent of unique OR and PH values in the system.

This formulation of identification as specification is universal, not language or writing-system dependent. The specification of a value on each constituent provides the identity of the word, as represented in a reader's mental lexicon. Thus, the process of identification becomes one of specifying constituents – the retrieval of orthographic form, phonological form and meaning from graphic input.

### *The time course of constituent activation in naming*

In this section, we briefly summarize primed naming data from Perfetti and Tan (1998) that expose the unfolding of lexical constituents over time. Chinese speakers were presented with a brief prime character followed by a target character at variable Stimulus Onset Asynchrony (SOA, the time interval between the onset of prime and target). The four types of primes included three that



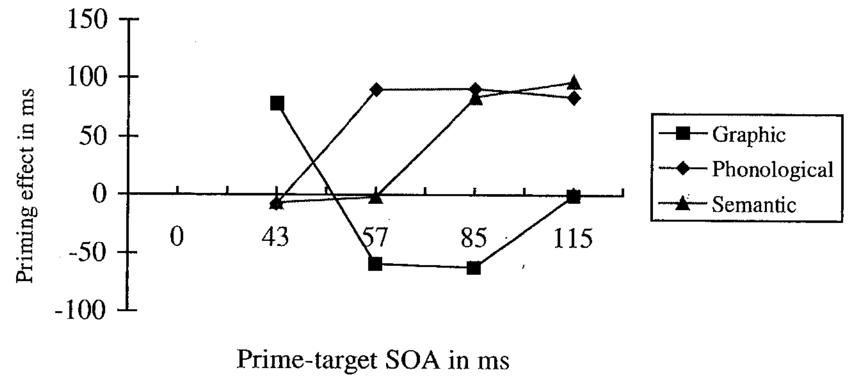


Figure 20.1 Priming effects in the experiments of Perfetti and Tan (1998)

briefly provided information relevant for the three lexical constituents. Graphic primes were visually similar to the target, sharing a radical (but no phonology or meaning) with the target. Phonological primes were homophones with no shared components and no graphic similarity. Semantic primes were related in meaning without graphic or phonological similarity. Unrelated primes served as a baseline. The SOA varied between 43 and 115 ms. The important results are the priming effects across SOA, as shown in figure 20.1.

Graphic, phonological, and semantic information, in that temporal order, affected target naming. Graphic information begins the identification process, and is the first to show a priming effect at 43 ms. Phonological information precedes semantic information in primed naming (57 ms vs. 85 ms). This is consistent with the task demands of producing a phonological output, although it may be observed in non-naming tasks as well under some circumstances (Perfetti & Zhang, 1995).

A nonobvious result visible in figure 20.1 is that the effect of graphic similarity was nonmonotonic over SOA.[1] The initial effect was facilitation at 43 ms SOA, but by 57 ms graphic similarity produced inhibition before it finally stabilized at the longest SOA, 115 ms. Notice that phonological priming became facilitative at just the point at which graphic similarity became inhibitory, a

[1] The facilitative graphic effect may be fragile. Shen and Forster (1999) also report graphic facilitation in naming (as well as lexical decision) with 50 ms of exposure. However, Chen and Shu (2001) report a study identical in critical respects to Perfetti and Tan (1998) in which they fail to find facilitative priming by a graphically similar prime at 43 and 57 ms, although they did find inhibition. Because graphic similarity provides the basis for both facilitation (similar form) and interference (similar-form, different pronunciation), the direction of graphic effects may be very sensitive to timing and viewing conditions if a brief period of facilitation prior to the onset of inhibition is to be detected. ERPs recorded during a decision task show an effect of orthographic similarity within the first 200 ms of viewing the second character (Liu, Perfetti & Hart, 2003).

pattern not observed in alphabetic reading. The general explanation for this oscillation pattern is as follows: the initial facilitation comes from the activation of a graphic constituent in the prime that activates other characters (including the target) that also have this constituent. The subsequent inhibition arises as the prime character itself is exposed long enough to become identified as a character, thus competing with the target. Because this description also applies to unrelated primes, which did not show this pattern, the correct explanation must include a role for the shared radical.

Finally, another result (not visible in figure 20.1) is the comparison between two kinds of semantic primes, vague and precise, as defined by subject ratings. This contrast reflects the perception of Chinese speakers that characters vary in the degree to which they provide clear meanings in isolation, a factor that affects word processing (Tan, Hoosain & Peng, 1995). What is interesting in the Perfetti and Tan data is that the effect of this semantic variable was dependent on the prime type. Graphic, phonological, and semantic primes all came in two types, precise and vague, but the effect of semantic vagueness was restricted to semantic primes, where priming occurred earlier for precise-meaning primes than for vague-meaning primes; for phonological and graphic primes, prime meaning was irrelevant. This suggests a functional independence between meaning and form features in primed naming. The earliness of graphic and phonological priming, relative to semantic, reflects pure form effects.

