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Contribution of cognitive and linguistic skills to word-reading accuracy and fluency in Chinese

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ABSTRACT

This study examined the contribution of phonological awareness, orthographic knowledge, morphological awareness and rapid naming to word-reading accuracy and fluency in Chinese. We tested 1776 children from Grades 1 to 6. The results of path analysis indicated that phonological awareness was a significant predictor of word reading only in beginning readers. Morphological awareness and orthographic knowledge were strong predictors of word reading across reading proficiency levels. Finally, rapid naming uniquely predicted oral reading fluency and its effects increased across reading proficiency levels. These findings suggest that the writing system children learn to read determines the strength of the cognitive and linguistic skills involved in reading acquisition and the time when they exert their influence.

1. Introduction

Reading development is characterized by a developmental shift from slow and effortful phonological decoding to fast and automatic recognition of whole-word forms (e.g., Chall, 1996; Ehri, 1995; Marsh, Friedman, Welsh, & Desberg, 1981; Share, 1995). Because fluent reading requires also a shift in reading strategies, one would expect that the relative contribution of different cognitive skills undergoes a similar shift (e.g., Badian, 2001; Moll et al., 2014; Vaessen & Blomert, 2010). The purpose of this study was to investigate the relative importance of several cognitive and linguistic skills in predicting word reading accuracy and fluency in a broad developmental span, ranging from beginning to advanced reading, in a non-alphabetic language – Chinese, that is spoken by the largest population in the world. In this study, we limited our investigation to the prediction of word reading (accuracy and speed) rather than on higher-order literacy skills such as reading comprehension.

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The significance of cognitive skills underlying reading development has been investigated intensively in both alphabetic (Goswami & Bryant, 1990; Parrila, Kirby, & McQuarrie, 2004; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009; Snowling, Hulme, & Nation, 1997) and non-alphabetic (Huang & Hanley, 1995; Li, Shu, McBride-Chang, Liu, & Peng, 2012; McBride-Chang et al., 2005; Park & Uno, 2015; Siok & Fletcher, 2001) languages. Researchers have argued that four are the main cognitive skills involved in reading development: phonological awareness (PA), orthographic knowledge (OK), morphological awareness (MA), and naming speed (also known as RAN) (e.g., Hulme & Snowling, 2014; Scarborough, 1998). To date, only a few studies have examined all four together to assess their joint and unique contribution to word reading across a long-ranged age band.

According to both Ehri's (1995) reading phase model and Share's (1995) self-teaching hypothesis, PA and OK are the two core cognitive skills necessary for reading development. The two approaches, however, differ on their predictions regarding the developmental contribution of PA and OK to word reading. In contrast to Share's model, in which the phonological skills are the most important skills throughout reading development (phonological recording acts as a self-teaching mechanism leading to orthographic knowledge), Ehri's model predicts that PA is more important during the early phases of learning to read and OK is more important during later phases of learning to read. No particular role has been proposed for morphological skills and for RAN by either theoretical model.

Due to the developmental nature of literacy acquisition, it is important to investigate what are the core cognitive skills underlying literacy development (particularly in a non-alphabetic language) and how they change across different phases of reading development. Some studies have already examined developmental patterns in the relations of these skills with word reading. For example, in a sample of 200 English-speaking children from Grade 1–6, Hammill et al. (2002) found that phonology and rapid naming significantly contributed to word identification performance (accuracy) only among younger and below-average in reading children, whereas some semantics factors (e.g., listening or spoken vocabulary and sentence) contributed in older and above-average in reading children (Hammill, Mather, Allen, & Roberts, 2002). In another study, Vaessen and Blomert (2010) investigated the cognitive dynamics (special focus on PA and RAN) underlying reading fluency in Dutch school-aged children. The results showed that both PA and RAN contributed substantially to reading fluency over all six primary school grades. However, the contribution of PA to reading fluency was much stronger in beginning readers, whereas the contribution of RAN was small in beginning readers, but gradually increased as reading experience increased. In a follow-up study, Vaessen et al. (2010) investigated the cognitive dynamics (PA, RAN, letter-sound knowledge, and working memory) of reading fluency in Grades 1–4 in three orthographies varying in orthographic consistency (Hungarian, Dutch, and Portuguese). The results showed that the contribution of PA was significant in all grades, but decreased as a function of grade, whereas the predicting power of RAN increased, and the overall pattern was similar among the three orthographies.

However, the previous studies examining the developmental changes in the role of different cognitive skills in learning to read have some important limitations. First, the measures of reading and cognitive skills varied in different studies. The reading performance in most English language studies is usually assessed with accuracy measures, whereas fluency measures are used in transparent orthographies (e.g., German, Greek). Similarly, PA is assessed with accuracy measures and RAN with speeded measures. Some researchers (e.g., Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012; Vaessen & Blomert, 2010) have proposed that this measurement–parameter incompatibility could possibly explain the mixed findings regarding the contribution of different cognitive skills to word reading across languages varying in orthographic consistency, i.e., studies in English usually report a stronger influence of PA on word reading, whereas studies in transparent orthographies report a stronger influence of RAN (e.g., Landerl & Wimmer, 2008; Lervåg, Bråten, & Hulme, 2009; Mann & Wimmer, 2002). Hence nowadays, there is a trend to investigate both reading accuracy and reading fluency simultaneously (Moll et al., 2014; Park & Uno, 2015; Ziegler et al., 2010) or to test both speed and accuracy of PA and other underlying factors (Vaessen & Blomert, 2010; Vaessen et al., 2010).

Second, some other important skills such as orthographic knowledge (OK) and morphological awareness (MA) have not been investigated simultaneously with PA and RAN. Both empirical data (Badian, 2001; Wagner & Barker, 1994) and theoretical models (Ehri, 1995; Share, 1995) have acknowledged OK's role during children's word reading development. In addition, some researchers have suggested that RAN contributes to OK (e.g., Bowers & Wolf, 1993; Manis, Seidenberg, & Doi, 1999; Sunseth & Bowers, 2002). Manis et al. (2000) reported that, for second graders, RAN explained significant variance in three orthographic knowledge tasks, after controlling for vocabulary and PA (Manis, Doi, & Bhadha, 2000). Several other studies have also reported findings supporting the relation between RAN and OK (Georgiou, Aro, Liao, & Parrila, 2016; Holland, McIntosh, & Huffman, 2004; Mesman & Kibby, 2011). Thus, it is worthwhile examining the role of RAN again when OK is also included in the equation. Another skill – morphological awareness (MA), conscious awareness of the morphemic structure of words and their ability to reflect on and manipulate that structure (Carlisle, 1995), has also been shown to be a significant predictor of word reading (Carlisle, 1995; Deacon & Kirby, 2004; Mahony, Singson, & Mann, 2000). MA may play a more important role in the development of later reading skills, because it can help children to access the meaning of unfamiliar words using morphemic clues. Specifically, it has been hypothesized that older children with better MA may find it easier to learn morphologically complex words (Carlisle, 1995; Mahony et al., 2000). However, there is dearth of research exploring the role of MA in later reading development.

