Chapter 2
Reading-Related Phonological Processing in English and Other Written Languages

Richard K. Wagner, Rachel Joyner, Poh Wee Koh, Antje Malkowski, Sunaina Shenoy, Sarah G. Wood, Chong Zhang and Fotena Zirps

Abstract The three major phonological skills related to word-level reading are phonological awareness, phonological short-term/working memory, and phonological retrieval (i.e., rapid automatized naming). These skills and their relations to reading development in English and other alphabetic writing systems are presented. Then, the phonological processes in a non-alphabetic writing system, Chinese, are explored, as are the phonological skills of multi-lingual students. Research in these areas helps provide a better understanding of the nature of reading and reading development in English and other languages.

R. K. Wagner (✉) · R. Joyner · A. Malkowski · S. G. Wood · F. Zirps
Florida State University, Tallahasee, FL 32306, USA
e-mail: rkwagner@psy.fsu.edu

R. Joyner
e-mail: rjoyner@psy.fsu.edu

A. Malkowski
e-mail: amalkowski@fsu.edu

S. G. Wood
e-mail: sgw12@my.fsu.edu

F. Zirps
e-mail: fzirps@psy.fsu.edu

P. W. Koh
Texas A&M University, College Station, TX, USA
e-mail: pohwee.koh@gmail.com

S. Shenoy
University of New Mexico, Albuquerque, NM, USA
e-mail: shenoy@unm.edu

C. Zhang
China National Institute for Education Sciences, Beijing, China
e-mail: zhangchongchina@126.com

D. A. Kilpatrick et al. (eds.), *Reading Development and Difficulties*,
https://doi.org/10.1007/978-3-030-26550-2_2

All writing systems convey information about meaning and pronunciation. This is true regardless of what oral language or languages you know and which of the many written scripts you are reading. Reading-related phonological processing refers to the pronunciation aspect of the information that is represented by print. The Greek word *phōnē* (**fwnh/)** refers to sound or voice, and it is the root of the family of words that includes *phonological, phonemic, phone*, and *phoneme*. The general term phonological processing refers to use of speech-based sounds/codes for processing oral or written language (Wagner & Torgesen, 1987).

The present chapter is divided into four parts. In the first part, we provide a brief review of the three most widely known reading-related phonological processes and their relations to reading. Much of this research is based on studies using alphabetic orthographies. For many years, it was assumed that completely different requirements were associated with different kinds of scripts, such as alphabetic writing systems versus non-alphabetic writing systems. However, we now have a rapidly growing body of literature based on non-alphabetic orthographies such as Chinese, so we provide a brief review of this growing literature in the second part. Reflecting the growing interest in bi- and multi-lingual individuals, part three provides a brief review of phonological processing in individuals' non-native languages. In the fourth and final part, we address the assessment of phonological processing.

2.1 Three Kinds of Reading-Related Phonological Processing

Three kinds of phonological processing are most commonly associated with reading: phonological awareness, phonological memory, and phonological recoding in lexical access (Wagner & Torgesen, 1987).

2.1.1 Phonological Awareness

Phonological awareness refers to one's awareness and access to the sound structure of one's oral language (Mattingly, 1972). Sound structure refers to how the words in an oral language are pronounced, and this structure can be represented at several levels. At the lowest level, *phones* refer to all sounds that are made when pronouncing the words in one's language. For example, pronouncing the first sound in the English word "tuck" involves placing the tip of the tongue on the back of the upper front teeth, blocking off the airway and building up some pressure in it, then explosively releasing the pressure by opening the airway and dropping the tip of the tongue away from the back of the teeth. This sound is labeled a plosive stop consonant because of the way it is produced. The first sound in the word "puck" is produced in a similar manner except that the tongue is not placed against the back of the teeth, but rather the lips are closed and then opened. Relatedly, doing similar articulatory gestures but pushing air through the vocal cords to get them to vibrate changes the sound from the unvoiced first sound in "puck" to the voiced first sound in the word "buck."