These time-course results expose the unfolding of lexical constituents. We turn next to how the time course of primed naming effects can be more precisely modeled.

### *A network implementation of the Lexical Constituency Model*

In this section, we describe a computational implementation of the Lexical Constituency Model that captures the time course of constituent effects in naming. The model implements the assumption that orthographic, phonological and semantic constituents jointly specify word identity. It implements also the determinacy principle: form–form relations are more deterministic than form–meaning relations. Thus, phonological form will be retrieved more quickly than meaning given a graphic form input.

The currently implemented model has a limited scope designed to recognize 204 characters that can be easily expanded within its general design principles. The model is a network of linked units of orthographic, phonological, and semantic constituents across which activation spreads. Its input units are radicals and spatial relationships between the radicals. The radical input and the phonological levels of the model can be considered distributed representations, whereas the orthographic and semantic representations can be considered



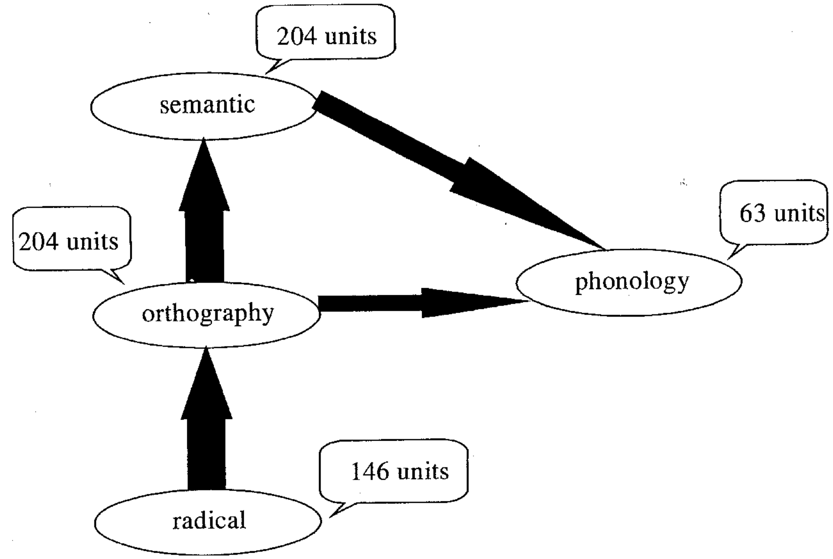


Figure 20.2 The Lexical Constituency Model. The input units are 146 radicals that begin activation in a three-constituent system. The three constituent levels – orthography, phonology, and semantic – combine to produce a three-constituent identification event.

localized representations. An illustration of the model is presented in figure 20.2 and its main design features are described below.

*Input (radical) level.* Among 146 input units, 144 units represent radicals, the basic components of Chinese characters, distributed across 9 slots × 16 binary-code units per slot. The other two units consist of a spatial slot to represent one of the four possible radical relationships within a Chinese character (left–right, top–down, close outside–inside, or open outside–inside). Each radical slot corresponds to one radical, assigned according to the writing sequence within a character. Because no character in the National Standard Chinese Character set (GB2312–80) has more than 9 radicals (Chinese Character Information Dictionary, 1988), 9 radical slots can represent all characters in our simulation set. The 16 binary-code units match the 16 binary codes for each character in the Chinese National Character Component Standard for Information Processing (GB2312–80). The model's input system is sufficient to represent the shared radical structure between almost any two Chinese characters. Radical unit $r_i$ ($i = 1, 2, \ldots, 146$) is either 0 or 1 for a given character.

*Orthography level.* The orthographic level is a localized representation of the abstract orthography of characters. Each orthographic unit represents one of the 204 characters. The activation value of orthography unit $o_i$ ($i = 1, 2, \ldots, 204$) is between 0 and 1. Negative (inhibitory) connections between each pair of orthographic units reflect competition between characters at the input level.

*Phonology level.* Phonology is implemented with the Chinese national standard alphabetic system, Pinyin. Each syllable is coded across 3 units – onset, vowel, and tone to represent Mandarin syllables, for which 24 onsets (one null), 34 vowels, and 5 tones are sufficient (63 units total). Because this level is a distributed representation, there are no within-level linkages, in contrast to the orthography and semantic levels. A phonology unit $p_i$ ($i = 1, 2, \ldots, 63$) has activation value between 0 and 1.