Third, th e evidence from non-alphabetic languages, such as Chinese, is scarce. Chinese script differs from alphabetic languages in the orthographic structures, the phoneme-grapheme mappings, and the morphological expressions. Chinese is a morphosyllabic orthography, where the basic graphic unit, the character, represents both a morpheme and a syllable (Shu & Anderson, 1997). More than 80% of modern Chinese characters are phonetic compound characters and consist of subcharacter components or radicals arranged according to orthographic rules. For example, a compound character (e.g., 清,/qing1/, *clear*) consists of two parts: a semantic radical (e.g., 氵, *water*) that carries the meaning information of a character and a phonetic radical (青, /qing1/), which provides the information about the pronunciation of a character. The semantic and phonetic radicals can be further divided into approximately 600 subcomponents (e.g., 十, 口), which have fixed internal structures. The components or subcomponents are combined to form thousands of characters. Many of the radicals or components have their legal positions within the characters, although others can occur in flexible positions. For example, some components can appear to the left (e.g., 扌), to the right (e.g., 刂), at the top (e.g., ⺮), or at the bottom (e.g., 灬) of characters. This implies that orthographic knowledge, defined in the context of Chinese as the awareness of inter-structure and position of components within characters, should play a significant role in character recognition, a hypothesis that has been confirmed before (e.g., Ho, Chan, Lee, Tsang, & Luan, 2004; Li et al., 2012; Wang, Georgiou, & Das, 2012). However, because of the complexity of orthographic rules, although some orthographic rules are taught in school, it takes children several years before they show adequate mastery of orthographic knowledge in Chinese (e.g., Ho, Yau, & Au, 2003; Luo, Chen, Deacon, & Li, 2011). Consequently, one would expect orthographic processing to predict Chinese reading across development, a hypothesis that has not been tested yet.

Importantly, the unit of interface between the written word and the spoken language in Chinese is not the phoneme (as in alphabetic orthographies), but the syllable, which corresponds to a morpheme. Hence, the operational definition of MA in Chinese differs from that in alphabetic languages. Two types of tasks have been used to assess children's MA – homophone sensitivity and compounding word construction and production in Chinese (Liu & McBride-Chang, 2010; Wu, Packard, & Shu, 2009). Awareness of compounding word is important in vocabulary development, because it helps children to access the meaning of new words based on morphemes which are familiar to children. This ability is relative easy to grasp and develops first for children (e.g., Chen, Hao, Geva, Zhu, & Shu, 2009; Lei et al., 2011). Homophone awareness emphasizes children's awareness of specific morphemes but not their knowledge of morphological structure. There are about 7000 morphemes, but only 1300 syllables in Mandarin Chinese (Chao, 1976), which means that, on average, more than five morphemes share the same syllable. The large number of homophones of Chinese, in sharp contrast to the relatively few in alphabetic languages, makes phonological or sound information relatively unreliable in identifying or decoding characters. Consequently, knowledge of homophones is crucial in learning to read Chinese characters, because a reader must be able to distinguish between the homophone characters that share the same syllable (e.g., /yi4/), but with different morphemes (e.g., 义 *'meaning'*, 易*'easy'*, 亿 *'a hundred million'*, 异 *'difference'*, 益 *'benefit'*, 艺 *'art'*, 议 *'discuss'*). Empirical data have confirmed the importance of MA in Chinese reading development (e.g., Li et al., 2012; Liu & McBride-Chang, 2010; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; McBride-Chang et al., 2005; Nagy et al., 2002; Shu, McBride-Chang, Wu, & Liu, 2006; Xue, Shu, Li, Li, & Tian, 2013). Despite the acknowledged importance of MA in Chinese reading, very few studies have examined the relative contribution of MA to Chinese reading across different grades (e.g., Hu, 2013; Li et al., 2012; McBride-Chang et al., 2003; Xue et al., 2013). According to Kuo and Anderson (2006), "morphological awareness becomes an increasingly important predictor of measures of reading as children grow older" (p. 161). Thus, we would expect the contribution of MA to Chinese reading to increase across grades.

In contrast to alphabetic orthographies, there is no grapheme-phoneme correspondence in Chinese. The syllable structure is relatively simple, which usually consists of an onset and a rime. Because the phonetic information in Chinese characters is encoded at the syllable level, the ability to dissect syllables into onsets and rimes should contribute to character recognition, particularly among preschool children (e.g., McBride-Chang, Bialystok, Chong, & Li, 2004; McBride-Chang & Ho, 2000; Pan et al., 2011; Tong et al., 2011; Zhang et al., 2013). Despite evidence showing that PA is important for early reading acquisition in Chinese, its contribution to reading in higher grades has been questioned (e.g., Liao, Georgiou, & Parrila, 2008; Siok & Fletcher, 2001; Tan, Spinks, Eden, Perfetti, & Siok, 2005). Tan et al. (2005), for example, found that syllable deletion did not account for unique variance in character recognition in intermediate readers, after controlling for nonverbal IQ and RAN. A possible explanation may be that syllable deletion is relative easy and has limited variability in upper elementary grades (see McBride-Chang et al., 2004, for a similar problem). Thus, it remains unclear if more sensitive PA tasks would predict Chinese reading in higher grades.

Several studies have also shown that RAN is a strong predictor of Chinese reading (e.g., Chow, McBride-Chang, & Burgess, 2005; Ding, Richman, Yang, & Guo, 2010; Liao et al., 2008; Liao et al., 2015; McBride-Chang & Ho, 2005; Pan et al., 2011; Tan et al., 2005; Yeung et al., 2011) surviving the statistical control of PA (e.g., Liao et al., 2015; Pan et al., 2011), OK (e.g., Ho et al., 2004; Liao et al., 2008), and MA (e.g., McBride-Chang et al., 2003). RAN may predict Chinese reading for at least two reasons. First, because Chinese involves many visually-complex characters, visual skills are important in Chinese reading (Huang & Hanley, 1995; Zhou, McBride-Chang, & Wong, 2014). Because visual processing plays a significant role in RAN performance (e.g., Arnell, Joanisse, Klein, Busseri, & Tannock, 2009; Stainthorp, Stuart, Powell, Quinlan, & Garwood, 2010), RAN should contribute to Chinese reading. Second, because Chinese has no grapheme-phoneme correspondences, part of Chinese characters (i.e., the simple characters) are even taught by rote memorization (particularly in Hong Kong where no phonetic transcription system is used; see also McBride-Chang et al., 2005). Thus, children are required to become efficient in making relatively arbitrary associations between prints and sounds. This arbitrariness has also been argued to be central in RAN since viewing a digit (e.g., "5") does not equip the readers with its pronunciation (Manis et al., 1999). It remains unclear (a) if RAN's effects on Chinese reading change across grades and (b) if its effects vary depending on the reading outcome (accuracy versus fluency). In English, Georgiou, Parrila, Kirby, and Stephenson (2008) and Georgiou et al. (2009) found that the RAN-reading accuracy relationship decreased across time and by Grade 3 it was no longer significant. In contrast, the RAN-reading fluency relationship remained strong throughout the elementary school years.

