and evidence (pp. 153-171). New York: Psychology Press

8 Phonology Is Critical in Reading
But a Phonological Deficit Is Not the Only Source of Low Reading Skill

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In the course of 30 years or so, the idea that reading words requires phonology has ascended from a minority view to one with such a substantial majority that it now amounts to a conventional wisdom. This sweeping change of opinion can be celebrated as a triumph of reading science. It can also provide a moment for reflection to consider the perils that come with being a comfortable majority. In what follows, I examine both the celebratory and the cautionary aspects of the ascendancy of phonology.

THE ASCENDANCE OF PHONOLOGY*

Skilled Adult Reading

Consider skilled word reading: In the 1970s, skilled reading was seen mainly as a matter of visually recognizing a familiar letter string as a word, whose access was said to be "direct" (Baron, 1977; Coltheart, 1978). The alternative route, by which letter strings were first converted to phoneme strings, was for unfamiliar words, and therefore more for young children than adults. And consider this observation about skilled reading of English from Frank Smith (1979): "We (fluent readers of English) ... recognize words in the same way that fluent Chinese readers recognize the words of their nonalphabetic written language..." (p. 103 of second edition, 1985). Interesting here, in addition to the claim that English is read without phonology, is the use of Chinese as a benchmark writing system

* Reading research has used the term "phonology" loosely. In expressions such as "phonological awareness" and "prelexical phonology," researchers usually refer only to the phoneme level and not to the broader set of speech elements (e.g., syllabic stress, phrasal contours, and sentence prosody) that comprise phonology. I will use "phonological processes" to refer to the full range of phonology that may engage during reading, including phonemic processes.

for strictly visually reading, that is, reading without involvement of phonology. It turns out that even Chinese reading involves phonology, making the claim of parallels between Chinese and English empirically true in a way quite different from the original meaning of the 1979 statement by Smith. Nevertheless, I think that it turns out that Smith was partly right even in the way he intended.

The view that phonology is for children and is a backup route for adults reading unfamiliar words yielded over time to corrective research. The ascendancy of phonology came about through research that discovered phonological effects in word reading across a variety of tasks (with significant task differences). Among many experiments showing such effects were three lines of research that, at about the same time, made a strong case for phonology, specifically the role of phonemes in word identification: (a) brief exposure identification with masking and priming (Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988), (b) semantic category decisions (Van Orden, 1987), and (c) primed lexical decisions (Lukatela, G., Lukatela, K., & Turvey, 1993). Each of these lines of research produced multiple demonstrations that phonology plays a role in identifying a single word, in deciding whether a word fits a semantic category, or even just in deciding whether a letter string is a word.

To illustrate just the research from our backward masking experiments, Perfetti et al. (1988) presented subjects with a word for a brief subthreshold duration (e.g., 30 ms) followed by a pseudo-word mask, also for a short duration (30 ms), with a final pattern mask to terminate all letter string processing. The logic of the task was to expose the partial products of identification attempts. At subthreshold presentation, identification would be interrupted prior to completion by a following letter string mask, which would in turn would be interrupted by the final pattern mask. But if the mask contained letter overlap with the target, it could reinstate the letter information that was being interrupted. Similarly, if the mask contained phonemes that overlapped with the target, it could reinstate the phoneme information that was being interrupted by the mask, providing phonemic information was available prior to the interruption. In the key condition, a word written in all capital letters (*BAKE*) was followed by a lowercase pseudo-word homophone (*baik*) that reinstated its phonemes. This pseudohomophone mask condition was compared with a graphemic mask condition that was identical in its graphemic overlap with the word (*biak*). Compared with a control mask that shared no letters with the target, both the homophonic mask and the graphemic mask produced higher accuracy in identifying the word. Thus, the conclusion was that prior to the completion of word identification, phonemes, as well as graphemes, were partially activated and thus, could benefit from reinstatement from the mask. In a paradigm that presented the mask in a prime position, prior to the target, Perfetti and Bell (1991) found that identification accuracy for briefly presented targets grew as a function of orthographic priming and phonemic priming. Orthographic effects grew between 25 and 35 ms of prime exposure and purely phonemic effects (beyond orthographic effects) grew between 35 and 45 ms. Thus, as advertised in the title of the paper, phonemic effects can be observed within the first 40 ms of word identification. Time courses are relative to paradigms, and other tasks and

measures produce different estimates. For example, in a recent ERP study, Ashby, Sanders, and Kingston (2009) found clear evidence for phoneme-level phonology effects at about 100 ms (an N170), again a pre-lexical effect within the masked priming procedure used.