At the next higher level of sound structure, related phones are categorized into abstract phonemes that signal differences in meaning. For example, "tuck" and "duck" mean two different things, and this is signaled by the fact that the words begin with different phonemes. In alphabetic writing systems, the sounds of letters of the alphabet correspond roughly to phonemes. The degree of correspondence varies depending on where the orthography falls on the continuum between transparent (e.g., Finnish, with a nearly perfect correspondence between letters and phonemes) to opaque (e.g., English, where there are many deviations from perfect correspondence). The sounds associated with the "t" in the words "top," "stop," and "pot" are identical phonemes but actually different phones in that there are subtle differences in the articulatory gestures used to pronounce them. To demonstrate this fact, hold your hand in front of your mouth while you say the words *top, stop,* and *pot*. You will notice differences in the degree to which you feel an explosive burst of air associated with the /t/ sound. The largest burst will be felt for the /t/ in *top*. Somewhat less of a burst will be felt for the /t/ in *pot,* and the least amount will be felt for the /t/ in *stop*. Different phones that are associated with the same phoneme, such as the three sounds of the /t/ are referred to as allophones of the phoneme /t/.

For Midwestern American English, which refers to the dialect spoken by most newscasters on national networks in the USA, all of the words in the language can be produced by stringing together a sequence taken from a basic list of just over 40 total phonemes. Combinations of phonemes give rise to additional levels of representation. A syllable, for example, is a unit of sounds that typically consists of an onset and a rime. The onset refers to the initial consonantal phoneme (e.g., the *h* in *hat*), and the rime refers to vowel and any trailing phonemes in that syllable (the *at* in *hat*). For example, the first syllable in the two-syllable word *subject* is made up of the onset /s/ and the rime /ub/. All whole words are made up of one or more syllables.

Different orthographies represent speech differently, depending on what the symbols signify. Japanese Kana is referred to as a syllabic orthography because the characters represent syllables for the most part. Regular or transparent alphabetic orthographies such as Finnish or Spanish are referred to as phonemic orthographies because the letters correspond to phonemes. Irregular or opaque alphabetic orthographies such as English or French are considered to be morphophonemic orthographies because the spellings represent sounds or phonemes but with exceptions that reflect morphemes or meaning (Seymour, Aro, & Erskine, 2003).

There is a well-established developmental order in which children are able to access levels of phonological representation. Larger units are easier to bring to awareness and manipulate than smaller units. The easiest and most accessible level for awareness and manipulation is compound words, which are composed of whole words (e.g., *cow-boy*). Next comes the ability to recognize and manipulate syllables within whole words (*en-ter*). Following that is an awareness of onsets (i.e., the initial consonant(s) of a syllable) and rimes (i.e., the vowel and remaining consonants within syllables) (e.g., *r-un*) and the ability to manipulate them. Then comes an awareness and ability to manipulate individual phonemes (e.g., /r/ /u/ /n/), followed by an awareness and ability to manipulate individual phonemes within phoneme clusters (e.g., /s/ /t/ /r/ /aw/) (Crowder & Wagner, 1992).

A practical application of this order of phonological development is in selecting test items for an assessment designed for individuals at different developmental levels. For example, blending is a common phonological awareness task in which separately presented speech segments are combined, often to form a whole word. The very easiest blending items, which can be performed by pre-readers, are blending two words together to form a compound word. The next easiest, which also can be performed by pre-readers, are items requiring blending syllables together to form a word. Then comes blending onsets and rimes into syllables, a task that can be difficult for pre-readers. Very difficult for most pre-readers are items that require blending of individual phonemes. By incorporating each of these kinds of items in the appropriate order, it is possible to come up with a blending task that can be used for all readers, from pre-readers to skilled readers.

2.1.2 Phonological Memory

Phonological memory refers to using phonological (i.e., speech-sound-based) codes for temporary storage of information. If you try to remember a series of numbers or letters, you typically will code them phonologically by saying and maybe repeating their names. This keeps them active in short-term memory. Information can be kept in short-term memory for short periods of time by using the phonological loop and an articulatory control process (Baddeley, 1986, 1992; Torgesen & Davis, 1996). The phonological loop can be thought of as a loop of recording tape that can store roughly the most recent 2 seconds worth of auditory input. The articulatory control process allows auditory information to enter the phonological loop and can also be used to refresh the information in the loop so that storage extends beyond 2 seconds.