Examining RAN's contribution to reading in relation to PA and OK is important in light of the dominant RAN-reading theoretical accounts (see Georgiou & Parrila, 2013; for a review). Specifically, if RAN is an index of the ability to access and retrieve phonological representations from long-term memory (e.g., Wagner & Torgesen, 1987; Ziegler et al., 2010), its contribution to reading should be eliminated after controlling for PA. Several studies, however, have shown that RAN continues to predict Chinese reading over and above the effects of PA (e.g., Chow et al., 2005; Ho et al., 2004; Liao et al., 2008; Pan et al., 2011; however, see also Ziegler et al., 2010). Likewise, if RAN predicts reading because it contributes to the development of OK, then controlling for OK should minimize its contribution to word reading. Several studies have shown that RAN continues to predict Chinese reading even after controlling for the effects of OK (e.g., Ho et al., 2004; Liao et al., 2008; McBride-Chang & Ho, 2005; Yeung et al., 2013).

Although there is adequate evidence supporting the contribution of all processing skills (PA, OK, MA, and RAN) to Chinese reading, these skills have rarely been examined within the same study. The few studies that included all four processing skills have only covered the early elementary school years (Li et al., 2012; Tong, McBride-Chang, Shu, & Wong, 2009; Wei et al., 2014; Yeung et al., 2011) and, as a result, we do not know if the pattern of relationships observed during the early grades continues into upper elementary grades. Tong et al. (2009), for example, found that OK and MA in the 3rd year of kindergarten in Hong Kong predicted character recognition both concurrently and longitudinally (Grade 1). RAN also accounted for unique variance in reading at the end of Kindergarten. On the other hand, PA failed to explain unique variance in reading at any measurement point. Likewise, Li et al. (2012) found that RAN, PA, and MA were unique predictors of reading in a cohort of preschool children. In contrast, in a cohort of primary school children (a combined sample of Grade 1, 2, and 3 children), OK, MA, and RAN made unique contributions to reading. Among the skills that explained unique variance in reading in both cohorts, the contribution of MA was larger in the primary school children and the contribution of RAN was about the same in the two cohorts.

To summarize, only a handful of studies have examined the role of PA, OK, MA, and RAN in Chinese reading and their results are mixed. This may be attributed to two reasons: First, not all studies have simultaneously examined the effects of all processing skills. As nicely demonstrated by McBride-Chang and Kail (2002) and McBride-Chang et al. (2005), the inclusion or not of MA in the regression equation determines whether or not PA will be a significant predictor of Chinese reading. Second, some studies have been conducted with children in Hong Kong learning to read Cantonese (e.g., Yeung et al., 2011) and some with children in mainland China learning to read Putonghua (e.g., Li et al., 2012). This difference may have implications in regards to the role of PA to reading. Specifically, because children in mainland China are exposed to Pinyin, a phonetic system that helps children learn new characters, they develop better PA skills than children in Hong Kong, where no phonetic transcription system is used (e.g., McBride-Chang et al., 2004, 2005). Researchers have also argued that Pinyin knowledge may mediate the relationship between PA and character recognition in Putonghua (e.g., Newman, Tardif, Huang, & Shu, 2011; Zhang et al., 2013). This may explain why some studies have found significant effects of PA to reading in Putonghua, but not in Cantonese.

The findings of this present study contribute to the literature in four important ways: First, we assessed a large sample of children (from Grade 1 to Grade 6) on each of the four critical processing skills as well as on reading accuracy and fluency. Second, in order to avoid differences in the format of the linguistic tasks that may account for some of the observed differences in their contribution to reading (e.g., speeded measures being stronger predictors of reading fluency), we created a task for each processing skill that has the same format and speed requirements as the rest (see Methods for more information) and hence the testing time is much shorter relative to traditional ones. Third, we conducted our study in Chinese – a non-alphabetic language. Given that the speakers of Mandarin are the largest population of Chinese-language users, understanding what processing skills predict word reading at different points in time will allow researchers to perform more targeted assessments when children experience reading difficulties and, in turn, develop intervention programs that align with the skills that exert the greatest impact on Chinese reading. Finally, we assessed both oral and silent reading fluency. As children grow, they gradually move from oral reading to silent reading and, therefore, we need to consider both facets of reading fluency.

Our study tested the following two hypotheses:

a. PA, OK, and MA will account for unique variance in word-reading accuracy and fluency. However, the contribution of PA will decrease across grades and the contribution of MA will increase across grades. The contribution of OK is expected to remain stable across grades.
b. RAN will predict reading over and above the contribution of PA, OK, and MA. However, its effects will be modulated by the type of reading outcome and grade level. RAN will be a stronger predictor of reading fluency than reading accuracy. In addition, we hypothesize that whereas the effects of RAN on reading accuracy will decline across grades, its effects on reading fluency will increase across grades.

2. Method

2.1. Participants

One thousand seven hundred and seventy-six children from Grades 1 to 6 (296 children from each grade, the male/female ratio was nearly equal to 1 for each grade) were selected from 24 middle-size (3–8 classes per grade) public schools in Beijing, China to participate in our study. First, the 24 schools were proportionately and randomly selected from the 1310 elementary schools located in the 18 districts of Beijing, which have been classified into four main groups (i.e., old quarter – 5 schools, the new town – 10 schools, suburb – 4 schools and exurb – 5 schools). Second, one class from each grade was randomly chosen. Finally, 6 girls and 6 boys were randomly selected from each of the participating classes. Because participants from two schools were more than 12 from each class (the teachers of these classes accidentally sent letters of information to the parents of 8 girls and 8 boys and we could not thereafter refuse to test these extra children), the final sample consisted of 1776 Chinese children. All children were native Putonghua speakers with no known physical, intellectual, or sensory deficits. Based on the location of the schools, the majority of our participants came from families of middle socioeconomic background. However, we also sampled schools located either in neighborhoods serving primarily children of low socioeconomic status or in neighborhoods serving primarily families of upper middle socioeconomic status. The mean age of the participants was 85.1 months in Grade 1, 97.5 in Grade 2, 109.5 in Grade 3, 120.9 in Grade 4, 133.4 in Grade 5, and 145.7 in Grade 6. Parent consent was obtained prior to testing.