Each of these lines of research, semantic category decisions and lexical decisions, as well as brief exposure identification, produced persuasive results and also created their own paradigm issues, prompting experiments that sometimes produced results less compatible with the assumption that all word reading includes prelexical activation of phonemes. For example, in the semantic category paradigm, which famously demonstrated homophonic confusions in category judgments (e.g., Flower: ROWS? Van Orden, 1987), additional experiments suggested that homophonic confusions might not be completely general, but restricted according to exemplar frequency and category breadth (Jared & Seidenberg 1991). In the case of lexical decisions, experiments with clearly subthreshold presentations tended not to find "prelexical" phonological priming (Forster & Davis 1984; but see Ashby et al., 2009).

The overall pattern of contrary results had the effect of suggesting limitations on the generalizations within a given task, rather than undermining the conclusion of pervasive phoneme-level phonology. Thus, the consensus that grew out of the aggregate research effort was that reading alphabetic writing involves phonology in the early stages of word reading, even in English with its spelling-pronunciation inconsistencies.

Adding to this research were studies with languages other than English showing phonological effects especially for shallower orthographies that have more consistent mapping between graphemes and phonemes (see Frost, 2005). The evidence across orthographies, including English, was persuasive enough to support what Frost (1998) termed the *strong phonological hypothesis*: that all word reading requires the engagement of phonological representations.

Reading Disability

Next consider views on the causes of reading disability. The early work on dyslexia seemed to point to a visual basis for developmental reading disorders. The very phrase "congenital word blindness" (Morgan, 1896) promoted by Hinshelwood (1917) conveys the visual basis of reading disorders. And although Orton's theory of dyslexia (Orton, 1928) was mainly about hemispheric specialization (i.e., the failure to have left hemisphere dominance was the hypothesized cause of disability), it was Orton's descriptions of the symptoms of dyslexia that drew attention. The "stephosymbolia" or twisted signs symptoms were observed in the letter reversals that came to be associated with a sort of popular image of dyslexia that implied a visual disorder. It is interesting, by the way, to consider that neuroimaging research suggests that Orton may have been more nearly correct on the theory of hemispheric specialization than on the defining symptom of dyslexia. Turkeltaub, Gareau, Flowers, Zeffiro, and Eden (2003) report a marked difference in laterality between more- and less-skilled children across temporal and

frontal brain regions associated with word reading. Other imaging research has shown that these differences can be reduced with phonologically based training (Shaywitz et al., 2004; Simos et al., 2007).

As is clear from these imaging studies, phonological factors have ascended to central causal roles in explanations of dyslexia. The beginning of this ascendancy may be traced to Frank Vellutino's influential review of relevant research that included a strong critique of the visual theories (Vellutino, 1981). The case for a specifically phonological basis of dyslexia gained evidence from many sources that showed multiple phonological dimensions, including the importance of awareness of phonology (syllabic and phonemic) in learning to read (Bradley & Bryant, 1985; Liberman, Shankweiler, Fischer, & Carter, 1974; Stanovich, Cunningham, & Cramer, 1984). Beyond phonemic awareness was evidence showing weak phonological processes in low-skilled readers (e.g., Brady & Shankweiler, 1991; Snowling, Stackhouse, & Rack, 1986). This evidence grew across studies of groups of less-skilled readers that varied from well-defined dyslexics to "garden variety" poor readers. This evidence was sufficiently strong, and the issue of whether "true dyslexics" were different from garden variety poor readers was sufficiently important that Stanovich (1988) could propose a comprehensive and psychometrically coherent model that attributes the bulk of reading problems to a core phonological deficit that is accompanied by variable adaptations. Shankweiler and colleagues made much the same point: "Phonological deficits consistently accompany reading problems whether they occur in relatively pure form or in the presence of coexisting problems" (Shankweiler, Crain, & Katz, 1994, p. 2)

This conclusion of a core phonological deficit, based on experimental work, is reinforced by case studies of dyslexia. In an analysis of 16 dyslexia case studies, Ramus (2003) concluded that, although some patients had visual, cerebellar, or auditory problems, all 16 patients showed phonological deficits. Thus, the conclusions from behavioral studies of low-skilled readers, behavioral and imaging studies of dyslexics, and clinical studies converge on a core deficit in phonological representations or phonological processes. This does not mean that there are no other sources of reading problems; for example, contemporary visual deficit hypotheses have adherents and experimental results (Livingstone, Rosen, Drislane, & Galaburda, 1991; Stein & Walsh, 1997). But the ground has shifted so that the question has become not whether phonological deficits are a cause of disability, but whether there are any causes of dyslexia beyond phonological deficits or whether phonological deficits are the deepest level explanation (cf. auditory deficits or neural timing deficits) (e.g., Merzenich et al., 1996).

WHY IS PHONOLOGY SO IMPORTANT TO READING?