Reading single words that are already known do not appear to rely heavily on phonological memory, but phonological memory appears to be more critical for other aspects of reading and language. First, phonological memory is used when a new word is encountered and one attempts to read it by sounding it out. What appears to be happening is that the sounds of individual letters are retrieved sequentially, and successfully sounding out the word requires storing the initial sounds while subsequent sounds are retrieved. Second, impaired phonological memory can make it more difficult to learn new words encountered in print and also appear to constrain adding new words to one's oral vocabulary (Gathercole & Baddeley, 1990; Gathercole, Willis, & Baddeley, 1991). The reason that impaired phonological processing appears to constrain adding new words to one's oral vocabulary may be the same reason that makes it difficult to read new words by sounding them out. New oral vocabulary words exist as a string of phonemes that must be stored in order to form a pronunciation that can be associated with meaning. Based upon David Share's *self-teaching hypothesis*, this sounding-out process plays an important role in remembering newly encountered words (see this volume Miles & Ehri, Chap. 4). Third, phonological memory appears to be required to support working memory when comprehending entire sentences. Although it is true that meaning is extracted when words are encountered in sentences, readers need a sense of the order of words in complex sentences to understand them. Phonological memory appears to facilitate this (see Oakhill, Cain, & Elbro, Chap. 5, this volume).

2.1.3 Phonological Recoding in Lexical Access

Phonological recoding in lexical access refers to coding information phonologically for the purpose of lexical entry, i.e., accessing the location in memory where a word's pronunciation, orthographic representation, and meaning are stored. Location may be the wrong metaphor because the three kinds of representations may be distributed rather than stored in a specific location in the brain. Yet the basic idea of using pronunciation to access a word's orthographic representation and meaning holds true regardless. Phonological recoding in lexical access is typically assessed by tasks that are commonly referred to as *rapid automatized naming* (RAN), or simply *rapid naming*. Such tasks require individuals to name strings of known items as quickly and accurately as possible. It has also been assessed in the laboratory using a computer presentation of single items and a voice-activated key measures, in milliseconds, when the pronunciation begins. Rapid naming of items such as the names of pictured objects, the names of the colors in colored squares, or the names of letters or digits requires efficient recall of the pronunciations that comprise the names from long-term or permanent memory. Although the name retrieval aspect of the task is clearly phonological in nature, rapid-naming tasks are different from phonological awareness and phonological memory tasks in that visual stimuli are required for such assessments. This makes the rapid-naming task a hybrid one in which a visual symbol must be processed or identified as an initial step in the name retrieval process. It has been assumed that the efficiency with which individuals are able to retrieve the phonological codes associated with individual phonemes, word segments, or pronunciations of complete words should influence the degree to which phonological information can be used to read words (Baddeley, 1986; Wolf, 1991).

The hybrid nature of rapid naming means that naming will depend on how well the items to be named are known, how well the associated phonological representation is known, and how strong the mapping is between the item and its pronunciation. Reading shares this hybrid nature, and this may be one reason why rapid naming is predictive of reading independently of measures of phonological awareness (Bowers & Swanson, 1991; Lervag & Hulme, 2009; Manis, Doi, & Badha, 2000; Parrila, Kirby, & McQuarrie, 2004).

Most of the research that was reviewed in the previous section was based on studies with participants who were learning alphabetic writing systems such as English. What is known about how phonological processing is related to reading non-alphabetic scripts such as Chinese?

2.2 Reading-Related Phonological Processing and Learning to Read Chinese

Decades ago, when research was primarily based on alphabetic writing systems, the most important link between phonological processing and reading was believed to be mapping phonemes onto letters. Alphabetic writing systems are designed to represent the spoken language at the level of individual letters, though as mentioned, some alphabet-based writing systems do so more transparently than others (Seymour et al., 2003). Impaired phonological processing was thought to interfere with developing tight connections between letters and sounds.

Non-alphabetic writing systems such as Chinese do not have alphabetic letters corresponding to individual phonemes/sounds. Consequently, learning to read Chinese does not involve learning to map phonemes onto letters. It was conjectured that it might be possible for individuals who struggled learning to read English to learn to read Chinese without difficulty. This conjecture was reinforced by the fact that reading disability has not been recognized as a problem for Chinese children by many parents and teachers. However, a growing body of research indicates that individuals who are impaired in phonological processing can be found regardless of the oral language they speak, and that phonological processing tasks predict learning to read regardless of the nature of the written script. This probably occurs because all written scripts convey information about both pronunciation and meaning, and phonological processing is related to the pronunciation aspect of what written scripts convey.

In this section of the chapter, we review empirical work examining (1) how different aspects of phonological processing relate to reading Chinese, drawing from investigations with typical and atypical readers, and (2) how these findings relate to the phonological structure of Chinese.