2.2. Measures

2.2.1. Reading

Word-level reading ability was assessed with three measures: Character Recognition, One-Minute Reading, and Word Chains. Character recognition has been used in previous studies in Chinese and showed adequate reliability and validity (e.g., Lei et al., 2011; Li et al., 2012; Xue et al., 2013). Children were asked to name 150 single-character Chinese words that were arranged in terms of difficulty. A discontinuation rule of 15 consecutive errors was applied. The participants' score was the total number of correctly read characters. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.84 to 0.97. One-Minute Reading was adapted from Ho, Chan, Tsang, and Lee (2000) and required children to read aloud as fast as possible 180 two-character Chinese words that were randomly arranged in 20 rows of 9. These words are familiar and are known by 1st graders according to our pilot study. The participants' score was the number of words read correctly within one minute time limit. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.83 to 0.97. Finally, Word Chains was adapted in Chinese from the work of Jacobson (1999) and required children to scan words presented as a continuous line of print without inter-word spaces (e.g., "苍蝇熊香蕉"). The children were told that each of the 45 clusters consisted of three words and their task was to identify the word boundaries within each cluster by putting a slash (e.g., "苍蝇 (housefly)/熊(bear)/香蕉(banana)"). All of the 135 words used in this task to create the Word Chains task are introduced in the first grader's language arts textbooks. The participants' score was the total number of correctly separated words within one minute time limit. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.77 to 0.93. Word Chains has been found to correlate 0.81 with Sentence Verification (Mather & Woodcock, 2001), which also measures silent reading fluency (Xia & Shu, 2014).

2.2.2. Non-character recognition (NCR)

In this measure of visual-orthographic processing, children were asked to cross out non-characters from a list of characters within a specified time limit (45 s in Grades 1 and 2 children, 35 s in Grades 3 and 4 children, and 30 s in Grades 5 and 6). For example, "刂页" is a non-character, although both of the two radicals were correct. In this case, not only the radical "刂" was in the wrong position (i.e., left side), but also these two radicals together cannot make a real character even if the radical "刂" was in its correct position. All the non-characters in this task were illegal characters following an ill-formed structure. This decreased the difficulty of the task and also made it different from the one used in previous studies that also included some well-formed pseudo-characters (Li et al., 2012; Xue et al., 2013). There were 50 target (38 left-right and 12 top-down configuration, which is approximately the proportion of them that taught in primary school, see Shu, Chen, Anderson, Wu, & Xuan, 2003) non-characters and 104 non-target real characters randomly arranged in an 11 × 14 matrix. Prior to timed testing, children did a practice trial with 5 items to ensure that they understood the instructions. The participants' score was the number of correctly identified non-characters minus the number of falsely chosen per second. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.69 to 0.86.

2.2.3. Onset judgment (OJ)

In this measure of PA, children were asked to cross-out the characters (irrespective of tone) whose pronunciation started with the onset "b", such as "白"/bai2/, within a specified time limit (120 s in Grades 1 and 2, 100 s in Grades 3 and 4, and 80 s in Grades 5 and 6). There were 50 target characters with the onset "b" and 104 non-target characters randomly arranged in an 11 × 14 matrix. All characters in the task were selected from the Grade 1 language arts textbook in order to be familiar to all children. Previous pilot studies that we carried out with children of the same age showed that all the characters were familiar to Grade 1 children and that the time limit for each grade level was appropriate (Xia & Shu, 2014). Prior to timed testing, children did a practice trial with 5 items to ensure that they understood the instructions. The participants' score was the number of correctly identified characters minus the number of falsely chosen per second. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.81 to 0.94. Performance on this task has also been found to correlate strongly with other measures of PA such as rime awareness and phoneme deletion (*r*s >0.55) and load on the same factor with these measures (Xia & Shu, 2014).

2.2.4. Pseudo-homophone detection (PHD)

In this measure of MA, children were asked to cross-out pseudo-homophone words that do not truly exist in Chinese (e.g., "何花"/he2hua1/), but are pronounced the same as real words (e.g., "荷花"/he2hua1/, lotus). There were 36 target pseudo-homophone words and 74 real words randomly arranged in an 11 × 10 matrix. All words were selected from the Grade 1 language arts textbooks in order to be familiar to all children. The time limit to complete the task was 75 s in Grades 1 and 2, 55 s in Grades 3 and 4, and 45 s in Grades 5 and 6. Previous pilot studies that we carried out with children of the same age showed that all the words in the task were familiar to Grade 1 children and that the time limit was appropriate (Xia & Shu, 2014). Prior to timed testing, children did a practice trial with 5 items to ensure that they understood the instructions. The participants' score was the number of correctly identified pseudo-homophones minus the number of falsely chosen per second. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.83 to 0.97. Performance on this task has also been found to correlate strongly with other measures of MAs such as morpheme production and morphological construction (*r*s >0.43) and load on the same factor with these measures (Xia & Shu, 2014).

2.2.5. Rapid automatized naming (RAN)

In this task, participants were asked to name as fast as possible five numbers (1, 2, 3, 5, and 8; pronounced as yi[1], er[4], san[1], wu[3], and ba[1]; the number in brackets refers to the tone) that were repeated 10 times each and arranged in semi-random order in five rows of ten. Prior to beginning the timed naming, the children were asked to name the digits in a practice trial to ensure familiarity. Each child named the matrix twice (in the second matrix, the digits were rearranged) and the number of items per second across the two matrixes was used as the participants' score. The number of naming errors was negligible (mean number of errors was less than 1) and for this reason it was not considered further. Test-retest reliability with a sub-sample of our participants (n = 20 from each grade) ranged from 0.76 to 0.91.

2.3. Procedure

All participants were individually tested in a quiet room at school from March to May (seven to nine months after the beginning of the school year) by trained graduate students who received extensive training on how to implement the tasks. Testing lasted approximately 30 min. The tasks were administered in the following order: Character Recognition, One-Minute Reading, RAN, NCR, OJ, PHD, and Word Chains.

To calculate the test-retest reliability of each task, we reassessed 120 children (20 from each grade) on the same tasks four weeks after the initial testing. The children who participated in this second phase of testing were randomly selected from the pool of participants.

2.4. Statistical analysis

When running the descriptive statistics and the correlation analysis, the original data for each variable were used. To simplify the presentation of our results, we collapsed the six grades into three reading proficiency groups: Grades 1 and 2 formed the beginning readers' group, Grades 3 and 4 the intermediate readers' group, and Grades 5 and 6 the advanced readers' group.