Phonology matters for reading because reading builds on language. If this is so, one then might wonder why phonology should be privileged over other levels of language, especially syntax and morphology. After all, syntax, morphology, and phonology are all part of the productive machinery of language, enabling it to code an infinity of messages through the combination of finite linguistic units.

Phonology is implicated so strongly because it is the level of language that provides the surface interface to written words. Graphic units map onto phonological units that can be phonemes (alphabetic writing) or syllables (either simple phonological syllables, as in Japanese Kana, or syllabic morphemes, as in Chinese). In the case of alphabetic writing, whether the orthography is shallow or deep, the basic units of writing are graphemes (consisting of one or more letters) that correspond to phonemes. Without sensitivity to the phonemic structure of language, and without word representations that include phonemes, there is a logical problem in mapping graphemes to phonemes.

It is important to be clear that this account does not claim that phonology is important only for alphabetic reading. When the focus was on English or other alphabetic orthographies, "phonology" tended to refer to the phoneme level, allowing the assumption that the importance of phonology (i.e., phonemes) was specifically about alphabetic reading. However, the discovery that reading a Chinese character also engages phonology (Perfetti & Zhang, 1991, 1995) demonstrated that the role of phonological factors in reading is highly general, probably universal. By now, there is substantial evidence that reading Chinese characters involves the activation of phonological representations, the spoken syllables that characters represent. (Some of this evidence is reviewed in Perfetti, Liu, and Tan (2005).) Phonology is not uniquely important for reading alphabets, although phonemes are. For once, it is appropriate to use the broad term "phonological processes" rather than "phonemic processes." To cover the broad universal character of phonology in reading, it is indeed *phonological* processes rather than merely phonemic processes that come into view. In the case of Chinese, the activated phonological unit in word reading is a syllabic form that includes non-segmental tone information (Spinks, Liu, Perfetti, & Tan, 2000). Phonemic knowledge is specifically important for reading alphabetic orthographies, whereas phonological knowledge is important for all types of reading systems. In addition, recent evidence suggests that a neglected aspect of phonology, syllabic stress, also plays a role in word reading (Ashby & Clifton, 2005).

Morphology: As Important as Phonology?

However, written word forms also represent morphemes, so we should expect morphosyntax to matter. Furthermore, morphology conditions lexical phonology, so that spellings may represent inflectional and derivational morphology more directly or more consistently than they do phoneme strings. English vowel alternation patterns in noun–adjective derivations (e.g., *nation* and *national*) illustrate the preservation of morpheme identity through spelling rather than pronunciation. Spelling also marks identity in bound morphemes affixes (e.g., *objection, protection*). Of course, spelling identity does not necessarily imply morpheme identity either in stems or affixes, so *mansion* and *revision* share a spelling but not a morpheme; *revision* and *omission* share a spelling and a morpheme, but the phoneme sequences that express the morpheme are different (*-zhun* vs. *shun*). *Omission* and *pollution* share a morpheme and pronunciation, but not a spelling.

These disassociations among morphemic, orthographic, and phonological components are subtle enough that skilled readers hardly notice them. But there is now substantial evidence that the morphemic status of a letter string—whether it is a morpheme or just a part of a word—affects written word identification across alphabetic orthographies (Feldman, Pnini, & Frost, 1995; Schreuder & Baayen, 1997). The issue for morphemic-based word identification is now strong enough that there is a corresponding issue for reading skill: that one source of reading problems is a morphemic processing deficit (Tsesmeli & Seymour, 2006). To the extent this is true, the question is whether such a deficit is primary, that is, independent of other problems, particularly phonology (Shankweiler et al., 1995).

One problem with the morphological deficit idea is that at least some of the evidence shows a surprisingly contrary result, namely, that both disabled and younger readers are more likely to show word reading benefits from morphemic constituents than are older and more skilled readers. Burani, Marcolini, De Luca, and Zoccolotti (2008) found clear evidence for this pattern in a study of Italian children's word reading, and Carlisle and Stone (2005) reported that in English, only younger readers showed a reading speed benefit for morphemically complex words compared with monomorphemes. Such a pattern suggests that morpheme constituents are available for younger and less able readers, and may provide a reading procedure to compensate for less-developed lexical and grapheme–phoneme strategies, which should be indifferent to the morphemic structure (Elbro & Arnbak, 1996).