*Semantic level.* Character meaning is a localized representation of 204 units, each corresponding to a unique meaning of a single character. Meaning precision is represented by connection weights between the orthographic and semantic levels. A semantic unit $s_i$ ($i = 1, 2, \ldots, 204$) has activation value between 0 and 1. Within the semantic level, two related meanings are connected at a weight of .5, arbitrarily reflecting the assumption that semantic relations are not perfectly determinate, hence 1. Other connections are set at zero.

*Connectivity between levels.* The radical level is fully connected to the orthography level, sending activation to the 204 character units along weighted connections, which reflect whether a given character contains a specified input radical in the sequence specified in the radical slot. All characters containing that radical in the correct position are activated. The connections between orthography and phonology comprise three links from each orthographic character to units at the phonological level: one to the onset, one to the vowel and one to the tone, each with a weight of 1, with all other connection weights at 0. Connections between orthography and semantics reflect meaning precision. A precise-meaning character is connected to one semantic unit with weight 1. A vague-meaning character connects to one semantic unit at weight 0.8 and to all other 203 semantic units at randomly distributed weights between 0 and 0.1. Each semantic unit is connected to each of three phonological units (onset, vowel, and tone) at weight 1. All other connection weights are zero.

*Formal and semantic similarity representation.* A key idea of the model is to represent similarity along graphic, phonological, and semantic dimensions. Graphic similarity results from shared radicals because a given radical input activates a cohort of similar characters. Phonological similarity results from shared phonological activation patterns. Homophones have identical patterns; lower levels of similarity result from shared onsets, vowels, or tones. Related meanings arise from above-zero connections between the semantic units of characters that are semantically related. For example, semantically related primes and targets are linked with connection weights .5.



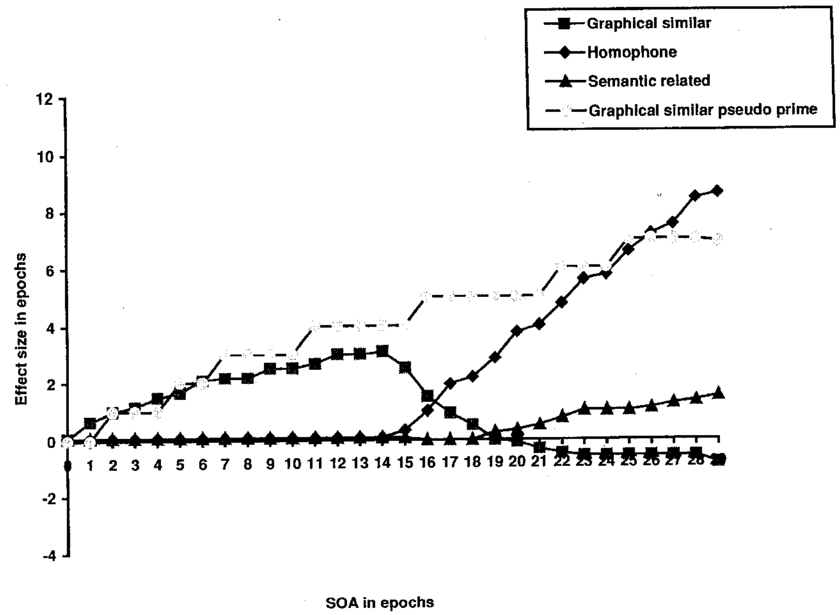


Figure 20.3 Simulated priming effect of four conditions

*Threshold.* Each unit in all three levels has a threshold below which the unit cannot send output to another level or within level. For example, below threshold, orthographic units send no output to phonology.

*A simulation of time-course data from Perfetti and Tan* (1998). Certain assumptions of the model – especially a threshold setting for orthographic units – turn out to be useful for simulating Perfetti and Tan's (1998) time-course results for graphic, phonological, and semantic priming effects. Of special interest is the oscillation effect for orthographically similar primes and the rise of phonological priming, coincident with orthographic inhibition. The simulation of this effect is shown above in figure 20.3. (The X axis shows processing cycles; the Y axis shows facilitation level; effects below 0 reflect inhibition.)[2]

The simulation captures clearly the pattern of graphic oscillation, with the onset of graphic inhibition coinciding with the onset of phonological facilitation. At short SOAs, the simulation produced facilitation from graphic primes

2 To simulate the primed naming experiment, a prime character is presented to the input units for 0 to 30 epochs and then switched to the target character. The model is allowed 100 iterations to achieve 0.9 activation in the corresponding onset, rhyme, and tone units linked to the target character. (Failure to achieve this level indicates an error.) The epoch number of the final iteration is treated as the reaction time of the current trial. Simulation algorithms can be obtained at http://www.pitt.edu/~liuying/simulation.zip.

through thirteen processing epochs, at which point interference began. The facilitation occurs because visually similar orthographic units are activated by the same radical; so with a graphic prime, the activation level of the target, which shares a radical with the prime, is nearer to threshold than it would be otherwise; hence, initial graphic facilitation without the orthographic unit of prime character itself reaching threshold.