Given that OJ and PHD tasks also involved processing of visually presented materials that could interfere with the effects of NCR, before running the path analyses we residualized OJ and PHD from NCR. Subsequently, we standardized our variables (Character Recognition, One-Minute Reading, Word Chains, RAN, OJ, PHD, and NCR) within each of the three reading proficiency groups. The *z* scores were used in all the analyses.

To examine the contribution of different predictors on reading accuracy and fluency, we ran path analysis. Maximum likelihood estimation procedures were used to analyze the variance/covariance matrix of the observed variables using Mplus 7.0 (Muthén & Muthén, 1998–2012). To evaluate the model fit, chi-square values and the following fit indexes were used: a) the comparative fit index (CFI); b) the goodness of fit index (GFI); and c) the root-mean-square error of approximation (RMSEA). A nonsignificant chi-square value coupled with CFI and GFI indices above 0.95 suggest that the model is acceptable (Hu & Bentler, 1999). RMSEA values below 0.05 indicate a close fit, but values as high as 0.07 are regarded as acceptable (Browne & Cudeck, 1993).

Separate models were constructed with Character Recognition, One-Minute Reading, and Word Chains as the outcome measures. The first step was to estimate the fit of a baseline model, depicted in Fig. 1, with all possible correlations between the predictor variables (RAN, OJ, PHD, and NCR) and all possible paths from the predictors to the dependent variables (Character Recognition, One-Minute Reading, and Word Chains) separately for the three groups of children. Age was included as a control variable. To increase the degrees of freedom and examine whether the most parsimonious well-fitting models

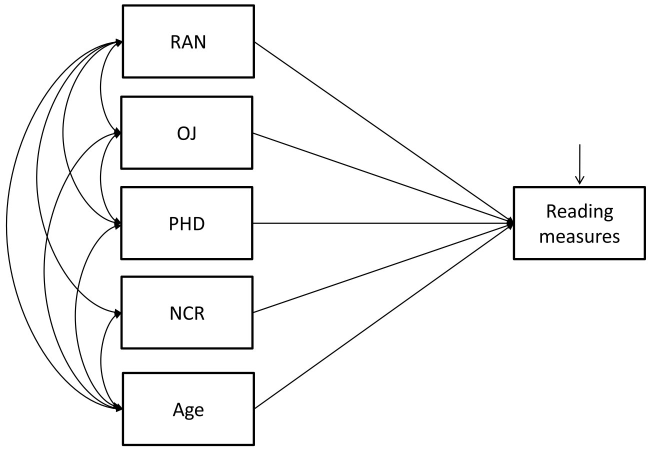

Fig. 1. Model of relationship between the predictor variables and the reading outcome. RAN = Rapid Automatized Naming; NCR = Non-Character Recognition; OJ = Onset Judgment; PHD = Pseudo-Homophone Detection.

are similar for different reading proficiency groups, non-significant regression paths were dropped one at a time until all remaining paths in the models were significant.

Next, we performed multigroup analyses in order to examine if the effects of the predictor variables on reading differed across the three reading proficiency levels. To increase the degrees of freedom in the tested models, only the paths from the predictor variables to the outcome measures that were significant in one or more groups were retained in the analyses. We then tested the fit of a model in which no equality constraints were imposed. This was followed by testing a model in which the effects of each predictor on the outcome measures were constrained to be equal across the three reading proficiency groups. To determine if the effects of a predictor on reading varied across the three groups, we compared the chi-square value of the constrained model with that of the initial multigroup model in which no equality constraints were imposed. If the difference in chi-square values, given the difference in the degrees of freedom between the two models (*df* constrained − *df* unconstrainted), was significant, then this indicated that the specific predictor was contributing in a different way to the outcome variables in the three groups of children. To further identify which group was responsible for the observed change in the chi-square value, we tested for invariance between two groups.

3. Results

3.1. Preliminary data analysis

Before running any analyses we examined the distributional properties of the variables. Six multivariate outliers (four in Grade 1, one in Grade 3, and one in Grade 4) were deleted from the sample. Table 1a and 1b shows the descriptive statistics for all the tasks used in the study, separately for each grade. One-way ANOVAs with Bonferroni correction showed that there was a significant effect of grade for each of the measures, which means that performance on each task improved across

Table 1a
Descriptive Statistics for all the Measures Used in the Study (Grade 1–3).

	Grade 1					Grade 2					Grade 3				
	M	SD	Range	Skewness	Kurtosis	M	SD	Range	Skewness	Kurtosis	M	SD	Range	Skewness	Kurtosis
Character Recognition	31.13	22.59	105.00	1.34	1.11	65.57	22.41	110.00	0.03	−0.61	95.64	17.55	102.00	−0.63	0.36
One-Minute Reading	43.40	15.12	70.63	0.22	−0.50	64.21	14.73	80.09	0.02	−0.24	77.60	15.32	97.23	0.29	0.30
Word Chains	2.99	3.16	12.67	1.18	0.69	6.33	3.98	18.00	0.41	−0.45	11.33	4.94	31.71	−0.05	0.58
Non-character Recognition	0.39	0.11	0.69	−0.06	0.19	0.59	0.11	0.64	0.10	0.11	0.73	0.13	0.74	0.22	0.06
Onset Judgment	0.10	0.05	0.26	0.75	0.41	0.18	0.07	0.38	0.52	0.48	0.24	0.08	0.47	0.40	0.22
Pseudo-homophone Detection	0.05	0.04	0.23	1.27	1.38	0.13	0.06	0.31	0.70	0.05	0.22	0.09	0.53	0.83	1.08
Rapid Naming	1.81	0.40	2.50	0.58	0.51	2.24	0.47	2.43	0.34	−0.18	2.63	0.55	3.81	0.66	1.30

Table 1b
Descriptive Statistics for all the Measures Used in the Study (Grade 4–6)

	Grade 4					Grade 5					Grade 6				
	M	SD	Range	Skewness	Kurtosis	M	SD	Range	Skewness	Kurtosis	M	SD	Range	Skewness	Kurtosis
Character Recognition	111.02	12.85	64.00	−0.23	−0.20	119.63	11.45	70.00	−0.96	1.27	126.67	10.06	55.00	−0.87	0.67
One-Minute Reading	85.46	15.41	77.59	0.08	−0.25	92.34	16.28	97.50	0.05	0.43	99.03	16.77	84.01	−0.03	−0.28
Word Chains	14.84	5.65	34.28	0.38	0.54	18.01	5.52	31.00	−0.31	0.38	19.81	5.92	41.00	0.21	0.96
Non-character Recognition	0.81	0.13	0.74	0.12	−0.09	0.94	0.15	1.03	0.50	0.41	1.02	0.16	0.87	−0.02	−0.42
Onset Judgment	0.27	0.08	0.39	0.44	−0.44	0.30	0.09	0.47	0.34	−0.09	0.34	0.10	0.66	0.38	0.51
Pseudo-homophone Detection	0.27	0.09	0.60	0.45	0.26	0.32	0.10	0.53	0.21	−0.29	0.37	0.11	0.64	0.12	−0.20
Rapid Naming	2.92	0.59	3.33	0.46	0.46	3.19	0.60	3.75	0.41	0.54	3.49	0.67	3.93	0.52	0.49

Note: The unit for Character Recognition is the number of characters correctly named. The units for One-Minute Reading and Word Chains are the number of words correctly named or separated in one minute. The units for Non-character Recognition, Onset judgment, and Pseudo-homophone detection are the number of correctly finished minus the number of falsely chosen per second; The unit for Rapid Naming is the number of digits named per second.

grades. Cohen's *d* values between two adjacent grades ranged from 0.9 to 1.9 for the younger children and between 0.3 to 0.6 for the older children.