There is an apparent contradiction between the general assumption that knowledge of morphemic structure is associated with skill in reading and the observation that skilled readers might use this knowledge less than disabled and younger readers. The solution may be that what is relevant is the aggregate of knowledge sources for word reading. Morphemic knowledge is one source, but there are three others that cohere around word knowledge: spelling, pronunciation, and meaning. (Notice that morpheme knowledge is similarly decomposable into spelling, pronunciation, and meaning.) In aggregate, these knowledge sources constitute lexical quality, the knowledge a reader has about a word. Accordingly, readers with generally low-quality lexical representations can have varying specific knowledge components about a word. In the case of a morphemically complex word, knowledge of a constituent morpheme may exceed knowledge at the word-as-a-whole level. Thus, a reader with generally low lexical quality may sometimes rely on morpheme knowledge to make up for weaknesses in other aspects of lexical knowledge. This possibility is consistent with the model of dual path word identification of Schreuder and Baayen (1997). A skilled reader can access a morphemically complex word through its constituent morphemes and through its whole lexical input. Highly familiar words can be accessed along the lexical path, whereas less familiar words can be accessed through a recognized morpheme constituent. Applied to the skill issue, a highly skilled reader can use high-quality representations for many words (i.e., representations that include detailed orthographic, phonologic, and semantic attributes), whereas a less skilled reader may benefit from using morpheme knowledge in reading many words of lower lexical quality.

Morphemes, as the basic form meaning units in language, are critical in the analysis of word knowledge and are functional as units in word reading. But because attention to morphology has traveled on the wake of an ascendant phonology, its importance has been a bit obscured. The importance of morphemic units in reading can be more readily seen in a writing system that elevates these units to greater prominence.

MORPHOLOGY, PHONOLOGY, AND ORTHOGRAPHY: A CROSS-WRITING SYSTEMS PERSPECTIVE

Relative to alphabetic writing, the high-contrast case is Chinese, which provides graphic units (characters and radicals) that correspond not to phonemes but to morphemes and syllables. The fact that characters correspond to spoken syllables as well as morphemes is critical, because it provides the basis for phonological processing in Chinese reading. Indeed, the role of phonology in reading Chinese characters is pervasive, instantiating the universal principle that writing systems are erected on language and not on conceptual objects directly. Although the pictographic nature of historically early Chinese writing reflects a competing correspondence principle of graph-to-concept, ultimately the full system evolved toward the universal language constraint that writing systems map language units. The general logic of writing systems—that their basic graphic units can correspond to language at the level of phonemes, syllables, and morphemes—compels corresponding units for reading procedures.

This logic was the basis for earlier hypotheses about reading units and reading development (Frith, 1985; Gleitman & Rozin, 1973) and has been an important part of the Universal Phonological Principle, which captures the observation that phonological units are immediately activated according to the units provided by the writing system (Perfetti, 2003). This logic is also the basis for the "psycholinguistic grain-size theory" of Ziegler and Goswami (2005), which adds the idea that the consistency of the mapping across written and language units affects the levels used, at least when the system provides multiple units (e.g., phoneme, syllable, and word or morpheme). Chinese writing, however, does not provide multiple levels systematically, and except for segmental and tonal cues provided by phonetic radicals, maps its written units to syllabic morphemes. Thus, in Chinese, unlike in other systems, reading procedures do not choose between a pronunciation unit and a meaning unit, they do both at once.

Here is the value of this perspective on the issue of whether morphemes are relevant in reading: If we are talking about a universal science of reading, morphemes have to be important. The question is how languages, which vary in their richness and expression of morphology, and writing systems, which vary in how directly basic writing units yield morphemes, modulate the role of morpheme units in reading. This question is difficult because of the tremendous variety among languages and writing systems in morphemic structures and their expressions, and it is beyond the scope of this chapter. However, for the present purpose,

the simple point is that languages other than English make clearer the centrality of morphemes in reading. By hypothesis (now with considerable evidence), this is true in English as well, but it is not always as easy to see.

The Lexical Constituency Model (Perfetti, Liu et al., 2005) expresses the dual outcomes of reading a Chinese character, namely, that the orthographic input units (radicals) yield both phonological syllables and meaning-bearing morphemes through connections from character units to syllabic and morphemic units. The importance of the model for the present purpose is its implementation of two basic principles of reading: (a) phonology in reading is universal and (b) the implementation of phonology is specific to writing system and language constraints. The procedures that produce phonology in reading Chinese characters are not identical to those that produce phonology in alphabetic reading. For example, some priming studies that vary the onset of primes and targets show that phonological primes facilitate word identification at the same time point at which orthographic priming, which occurs earlier, turns to inhibition (Perfetti, et al., 2005). Such a result suggests that reading a Chinese character produces phonology (i.e., activates the corresponding syllable) only when the orthographic character is accessed, not before. This threshold-style processing, which places phonology at the point of lexical access and not prior to it, contrasts with alphabetic reading, which proceeds with rapid cascaded activation based on smaller units (graphemes to phonemes), allowing phonology to precede and contribute to lexical access. At the Chinese character access point, both the morpheme and the syllable connections to the character are available and can be accessed in parallel, with other factors determining the relative timing of meaning and pronunciation information.