2.2.1 Phonological Awareness in Chinese

Among the three kinds of phonological processing, phonological awareness has been examined most extensively in Chinese. As mentioned, phonological processing is important for reading all written scripts because they convey information about pronunciation as well as meaning. Additionally, phonological awareness is important for reading Chinese because of several unique characteristics associated with the Chinese orthography (i.e., writing system). First, written Chinese maps primarily onto syllables (McBride-Chang, Bialystok, Chong, & Li, 2004). It is estimated that there are 400 and 600 syllables in Mandarin and Cantonese, respectively. The number of unique syllables in each of the two Chinese languages increases when tones are considered, which feature as the second unique characteristic of Chinese. Specifically, Mandarin has four tones and Cantonese has six. Third, syllables are commonly segmented into onsets and rimes in Chinese for instruction, at least in countries such as Mainland China and Taiwan, where phonological cueing systems such as *pinyin* and *zhuyin fuhao* are used to help children map sounds onto Roman characters (pinyin) or specialized non-Roman characters (zhuyin fuhao) in the early stages of learning.

Similar to the developmental pattern observed in alphabetic languages in which young children are initially aware of larger phonological units and eventually become aware of smaller units, the development of phonological awareness in Chinese is characterized by larger sound units being acquired before more fine-grained ones (Ho & Bryant, 1997). Specifically, the development of phonological awareness in Chinese has been shown to progress from the awareness of syllables, to that of rimes and tones, and finally onsets (Ho & Bryant, 1997; Shu, Peng, & McBride-Chang, 2008).

Phonological awareness in Chinese takes the form of syllabic and tone awareness related to character reading across different Chinese learning contexts and ages (e.g., McBride-Chang & Kail, 2002; McBride-Chang et al., 2008; Shu et al., 2008; Tong et al., 2011; Tong, Tong, & McBride-Chang, 2015; Yeung & Ganotice, 2014). For example, Tong et al. (2015) found that the ability to detect tones was a significant predictor of character reading among kindergarteners in Hong Kong. In another study conducted by McBride-Chang et al. (2008) with kindergarteners in Hong Kong, both tone and syllable awareness were significant predictors of Chinese character reading.

Extending these findings, longitudinal studies suggest that syllable awareness is a predictor of subsequent reading in Chinese (Lei et al., 2011; Pan et al., 2016). For example, in the study conducted by Pan and colleagues (2016) children's syllable awareness assessed in kindergarten and Grade 1 remained a significant predictor of reading in Chinese in subsequent years. Intervention studies also suggest causal relationships between these two aspects of phonological awareness and character reading (e.g., Wang, Liu, Chung, & Yang, 2017). In the study conducted by Wang et al. (2017), Grade 2 children with dyslexia in Hong Kong showed an improvement in a character-naming task after receiving an intervention targeted at the development of tone awareness.

By contrast, studies that have examined the role of onset and rime awareness in character reading have yielded mixed findings (e.g., Ho & Bryant, 1997; So & Siegel, 1997; Wang, Lin, & Yang, 2014). On the one hand, Wang et al. (2014) found rime awareness to be a significant predictor of Chinese word reading among Grade 1 Chinese–English bilingual children in the USA. On the other hand, research conducted by McBride-Chang and colleagues (2008) showed that onset awareness did not predict Chinese word reading among kindergarteners in Hong Kong. In yet another study, Ho and Bryant (1997) found that rime awareness was a significant predictor of Chinese word reading among Grade 1 children but not Grade 2 children in Hong Kong. These inconsistent findings across studies are possibly attributed to differences in learning and instruction. Instead of using phonological cueing systems to aid character learning, Hong Kong children are taught using the whole word/look-say method (see Kilpatrick & O'Brien, Chap. 8, this volume) which encourages the rote memory of visual representations of characters (McBride-Chang et al., 2005), rather than the segmentation of character sounds into onsets and rimes. Therefore, the role of onset and rime awareness in predicting word reading is more unpredictable. By contrast, being in an English-majority environment might encourage children in the study conducted by Wang et al. (2014) to segment sounds into smaller units in a way similar to how they learn English.