Table 2 presents the correlations between the measures used in the study, separately for each reading proficiency group. In addition, we partialled out the effects of age within each of the three reading proficiency groups. The three reading tasks correlated strongly with each other (*r*s ranged from 0.44 to 0.76), particularly in the group of beginning readers. RAN correlated strongly with One-Minute Reading (*r*s ranged from 0.64 to 0.69), but only relatively weak with Character Recognition (*r*s ranged from 0.34 to 0.37) and Word Chains (*r*s ranged from 0.27 to 0.31). Among the component skills, Pseudo-Homophone Detection (PHD) showed the strongest correlations with the reading measures (*r*s ranged from 0.41 to 0.72). Strong correlations were also observed between Onset Judgment (OJ) and reading in the group of beginning readers (*r*s

Table 2
Correlations Between the Measures Used in the Study (Controlling for Age).

	1.	2.	3.	4.	5.	6.	7.
Beginning Readers (n = 588)							
1. CR							
2. OMR	0.76						
3. WC	0.64	0.59					
4. RAN	0.35	0.64	0.29				
5. NCR	0.45	0.49	0.36	0.35			
6. OJ	0.63	0.67	0.50	0.48	0.52		
7. PHD	0.72	0.63	0.56	0.35	0.54	0.57	
Intermediate Readers (n = 590)							
1. CR							
2. OMR	0.57						
3. WC	0.58	0.49					
4. RAN	0.37	0.69	0.31				
5. NCR	0.37	0.43	0.46	0.33			
6. OJ	0.37	0.42	0.35	0.36	0.38		
7. PHD	0.65	0.57	0.65	0.39	0.57	0.46	
Advanced Readers (n = 592)							
1. CR							
2. OMR	0.49						
3. WC	0.53	0.44					
4. RAN	0.34	0.69	0.27				
5. NCR	0.25	0.28	0.45	0.21			
6. OJ	0.36	0.33	0.34	0.38	0.28		
7. PHD	0.59	0.41	0.64	0.33	0.49	0.37	

Note: CR = Character Recognition; OMR = One Minute Reading; WC = Word Chains; RAN = Rapid Automatized Naming; NCR = Non-Character Recognition; OJ = Onset Judgment; PHD = Pseudo-Homophone Detection.
All correlation coefficients were significant at $p < 0.001$.

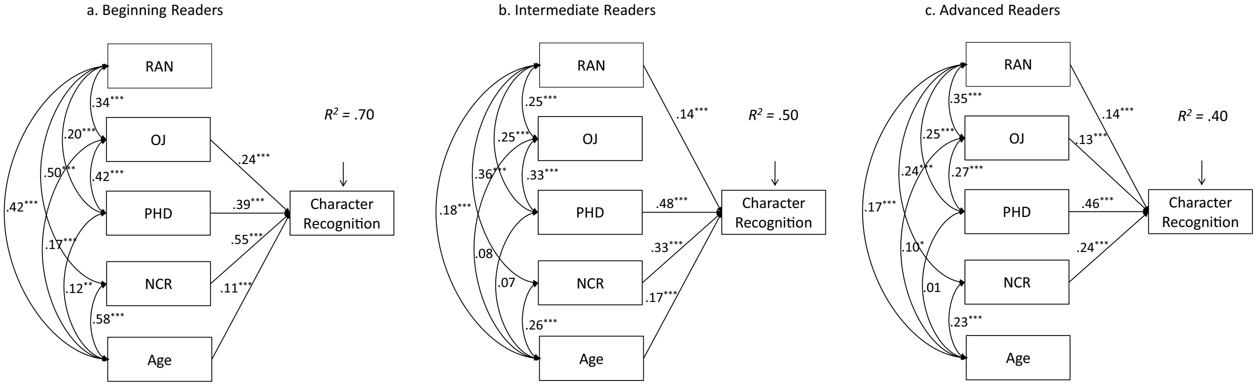

Fig. 2. The final path model for predictors of Character Recognition for the beginning readers (a), the intermediate readers (b), and the advanced readers (c). RAN = Rapid Automatized Naming; NCR = Non-Character Recognition; OJ = Onset Judgment; PHD = Pseudo-Homophone Detection; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

ranged from 0.50 to 0.67), but decreased thereafter. Finally, RAN correlated relatively weak with the other processing skills (rs ranged from 0.21 to 0.48).

3.2. Predictors of character recognition

The most parsimonious models (see Fig. 2) predicting Character Recognition fitted the data very well, $\chi^2(3, N = 588) = 0.02$, $p = 0.999$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for beginning readers, $\chi^2(3, N = 590) = 2.38$, $p = 0.498$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for intermediate readers, and, $\chi^2(3, N = 592) = 1.64$, $p = 0.651$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for advanced readers, respectively, and accounted for 70% of the variance in the beginning readers' group, 50% of the variance in the intermediate readers' group, and 40% of the variance in the advanced readers' group. There were four significant predictors of Character Recognition in the beginning readers' group: OJ, PHD, NCR and age; four significant predictors in the intermediate readers' group: RAN, PHD, NCR, and age; and four significant predictors in the advanced readers' group: RAN, OJ, PHD, and NCR.

After establishing the most parsimonious model for each reading proficiency group, we ran multigroup analyses. Table 3 presents the changes in the χ^2 values when predictors of interest were constrained to be equal across the three groups. There were no significant changes in the model fit when the regression coefficients of PHD were constrained to be equal across groups. However, the fit of the model deteriorated significantly when the effects of either RAN, $\Delta\chi^2 = 11.03$, $p < 0.001$, OJ, $\Delta\chi^2 = 21.91$, $p < 0.001$, or NCR, $\Delta\chi^2 = 52.28$, $p < 0.001$, on Character Recognition were constrained to be equal.

Table 3
Changes in $\chi 2$ After Constraining Paths to be Equal Across Reading Levels.