Reading Problems Traced to Orthography and Morphology

This model of Chinese reading places orthographic and morphemic information in prominent positions (while maintaining an important, automatic role for phonology). The orthographic representation is the critical starting point for word identification universally; it may turn out to be important in Chinese reading disability in a way that exceeds its role in alphabetic reading. To be clear on this point, there is no reason to think that orthographic processing is not just as important in alphabetic reading; indeed the establishment of high-quality orthographic representations is the gateway to efficient reading. It is just that the importance of orthographic representations for reading ability has been obscured in English because of the well-demonstrated limitations placed by phonological processes. The way to understand the big picture here is to see that weak phonological processes have their effect in part by inhibiting the formation of quality orthographic representations. In alphabetic writing, orthography depends on phonology and in alphabetic reading, acquiring orthographic representations depends to some extent on being able to decode, to provide the phoneme strings that correspond to a word's letters (Share, 1995). In Chinese, by contrast, orthography depends on orthography. That is, the orthographic form

in Chinese depends on graphic conventions that have evolved over centuries with only ad hoc connections to a word's phonology.

Given this analysis, it should come as no surprise that reading disability in Chinese may have causes beyond a phonological deficit. Again to be clear, a phonological deficit in Chinese will lead to a reading disability. However, a phonological disability might be more selective in its manifestations, more specific to phonological aspects of reading, less disabling to reading for meaning under circumstances in which a reader can gain sufficient practice in reading. Because Chinese characters are learned as graphic forms with strict compositional principles and no principled phonological aspects, the burden on learning is visual-motor memory. It is true, but irrelevant for the present argument, that children learn pinyin, an alphabet, before learning characters. This provides a phonological underpinning to reading in general (children learn that reading is about connecting print to spoken language) and to character reading in particular (as the character for a syllable replaces the pinyin for that syllable). But it does not alter the basic visual-motor learning required (motor, because children learn to write characters along with learning to read them).

The theoretical perspective sketched above has empirical support. Ho, Law, and Ng (2000) concluded that reading-disabled children have deficits in phonological processing, but only those who also have writing deficits. The idea that, in Chinese, reading depends on writing received confirmation from Tan, Spinks, Eden, Perfetti, and Siok (2005) in a study of Hong Kong children. They found a zero correlation between a phonemic odd-man-out task and beginning reading scores; similarly, syllable deletion was not correlated with beginning reading. What was correlated with beginning reading scores was copying performance on pseudocharacters (r = .49). Picture drawing performance showed a more modest correlation (r = .23) with reading. This pattern seems to suggest the importance of a specific orthographic form component that is measured by pseudocharacter copying. It is not just a cultural tradition that children in China spend their homework hours writing characters; the demands of recognizing hundreds of characters place a premium on a quality representation that is enhanced by practice at producing the character. There is even evidence that the perception of a character by adults is sensitive to the stroke orders used in production (Flores d'Arcais, Saito, & Kawakami, 1995). The big picture here is that the relative importance of lexical components (phonology, orthography, morphology) is shaped by the writing system and the specific orthography that implements the system, which cause writing-specific adaptations in learning to read. It is not that phonology is not important in Chinese reading. Indeed, not only is there ample evidence for automatic access of phonological information in character reading (e.g., Perfetti et al., 2005), beginning reading correlates with phonological awareness. However, in at least some of this research (Ho & Bryant, 1997; McBride-Chang & Kail, 2002), the relevant level of phonological awareness does not appear to be the phoneme, but the syllable. Beyond phonological awareness, at whatever level, the added demands of Chinese orthographic units, which have limited decomposability

compared with alphabetic writing, require more ability at forming character-at-a-time representations through practice at reading and writing.

Universality and the Neural Basis of Reading

The idea that there is a universal phonological basis for reading and for reading disability comports with the assumption that there is a universal set of neural networks that underpin reading. This idea gains support from comparative studies of European alphabetic reading (Paulesu et al., 2000) and is captured in Paulesu et al.'s (2001) title *Dyslexia: Cultural diversity and biological unity.* The conclusion reflected evidence that the consistency of grapheme–phoneme mapping was reflected in the relative use of lexical and sublexical pathways in reading, and a corresponding variation in the expression of reading disability across different orthographies.