2.2.2 Phonological Recoding in Lexical Access in Chinese

Phonological recoding in lexical access in Chinese is assessed using RAN tasks (Wagner & Torgesen, 1987) where participants verbally name objects, digits, colors, or characters/words presented to them in the shortest time possible. Why is phonological recoding in lexical access important for reading in Chinese? Chinese characters are phonologically opaque in that word identification, and naming is accomplished by accessing the character as a whole unit rather than segmenting the character into component sounds. The ability to rapidly access character names in the mental lexicon is thus important for success in reading in Chinese and RAN tasks tap into this rapid retrieval process (Liao, Georgiou, & Parrila, 2008). The role phonological recoding in lexical access plays in Chinese reading is also likely attributable to instructional practices (McBride-Chang & Ho, 2000). Chinese instruction in many Chinese-speaking contexts emphasizes the use of rote memory which likely promotes the automaticity of retrieval of words (McBride-Chang & Ho, 2000). In regard to the RAN-reading relation, three trends have been observed.

First, concurrent relations between different RAN tasks and Chinese character reading have been established across a number of studies (e.g., Chow, McBride-Chang, & Burgess, 2005; Hu & Catts, 1998; Liao et al., 2015; McBride-Chang, Liu, Wong, Wong, & Shu, 2012; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Xue, Shu, Li, Li, & Tian, 2013). For example, digit- and object-naming tasks were significant predictors of Chinese character reading in kindergarten and Grade 2 children in Hong Kong (McBride-Chang et al., 2003). Xue et al. (2013) also found that a digit-naming task was a significant predictor of character reading among children in Grades 2, 4, and 6 in China.

Second, findings of longitudinal relations between RAN tasks and Chinese character reading have been mixed (McBride-Chang & Zhong, 2003; Pan et al., 2011; Wei, Georgiou, & Deng, 2015). On the one hand, McBride-Chang and Zhong (2003) found that among kindergarteners in Hong Kong, RAN abilities measured in kindergarten significantly predicted later character reading. In another study with Taiwanese children (Chang et al., 2014), RAN was consistently a significant predictor of Chinese character reading across three years (Grades 1 to 3) for children who were identified as delayed in naming tasks in kindergarten. Pan and colleagues (2011) also found that among children in China, performance on a composite of the four RAN tasks measured at age 5 was a significant predictor of character reading at ages 7 through 10. These findings are in line with the view that the role of RAN in Chinese reading increases with age (Liao et al., 2008; Tan, Spinks, Eden, Perfetti, & Siok, 2005). By contrast, McBride-Chang and Ho (2005) found that kindergarteners' performance on an object-naming task did not predict character reading two years later. Similarly, Wei et al. (2015) also found no significant longitudinal relations between RAN and word reading in Chinese children who were assessed in Grades 3, 4, and 5.

Third, research has shown that RAN is more predictive of reading fluency as compared to reading accuracy in Chinese (Liao et al., 2015; Shum & Au, 2017; Wei et al., 2015). The explanation put forth is that reading fluency tasks in Chinese are made up of characters or words that are familiar to children and therefore, promote the automaticity of retrieval. In comparison, not all words are familiar in word recognition and character-reading tasks. Thus, automaticity of retrieval might not be as relevant a skill in such a task (Liao et al., 2015).

2.2.3 Phonological Memory

Compared to the other two aspects of phonological processing, there are very few empirical investigations on phonological memory in Chinese. It has been argued that phonological memory is important for Chinese reading for a somewhat unique reason relative to alphabetic orthographies. There are no spaces between characters in Chinese print, which makes word boundaries less obvious. Therefore, when encountering unfamiliar words or characters, readers often have to maintain sounds in memory while processing other characters until word boundaries are identified and word decoding and identification can proceed (Hu & Catts, 1998).

Several tasks have been used to assess phonological memory in Chinese reading. One such task is the short-term memory task developed by So and Siegel (1997). In this task, participants are initially presented with a set of four Chinese characters, after which they are asked to identify the character that was presented in the previous set among five options provided. Other commonly used tasks include digit, word, or nonword repetition tasks where participants are asked to repeat a series of numbers, real Chinese characters, or pseudo-characters, respectively (e.g., Ho & Lai, 1999; Hu & Catts, 1998).