The phonological priming is very straightforward: when an orthographic unit does reach threshold, it sends its activation to the phonological unit, immediately allowing a phonological priming effect to occur if the activated unit happens to be a homophone – i.e. a pronunciation shared with the target. However, in the case of graphic priming, because it has reached threshold, the orthographic unit itself is available to compete with the target: it has sent activation to an incompatible phonological output. The appearance of the target briefly keeps the prime orthographic unit activated, because of the radical shared by the prime and target orthographic units. The net result is competition that causes delay in the identification of the target. This competition does not occur with a prime that is not graphically similar to the target, because it does not share a radical with the target. The target's orthographic unit must be activated "from scratch" and by the time it reaches threshold, the prime's phonological unit, which was briefly available at threshold, has returned to below-threshold levels. Thus, two important form-priming effects are simulated successfully within the same processing time line. After a brief period of pre-threshold graphic facilitation, graphic inhibition and phonological facilitation simultaneously emerge.

Semantic priming also results from an orthographic unit that reaches threshold and sends its output to its semantic unit, which can activate related semantic units, including the semantic unit of the target. However, this priming is not as rapid as phonological priming, because the link between a target's semantic unit and that of a related prime is not as strong as the link between the target's orthographic unit and its phonological units. This difference in semantic and phonological linkages is an implementation of the assumption of differential determinacy of semantics and phonology, given an orthographic form. It might equivalently be characterized as capturing the idea that while forms can be identical (homophones), meanings cannot.

### *Implications of the model*

The importance of the computational model lies not in its details or even its correctness, but in its instantiation of the principles that are central to the Lexical Constituency Model. The organization of word identity as a triple of its three constituents allows for their mutual activation. Rapid phonology arises through direct connections between orthographic word forms and



phonological word forms. Meaning arises from direct connections between orthographic characters.

The extent to which a model for naming might generalize to semantic tasks is an open question. However, most of the models developed for alphabetic reading have been exclusively about naming. In that context, the specific contribution of the implemented Lexical Constituency Model is to demonstrate how a model of Chinese might accommodate existing modeling devices (e.g. representation of form and meaning levels, activation spread across levels) to the specific features of Chinese writing.

From this point of view, the major accommodation to be made is at the orthographic unit level, not at the level of connections between orthographic units and phonological units. Models for an alphabetic writing system must represent units at the letter level (or subsymbolic equivalents) and connect them to units at the phonological level to explain the facts of alphabetic word reading, including pseudoword reading. A model for Chinese must represent units at the radical level. The difference between writing systems thus becomes not whether there are connections to phonology but rather what the relevant units are. In Chinese, the phonological units are syllables, linked to characters, which themselves include perceptually functional components.

The fact that the characters are decomposable into radicals is important in our model. (Indeed, other research suggests that radicals have important but complex functions as input units to character recognition; Taft & Zhu, 1997; Peng & Tan, 1987; Feldman & Siok, 1999). However, the lexical composition of Chinese is not the same as for alphabetic systems, and it is important not to be misled by a superficial analogy, i.e. radicals are to characters as letters are to words. The radicals are orthographic units that may have value as morphemes (unlike letters). Some of the radicals themselves can be characters, having both meaning and pronunciation. Furthermore, they have no further orthographic constituents to correspond to phonology.

A possible limitation of the implemented model is that it ignores the validity of the radicals (those that could be considered phonetic radicals). The results of naming experiments suggest that characters with valid phonetics are named faster than characters without valid phonetics (Fang, Horng & Tzeng, 1986; Hue, 1992; Seidenberg, 1985; Yang & Peng, 1997) at least for low-frequency characters. Such a result has created a parallel with the frequency-by-regularity interaction in English (Paap & Noel, 1991; Seidenberg et al., 1984). The Lexical Constituency Model would capture such effects by representing the pronunciations of radicals that are part of the orthographic character level and connecting their output to phonological units. The general structure of the model is compatible with a stronger role for radicals, both semantic and phonetic, than is seen in the current version.

**Summary**

Research on Chinese reading has provided a better understanding of how readers use phonology even while taking advantage of the direct mappings between characters and meanings. The activation of phonology during reading appears to be universal and the co-activations of pronunciation and meanings are linked even in Chinese. The Lexical Constituency Model is a general framework for word reading within the family of network reading models. It explains the time course of constituent (orthography, phonology, and meaning constituents) activation during explicit word identification.

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