The existence of universal neural circuits for reading makes sense to the extent that visual, orthographic, phonological, and semantic components of word identification are universal. Meta-analyses of word reading studies show an alphabetic reading network that includes posterior visual regions (occipital areas and left mid-fusiform gyrus) for orthographic processes, temporal/parietal (superior temporal sulcus) and anterior areas (inferior frontal gyrus and sulcus/insula) for phonological processes, and both posterior (posterior temporal/anterior fusiform) and anterior regions (anterior portion of inferior frontal gyrus) for meaning (Bolger, Perfetti, & Schneider, 2005; Fiez & Petersen, 1998; Jobard, Crivello, & Tzourio-Mazoyer, 2003; Mechelli, Gorno-Tempini, & Price, 2003; Price, 2000; Turkeltaub, Eden, Jones, & Zeffiro, 2002).

This network may indeed be universal in general terms. Visual processing in any writing system involves occipital areas and the left fusiform gyrus is involved in visual word recognition for characters as well as for alphabetic words (Bolger et al., 2005). However, there also appear to be some writing-system-related variation. Perfetti et al. (2007) review this question, pointing out that with a growing body of imaging research in Chinese (Tan et al., 2001, 2003), the differences between Chinese and alphabetic reading have become impossible to ignore (see Tan, Laird, Li, & Fox, 2005, for a review and meta-analysis). Imaging results show more bilateral activation for Chinese in occipital and fusiform regions and more activation in a frontal area, the left middle frontal gyrus (LMFG), compared with alphabetic reading. Siok, Perfetti, Jin, and Tan (2004) further report that Chinese children who were poor in reading showed underactivation of the LMFG, compared with children who were skilled readers, and structural evidence suggests reduced mass of the LMFG for Chinese dyslexics (Siok, Niu, Jin, Perfetti, & Tan, 2008).

Studies of Chinese reading also find less involvement of the temporal-parietal region and the inferior frontal gyrus, compared with studies of alphabetic reading, where both are assumed to support phonological processes. It is possible that the LMFG is serving phonological processing in Chinese, but it also is possible that it is serving some other function (e.g., memory for character form). Its function is not clear, but its persistent appearance in imaging studies points to

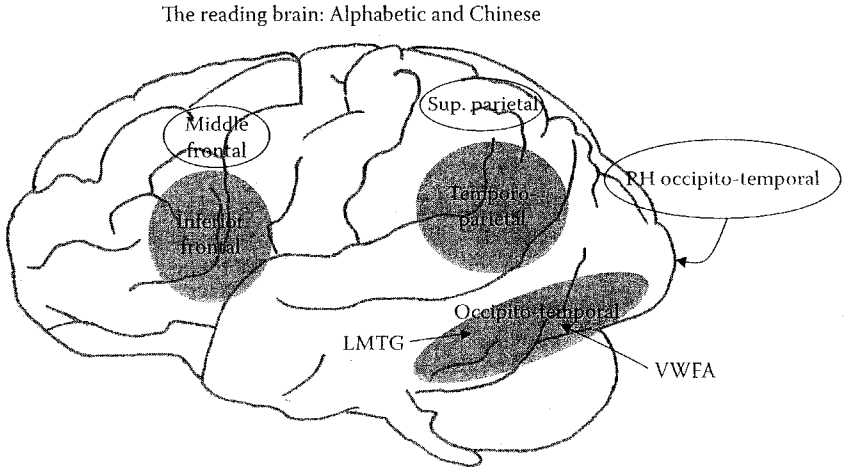

FIGURE 8.1 Schematic representation of left hemisphere reading networks highlighting areas identified for alphabetic reading (gray) and Chinese reading (based on Tan et al., 2005 and Bolger et al., 2005). Although there is evidence that part of this network is universal across writing systems, some differences between Chinese and alphabetic reading are highlighted. In particular, the frontal component for Chinese reading and Chinese dyslexia shows more involvement of the left middle frontal gyrus (labeled Middle frontal in the figure) and less for the inferior frontal gyrus. Chinese also shows less involvement of left temporal parietal areas and the left middle temporal gyrus (LMTG) and more for the superior parietal area (sup. parietal). Finally, the visual areas the visual word form area (VWFA) show more bilateral activation for Chinese (indicated by the label for the right hemisphere (RH) occipito-temporal region) as compared with the left hemisphere-dominant activation for an alphabetic system.

a routine and important role in character reading. (See Perfetti et al. (2007) for discussion of possible roles for the LMFG in reading.)

Thus, it appears that most imaging studies support a picture of Chinese reading that is illustrated in Figure 8.1, based on the Tan et al. (2005) meta-analysis. This shows that reading in Chinese recruits bilateral occipital-temporal areas and a frontal system that includes the LMFG, at least when phonology is involved. The frontal system for alphabetic reading, in contrast, makes greater use of the left inferior frontal cortex. There appears to be a universal reading network because orthographic, phonological, semantic, and morphosyntactic processes are part of word reading. (The last is little studied in single-word reading but becomes important in sentence reading.) An unexpected implication of some studies of bilingual reading is that the Chinese reading network may provide a general procedure for reading that can assimilate an alphabetic writing system, whereas the alphabetic network cannot be applied to Chinese (Perfetti et al., 2007).