In the limited literature available, findings point to the importance of phonological memory for Chinese reading (e.g., Chan & Siegel, 2001; Ho, Chan, Tsang, & Lee, 2002; Ho & Lai, 1999; Hu & Catts, 1998; So & Siegel, 1997; Xue et al., 2013). For example, Hu and Catts (1998) found that phonological memory, measured using a multi-syllable nonword repetition task, was a significant predictor of reading of Chinese characters among first-grade children in Taiwan. Studies with atypical readers have also yielded similar conclusions. Chan and Siegel (2001) found that poor readers between 7 and 12 years of age in Hong Kong performed significantly lower on a short-term memory task compared to typical readers matched on age. Similarly, Ho and colleagues (2002) found that dyslexic children in Hong Kong performed worse on a word repetition task compared to age-matched controls. It was interesting to note that no significant between-group differences were observed on the nonword repetition task in this study. Considering that different tasks were used across studies, future studies should examine how different tasks of phonological recoding in working memory relate to Chinese reading.

Several studies have compared the predictive performance of the three kinds of phonological processing tasks in the same study (Hu & Catts, 1998; McBride-Chang & Ho, 2000; Xue et al., 2013). For example, McBride-Chang and Ho (2000) showed that when all three components were considered in the same model predicting character recognition, phonological awareness was a stronger predictor of reading compared to phonological memory and rapid naming based on a study of preschoolers in Hong Kong. However, based on their findings with older dyslexic children, Ho et al. (2002) concluded that deficits in rapid naming were the most significant type of deficit among children with reading disabilities in Chinese. Although this difference in findings is in line with the notion that the strength of the relation between rapid naming and reading increases with age (Liao et al., 2008; Tan et al., 2005), further investigations that test children on the relevant constructs over time are needed to draw more definitive conclusions.

Regarding differences in findings described earlier, we speculate on a number of possible explanations. First, the differences in findings regarding the roles of onset and rime awareness in Chinese reading could be due to differences in instruction and learning across different Chinese learning contexts. Of particular importance is whether some phonological system such as pinyin is used in instruction. Turning to the mixed findings in regard to the longitudinal relations between RAN and reading, questions about the mechanisms underlying RAN and why this set of tasks that assess phonological recoding in lexical access predicts Chinese reading should be investigated further. Finally, a variety of tasks have been used across different studies to measure the same construct. Task differences could also have an impact on the associations observed. Thus, future studies should also examine how task differences contribute to the phonological processing–reading relations.

2.3 Reading-Related Phonological Processing Abilities in Multi-lingual Children

Many studies have shown that there is a proximal and likely if not causal relationship between phonological processing skills and reading in English and other alphabetic languages (e.g., Caravolas et al., 2012; Wagner & Torgesen, 1987; Ziegler et al., 2010). Recently, there has been an expansion of studies to measure the relationship between phonological processing skills and reading in other languages, including studies of individuals who know more than one language. This literature is guided by the psycholinguistic grain size theory (Ziegler & Goswami, 2005, 2006) which states that producing meaning from text is guided by the availability of sounds in the spoken language, the granularity of the writing system, and the overlap between the spoken and written systems. Thus, a writing system with a highly regular representation of phonemes (e.g., Spanish, Korean) would be easier in terms of phonological processing compared to a writing system with numerous irregularities (e.g., English, French) or one in which phonemes are not clearly represented (e.g., Chinese, Japanese). This is critical in examining cross-language relationships in phonological awareness tasks.

Melby-Lervag and Lervag (2011) conducted a meta-analysis on cross-linguistic transfer of oral language, decoding, phonological awareness, and reading comprehension. They found a small meta-correlation for the transfer of oral language between L1 and L2, but a moderate to large correlation for the transfer of phonological awareness and decoding between L1 and L2. According to Branum-Martin, Tao, Garnaat, Bunta, & Francis (2012), there is a high correlation between phonological tasks in English and other alphabetic languages. Similar findings were reported by Comeau, Cormier, Grandmaison, and Lacroix (1999) who found the relationship between phonological awareness and reading achievement were similar in both English and French, and confirmed a transfer of these skills between these two alphabetic languages. A study by LaFrance and Gottardo (2005) found that phonological awareness in both French and English were uniquely predictive of reading achievement in both languages, after accounting for the effects of cognitive ability, reading ability, working memory, and naming speed (see Geva, Xi, Massey-Garrison, & Mak, Chap. 6, this volume for a more extensive review of this research).