Measure	Character Recognition	One-Minute Reading	Word Chains
$RAN_B = RAN_I = RAN_A$	11.03***	41.71***	–
$RAN_B = RAN_I$	7.86**	18.07***	–
$RAN_B = RAN_A$	7.64**	38.68***	–
$RAN_I = RAN_A$	0.01	4.22*	–
$NCR_B = NCR_I = NCR_A$	52.28***	66.75***	0.68
$NCR_B = NCR_I$	24.15***	28.45***	–
$NCR_B = NCR_A$	48.88***	62.24***	–
$NCR_I = NCR_A$	4.82*	6.73**	–
$OJ_B = OJ_I = OJ_A$	21.91***	31.79***	14.69***
$OJ_B = OJ_I$	21.26***	18.51***	13.91***
$OJ_B = OJ_A$	6.44*	25.92***	7.39**
$OJ_I = OJ_A$	2.86	0.93	1.11
$PHD_B = PHD_I = PHD_A$	4.71	6.91*	10.53**
$PHD_B = PHD_I$	–	0.11	8.37**
$PHD_B = PHD_A$	–	5.17*	7.70**
$PHD_I = PHD_A$	–	5.71*	0.02
All effects equal	69.37***	99.33***	19.26**

Note: the subscript B = beginning readers, I = intermediate readers, A = advanced readers. RAN = Rapid Automatized Naming; NCR = Non-Character Recognition; OJ = Onset Judgment; PHD = Pseudo-Homophone Detection.
* $p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

In regards to RAN, the significant changes in the χ^2 were caused by differences between the beginning and intermediate readers' groups, $\Delta\chi^2 = 7.86$, $p < 0.01$, and between the beginning and advanced readers' groups, $\Delta\chi^2 = 7.64$, $p < 0.01$. Thus, these results, combined with the coefficients in Fig. 2, indicate that RAN had a modest effect in beginning readers, and a relatively stronger effect on Character Recognition in intermediate and advanced readers. The reverse pattern was found on OJ, that is, OJ exerted a moderate contribution to Character Recognition only in beginning readers and no effect in intermediate and advanced readers. For NCR, significant differences were found for each pairwise comparison, suggesting that the effects of NCR on Character Recognition declined across reading proficiency levels. PHD had the largest effect to Character Recognition, and did not differ among the three groups of readers.

3.3. Predictors of one-minute reading

The second set of analyses examined the predictors of One-Minute Reading. The most parsimonious models (Fig. 3) fitted the data very well, $\chi^2(3, N = 588) = 1.59$, $p = 0.661$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for the beginning readers, $\chi^2(3, N = 590) = 0.43$, $p = 0.935$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for the intermediate readers, and $\chi^2(4, N = 592) = 0.37$, $p = 0.985$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for the advanced readers, respectively, and accounted for a moderate to high proportion of variance (beginning readers: $R^2 = 0.74$; intermediate readers: $R^2 = 0.60$; advanced readers: $R^2 = 0.52$). There were four significant predictors of One-Minute Reading in the beginning and intermediate readers' groups: RAN, OJ, PHD, and NCR, and three significant predictors in the advanced readers' group: RAN, PHD, and NCR.

The results of multigroup analysis indicated that the model fit deteriorated significantly after constraining the effects of either one of the predictors to be equal across the three groups. The changes in the χ^2 values are presented in Table 3. These results, combined with the coefficients in Fig. 3, suggest that the effect of RAN on One-Minute Reading was strong and increased across reading proficiency levels. In contrast, the effect of NCR on One-Minute Reading was also significant but decreased across reading proficiency levels. The OJ had an effect in beginning readers, but its effect was weak or none in intermediate and advanced readers. PHD had a moderate effect and showed some decrease in advanced readers.

3.4. Predictors of word chains

The third set of analyses examined the predictors of Word Chains. The most parsimonious models (Fig. 4) fitted the data very well, $\chi^2(4, N = 588) = 0.70$, $p = 0.952$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for the beginning readers, $\chi^2(5, N = 590) = 4.57$, $p = 0.470$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for the intermediate readers, and, $\chi^2(4, N = 592) = 1.91$, $p = 0.750$, CFI = 1.00, GFI = 1.00, RMSEA = 0.00, for the advanced readers, respectively, and accounted for a moderate proportion of variance (beginning readers: $R^2 = 0.45$; intermediate readers: $R^2 = 0.45$; advanced readers: $R^2 = 0.44$). There were three significant predictors of Word Chains in the beginning and advanced readers' groups: OJ, PHD, and NCR, and two significant predictors in the intermediate readers' group: PHD, and NCR. Thus, RAN had no effect on Word Chains in any group of readers.

Finally, we examined if there were any differences in the significant predictors of Word Chains across the three groups. The changes in the χ^2 values when predictors of interest were constrained to be equal across groups are presented in Table 3. No significant changes in the model fit were observed when the effects of NCR on Word Chains were constrained to be equal across the three groups. Taking the coefficients in Fig. 4 together, NCR was the strongest predictor to Word Chains among the three groups of readers. In contrast, the model fit deteriorated significantly when the effects of OJ, $\Delta\chi^2 = 14.69$, $p < 0.001$, and PHD, $\Delta\chi^2 = 10.53$, $p < 0.01$, were constrained to be equal across the three groups. OJ was a moderate predictor of Word Chains in beginning readers, but showed no or weak effect in intermediate and advanced readers. In contrast, PHD had a strong effect and increased in intermediate and advanced readers.

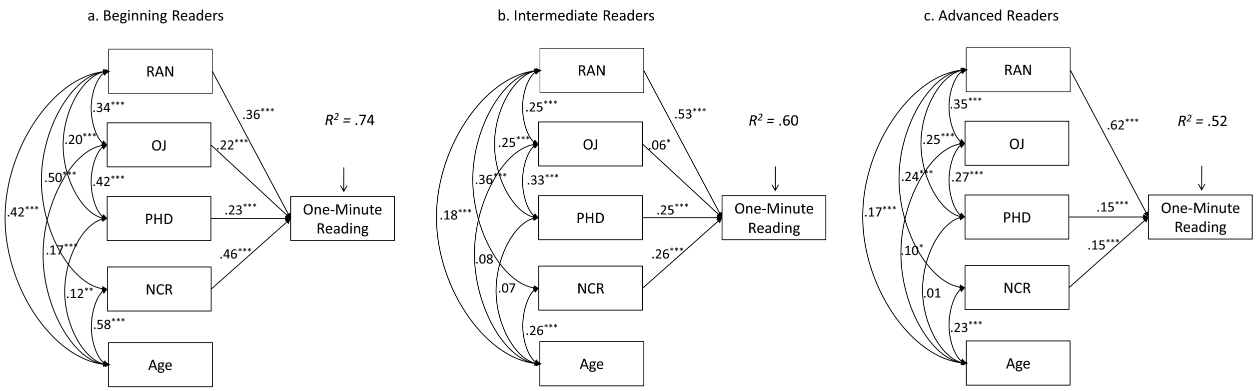

Fig. 3. The final path model for predictors of One-Minute Reading for the beginning readers (a), the intermediate readers (b), and the advanced readers (c). RAN = Rapid Automatized Naming; NCR = Non-Character Recognition; OJ = Onset Judgment; PHD = Pseudo-Homophone Detection; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