To put these observations in the context of the main question about the role of phonological processes in reading, it is perfectly coherent and arguably true to conclude that phonology is universal in reading, whereas the implementation of phonology depends on the writing system. Theoretically, the incremental

cascaded style of alphabetic phoneme-level phonology contrasts with the all-or-none threshold style of syllabic phonology in Chinese (Perfetti et al., 2005). These two complementary procedures both yield phonology as a routine part of reading. Further, a deficit in processing phonology at the level needed for the writing system leads to an impairment in reading Chinese, just as it does in reading English. The details matter, however. Thus, we should expect to see that visual-orthographic skill is important in Chinese, and it is. We should expect to see neural evidence that character reading involves phonology through cortical areas associated with lexical phonology more than assembled phonology, and we do. It should be possible to be impressed by universality and diversity at the same time.

READING SKILL DEPENDS ON WORD KNOWLEDGE

In this section, I consider an additional perspective on reading skill that requires more than phonology. It follows from one interpretation of phonological deficits (that such deficits are in the phonological system that serves spoken language) that reading disability implies a language disability. However, because reading requires using the phonological system in a new way with phonological units of limited accessibility being mapped to meaningless letters, reading may be the stressor that exposes a phonological deficit that can go undetected in spoken language. Either way, the phonological deficit hypothesis has a large scope: all difficulties in reading may be due to phonological deficits. The upward reach of the hypothesis was clearly expressed by Shankweiler (1989): "Difficulties at each level [the word, the sentence, the text] might stem from a deficit in phonological processing." This deficit was not about phonemic awareness, which came to be seen as just one symptom of a deeper phonological deficit, a point made very clearly by Liberman and Shankweiler (1991).

In the first part of this chapter, I reviewed some reasons to accept the centrality of phonology in explanations of reading disability, with other observable problems often secondary rather than primary causes. My point of departure is that, whereas the phonological deficit hypothesis is correct even with its large scope, it is not the end of the story. The scope of the phonological deficit hypothesis is parallel to the scope of the verbal efficiency hypothesis (Perfetti, 1985). The first traces problems in word knowledge and sentence and text comprehension to problems in phonological processes. The second traces problems in meaning and comprehension at the word, sentence, and text levels to word and subword processes that include phonology.

However, it is useful to qualify the upward implications of both theories. Neither verbal inefficiency nor phonological deficits are assumed to be the only cause of reading comprehension problems. One implication of any theory that postulates higher level consequences of lower level processing limitations is that identifying groups with comprehension problems in the absence of decoding or phonological problems requires stringent assessment of those lower level skills. This stringent assessment standard has not always been reached and much research that has claimed to identify higher level problems as causal has failed to

do so because of this. However, there are now enough studies that have done more stringent assessments to allow the conclusion that there are both children and adults whose problems in reading are observable in the absence of phonological decoding problems. (See Nation (2005), for a review of such studies.)

Among the many other things that go wrong, knowledge of word meanings is a major candidate for a factor in reading skill beyond phonology. Beyond the obvious observation that it is difficult to understand a text that contains many words beyond the reach of the reader's vocabulary, the intertwining of word understanding and text understanding is a central part of reading. The general relation between vocabulary and comprehension is a strong one with reciprocal causation. (See Perfetti et al. (2005), for a review.)

Two large-scale studies with two different populations and writing systems suggest the power of word meaning knowledge relative to other factors. Protopapas, Sideridis, Simos, and Mouzaki (2007) studied a large sample (n = 534) of Greek children in Grades 2–4, taking measures of vocabulary, comprehension, fluency, and word and pseudo-word reading. The measures correlated in sensible ways over the age range. Especially interesting is that in a hierarchical regression analysis, the unique contribution of word reading to comprehension became negligible after vocabulary measures were entered, especially in the third and fourth grades. We can infer that the effects of word decoding on comprehension become lexically mediated, with word meanings more relevant than simple decoding. The authors' final structural model most consistent with the data showed vocabulary as a covariant of word reading accuracy and a direct cause of comprehension. Of course, Greek is a transparent orthography and this pattern of results and the model's causal pathways may reflect the relative ease of phonological decoding in a transparent orthography. But that is another way of expressing the argument made here: That when phonological decoding is mastered, problems in reading, both word reading and comprehension, become linked to low knowledge about word meanings.