Phonological awareness skills in other languages are moderately to highly correlated with English phonological awareness tasks (Branum-Martin et al., 2012). According to Dickinson, McCabe, Clark-Chiarelli, and Wolf (2004), the development of phonological awareness in either Spanish or English among Spanish–English bilinguals is strongly predictive of the development of phonological awareness in the other language. Similar findings were reported for Persian–English bilinguals and Arabic–English bilinguals. Arab-Moghaddam and Senechal (2001) measured the concurrent development of reading and spelling in Persian and English bilinguals. They found the predictors of reading were similar across the two languages, with phonological and orthographic skills predicting variance in word reading in both English and Persian. Al Ghanem and Kerns (2015) conducted a synthesis of existing literature to measure whether orthographic, morphological, or phonological skills played a bigger role in learning to read in Arabic. They found that phonological skills had the strongest association with learning to read in Arabic, across vowelized and unvowelized texts.

By contrast, some researchers have found phonological processing skills to play a minimal role in reading acquisition in Korean and Chinese. According to Fraser (2010), phonological awareness was not predictive of Hangul word reading. Chen, Ku, Koyama, Anderson, and Li (2008) measured the development of phonological awareness in Chinese bilingual children and found that while onset-rime awareness had a more universal development pattern across Mandarin and Cantonese, tone awareness was a more language-specific construct which developed faster among Mandarin-speaking children compared to Cantonese-speaking children. Chow, McBride-Chang, and Burgess (2005) examined the relationship between Chinese phonological processing skills (phonological awareness, rapid automatized naming, and short-term verbal memory) in early Chinese and English readers who were kindergarten-aged in Hong Kong. They found that out of the phonological processing skills that were measured, only phonological awareness remained a significant predictor both concurrently and longitudinally for both Chinese- and English-reading skills.

Although more research remains to be done, the past decade has been characterized by a surge of studies with non-alphabetical writing systems. The main conclusion appears to be that the commonalities outweigh the differences in terms of how phonological processing is related to ostensibly very different writing systems.

2.4 Measuring Phonological Processing

A variety of tests are available that include measures of one or more of the three kinds of phonological processing abilities presented in this chapter—phonological awareness, phonological memory, and rapid naming. We will begin by describing a test that was developed specifically for measuring these three reading-related phonological processing abilities and then describe other measures that include subtests that measure various aspects of phonological processing.

The *Comprehensive Test of Phonological Processing—Second Edition* (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013) is an individually administered test battery that was specifically designed to measure phonological awareness, phonological memory, and rapid naming. It is appropriate for individuals from age 4 through 24. The CTOPP-2 differs from other tests in its comprehensive measurement of phonological processing (Dickens, Meisinger, & Tara, 2015), given that it includes multiple measures of each of the three types of phonological processing abilities. The multiple measures are combined into composite scores that are more reliable than are individual subtest scores. There are two versions of the test, one for children aged 4–6 and a second for individuals from age 7 to 24. The composite scores and the subtests that comprise them for both versions are presented in Tables 2.1 and 2.2. The composites are similar for both versions with a few differences. Rapid naming for the 4- to 6-year-old version has composites for both symbolic items (e.g., letters and digits) and non-symbolic items (e.g., colors and objects). There is an alternate phonological awareness composite for the 7- through 24-year-old version that is made up of two phonological awareness tasks with nonword items. Finally, the phonological awareness composite includes sound matching for the 4- to 6-year-old version, and this subtest is replaced by a phoneme isolation subtest in the 7- through 24-year-old version.

There are also phonological processing measures on achievement, language, and cognitive test batteries. The *Kaufman Test of Educational Achievement—Third Edition* (KTEA-III; Kaufman & Kaufman, 2014) includes individual subtests for measuring phonological awareness and rapid object naming. Multiple subtests are not provided, so composite scores are not available. The *Process Assessment of the Learner—Second Edition* (PAL II; Berninger, 2001) is a comprehensive system for screening, assessment, and ongoing monitoring of intervention. The PAL II includes