Moreover, this important role for word knowledge is not restricted to transparent orthographies. Braze, Tabor, Shankweiler, and Mencl (2007) studied older readers (age 16–24) of English, using an array of assessments—phonological awareness, decoding, verbal working memory, listening comprehension, reading comprehension, word knowledge, and print experience. Whereas decoding was related to reading comprehension, an orally administered vocabulary test accounted for unique variance in reading comprehension even after listening comprehensions and decoding skill were accounted for. The differences between these two studies in reader ages and orthographies suggest that the role of word meanings in reading comprehension is quite robust beyond the beginning stages of reading.

None of this really surprises. We expect word meaning to be relevant, and no one has ever argued to the contrary. However, word meaning has not been afforded the same critical status as phonology and decoding, because one could argue that phonology and decoding were limiting factors in the acquisition of reading and, in turn, of word meanings. Therefore, one could assume that word

meanings are secondary factors, whereas phonology and decoding (or maybe just phonology) are primary causes. However, although the logic of this view is correct as far as it goes, it leaves an incomplete picture. A reader who has acquired phonological decoding sufficient to decode an unfamiliar nonword can have a knowledge of word meanings (and word spellings) that is insufficient for many reading situations and thus costly to comprehension (e.g., Chall, Jacobs, & Baldwin, 1990). The consequences of low vocabulary knowledge can be a semantic deficit that affects not only comprehension, but, in English, the identification of words that are exceptional in their spelling–phoneme mappings (Nation & Snowling, 1998; Ricketts, Nation, & Bishop, 2007). Moreover, the use of word meanings may facilitate the acquisition of decoding skill. Sumutka, Brady, and Scarborough (2005) found that vocabulary knowledge supports the decoding of regularly spelled words when children first encounter them in print.

A general word knowledge perspective on reading skill is the lexical quality hypothesis (Perfetti, 2007; Perfetti & Hart, 2001), which claims that variation in the quality of individual word representations over phonological, orthographic, and semantic constituents has consequences for reading skill, including comprehension. Because phonology is a gateway to increasing lexical representations, it is reasonable to say that phonological representations and the phonological abilities that allow them are critical to word reading. However, it is equally clear that, with practice, orthographic representations of individual words are established and these become the gateways to highly skilled reading. If phonological decoding is the hallmark of basic word reading, the rapid use of orthographic patterns, including whole words, is the hallmark of fluent reading. The evidence that orthographic knowledge is related to reading skill has been around in one form or another for a long time (e.g., Katz, 1977; Mason & Katz, 1976) and supports the conclusion that orthographic knowledge makes a unique contribution to reading beyond phonological knowledge (Barker, Torgesen, & Wagner, 1992; Cunningham & Stanovich, 1990; Stanovich & West, 1989). However, the implications of this consistent result seem to have lost some visibility because of the attention given to phonological factors. Thus, even the unique role of orthographic knowledge is often termed "secondary" to the primary role of phonology (e.g., Share & Stanovich, 1995). Indeed, in the search for primary causes in complex causal chains, phonological processes deserve this primary status. However, to take seriously the results that show unique variance due to orthography, we must conclude that orthographic knowledge causes reading success. Of course, this is not a one-or-the-other issue. Orthographic and phonological knowledge both contribute to reading skill, and, as reviewed in the first section of this chapter, phonology continues to be part of word identification and a part of comprehension even in highly skilled reading. The acquisition of high-quality orthographic representations enables rapid lexical access with phonology.

Spelling is an indicator of the quality of orthographic representations, even though, of course, we can read words we cannot spell. Word reading skill depends on the refinement of word representations that add spelling knowledge to spoken word representations. Research on word reading skill has tended to ignore

spelling. We are learning, however, that even among "good readers," differences in knowledge of word spellings leads to differences in word reading processes (Andrews, 2008).

CONCLUSION

Research leading to the ascendency of phonology as the critical component in learning to read and the major factor in dyslexia is one of the major achievements in reading science. The evidence that phonology continues to play a role in skilled adult reading and does so universally across writing systems is part of this achievement. The work of Shankweiler and his colleagues has been on the leading edge of this ascendency of phonology. The time has come to take a step back and appreciate the scope of this achievement, both as a scientific breakthrough and as a salubrious injection of scientific results into reading pedagogy and remediation. It is also a time to think about other parts of the reading puzzle. Phonology is universal in reading, but not uniformly implemented and certainly not reliant on universal units of language and writing. Ironically, the more universal procedures may have less to do with phonemes than with larger units of both speech and writing. What develops along with phonology is orthography, and in skilled reading, orthographic representations take on an increased role. Finally, word meanings and their associated morphological constituents are important in ways that go beyond phonology. Reading is above all dependent on word knowledge, including the spoken forms, written forms, meanings, and morphosyntactic structures of words. Although we have learned that acquiring this lexical knowledge depends significantly on a skilled phonological component, we have more to learn about the fuller story of word knowledge and skilled reading.

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