Table 2.1 CTOPP–2 composite scores and subtests for the 4 to 6-year-old version

Composites				
	Phonological awareness	Phonological memory	Rapid symbolic naming	Rapid non-symbolic naming
Core subtests				
Elision	X			
Blending words	X			
Sound matching	X			
Memory for digits		X		
Nonword repetition		X		
Rapid digit naming			X	
Rapid letter naming			X	
Rapid color naming				X
Rapid object naming				X
Supplemental subtests				
Blending nonwords				

measures of phonological awareness, phonological processing, and rapid automatized naming, but no composite scores and many subtests have a limited number of items. The *Woodcock Johnson Tests—Fourth Edition WJ IV* (LaForte, McGrew, & Schrank, 2014) include separate assessment batteries for *Oral Language* (*WJ IV OL*), *Cognitive Abilities (WK IV COG*) and *Achievement* (*WJ IV ACH*). The batteries include measures of phonological awareness, phonological processing, and rapid automatized naming. To get the three skills measured, however, requires use of multiple batteries (WJ IV OL and WJ IV COG). The *Woodcock Reading Mastery Test—Third Edition* (WRMT-III; Woodcock, 2011) was recently updated to include a phonological awareness subtest and rapid-naming subtests. The *Wechsler Individual Achievement Test—Third Edition* (WIAT-III; Wechsler, 2009) does not have any phonological processing subtests. However, the WIAT-IV, under development at this writing, is slated to have a phonological awareness subtest.

The *Emerging Literacy and Language Assessment* (ELLA; Wiig, & Secord, 2006) includes subtests that measure phonological awareness and rapid automatized naming. The *Gray Diagnostic Reading Test—Second Edition* (GDRT-2; Bryant, Wiederholt, & Bryant, 2004) includes supplemental subtests that assess rapid naming and phonological awareness. The *Dynamic Indicators of Basic Literacy Skills* (DIBELS;

Table 2.2 CTOPP 2 composite scores and subtests for the 7 to 24-year-old version

Composites				
	Phonological awareness	Phonological memory	Rapid symbolic naming	Alternate phonological awareness
Core subtests				
Elision	X			
Blending words	X			
Phoneme isolation	X			
Memory for digits		X		
Nonword repetition		X		
Rapid digit naming			X	
Rapid letter naming			X	
Supplemental subtests				
Blending nonwords				X
Segmenting nonwords				X

Good & Kaminski, 2002) includes measures of phonological awareness in the form of initial sound fluency and phoneme segmentation fluency. The *Test of Preschool Early Literacy* (TOPEL; Lonigan, Wagner, Torgesen, & Rashotte, 2007) includes a measure of phonological awareness. The *Phonological Awareness Profile* (PAP; Robertson & Salter, 1995) is a criterion-referenced test that is administered individually and designed to track progress in phonological awareness skills. The *Phonological Awareness Test—Second Edition* (PAT-2) includes multiple phonological awareness subtests (Robertson & Salter, 2017). The *Rapid Automatized Naming and Rapid Alternating Stimulus Tests* (RAN/RAS; Wolf & Denkla, 2005) include subtests that measure rapid naming of letters, numbers, objects, and colors. The *Wechsler Intelligence Test for Children—Fifth Edition* (WISC-V; Wechsler, 2014) has subtests for phonological memory and rapid naming. The *Differential Abilities Scales—Second Edition* (DAS-2; Elliot, 2007) includes a rapid-naming subtest. Finally, the Phonological Awareness Screening Test (PAST; Kilpatrick, 2016) is a free, standardized but non-normed assessment of phonological awareness with a focus on the speed of responding to the individual test items.[1] It can function as a supplement to normed

[1]This is not to be confused with another free test with the same acronym of PAST which is the Phonological Awareness Skills Test, which approaches assessment of phonological awareness in a very different manner and has no focus on speed of response to test items.

assessments, such as the CTOPP-2 *Elision* and *Phoneme Isolation,* providing some information about the proficiency of phonological skills given the element of response time per item feature of the PAST.

2.5 Summary

In this chapter, we addressed four topics regarding reading-related phonological processing. First, we reviewed the three most common reading-related phonological processes: Phonological awareness; phonological memory; and phonological recoding for lexical access (i.e., rapid naming or RAN). We discussed how they are related to reading. Second, we reviewed the literature on phonological processing and its relations with reading Chinese. It was shown that the similarities were greater than the differences in how phonological processing is related to alphabetic and non-alphabetic scripts. Third, given that an increasing number of children learning to read know more than one spoken language, we reviewed what is known about phonological processing in multi-lingual individuals. Finally, we did a brief review of measures of phonological processing available in English. This chapter functions as a primer on phonological processing, a theme that emerges over and over again in the other chapters throughout this volume, given the intimate relationship between phonological processes and reading.

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