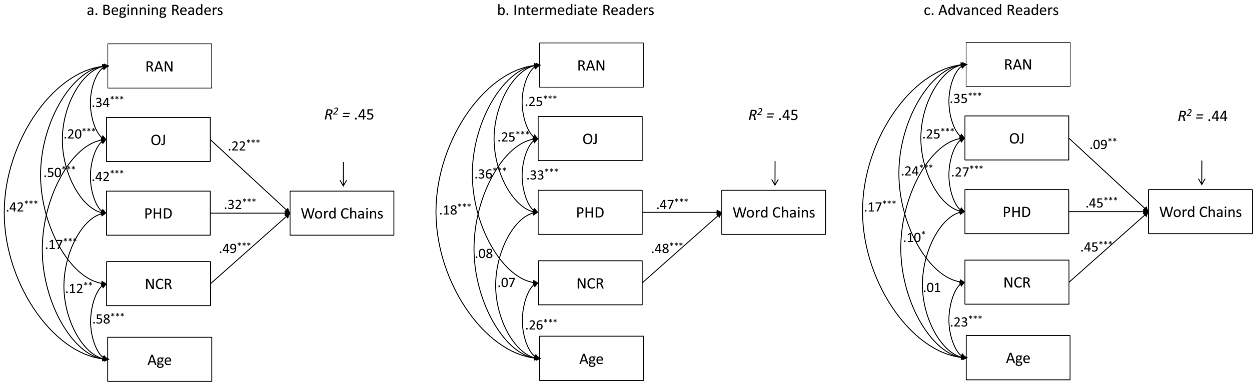

Fig. 4. The final path model for predictors of Word Chains for the beginning readers (a), the intermediate readers (b), and the advanced readers (c). RAN = Rapid Automatized Naming; NCR = Non-Character Recognition; OJ = Onset Judgment; PHD = Pseudo-Homophone Detection; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4. Discussion

The objective of the present study was to investigate the relative importance of different cognitive and linguistic skills in predicting word reading accuracy and fluency in primary school children. To summarize our results, the descriptive analysis showed that the performance on each of our tasks increased as a function of grade, which suggests that our tasks are appropriate and can differentiate the children in each grade from others. The results from path analysis and multigroup analysis suggested that, phonological awareness (PA) had a moderate effect to word reading (accuracy and fluency) only in beginning readers, and its effect diminished in intermediate and advanced readers. In contrast, morphological awareness (MA) had a strong effect on each of the three reading measures across the three levels of readers. Further, the effect of MA was much stronger on oral word reading accuracy and silent reading speed than on oral word reading fluency, and increased in intermediate and advanced readers. Similarly, orthographic knowledge (OK) had a strong effect on each of the three reading measures across the three groups of readers. Developmentally, the effect of OK slightly decreased as a function of reading proficiency on oral word reading (accuracy and fluency), but was rather stable when predicting silent word reading. RAN had a stronger effect on oral word reading fluency which also increased with reading proficiency.

Overall, our study confirmed that the contribution of these linguistic skills to word reading varied across reading proficiency levels, by investigating multiple reading measures simultaneously, and a relatively more comprehensive set of potential predictors with a large, wide-aged range of sample. In line with our expectation, PA accounted for unique variance in oral reading accuracy and fluency only in beginning readers (see Hammill et al., 2002; Vaessen & Blomert, 2010; Vaessen et al., 2010; for similar findings from alphabetic languages). This is consistent with the findings of previous studies in Chinese and suggests that PA is important for early reading acquisition in Chinese (e.g., Ho & Bryant, 1997; McBride-Chang et al., 2004; Pan et al., 2011; Zhang et al., 2013). Taken together, this supports the idea that at least during the early stages of reading acquisition PA is likely a universal predictor of reading (e.g., Caravolas, Vólin, & Hulme, 2005; Georgiou, Parrila, and Papadopoulos, 2008; Vaessen et al., 2010; Ziegler et al., 2010). Our finding may also reflect the fact that during the early stages of reading acquisition in Chinese, children are exposed to Pinyin, a phonetic coding system that is used to help children learn new characters. Huang and Hanley (1997; see also Yin et al., 2011) found that Pinyin knowledge (or Zhu-Yin-Fu-Hao in Taiwan) mediates the relationship between PA and character recognition. Once Pinyin is withdrawn from reading instruction around Grade 3 (Xiang & Ren, 2010), PA may lose its predictive value (McBride-Chang et al., 2005; Tan et al., 2005).

The importance of OK, together with PA, has been established in both Ehri's (1995) and Share's (1995) models of reading development. However, much fewer empirical studies, compared to PA and RAN, have investigated OK's role to reading development in alphabetic languages. Roman et al. (2009) investigated the relative contribution of four variables to word reading accuracy with a sample (92 children) of Canadian children in Grade 4, 6, and 8, and observed that OK, PA, and MA each significantly contributed to word reading accuracy, whereas RAN did not. Unfortunately, the study combined three grades together, when analyzing the data, and could not investigate their dynamics changes across grades because of a small sample size. As expected, our current study has found that OK had a strong effect on word reading accuracy and fluency, especially on silent reading, which is consistent with the findings of previous studies (e.g., Ho et al., 2004; Li et al., 2012; Xue et al., 2013), and reconfirmed that OK is very important to Chinese reading.

The present study, further, revealed that the changes of orthographic processing's contribution to reading across proficiency levels depended upon whether the task was reading aloud or reading silently, which means that its contribution to reading aloud (measured by the tasks of Character Recognition and One-Minute Reading) relatively decreased across reading proficiency levels, but remained relatively stable when reading silently (measured by Word Chains). The task of orthographic knowledge used in present study required children to discriminate the ill-formed non-characters with radicals in their wrong positions from those real characters. The children had to use their knowledge of specific locations of radicals in Chinese to accomplish this task. The results of our present study reconfirmed that Chinese children acquire the radical position knowledge at an early stage. For example, Shu and Anderson (1999) asked first, second, fourth and sixth graders to make lexical decision for real, pseudo-characters (well-formed, radicals in their typical positions) and two types of non-characters (ill-formed, radicals in wrong positions and not a real radical in Chinese writing). The results showed that the judgment for non-characters with radicals in wrong positions was the easiest, and the error rate decreased over the school years. Researchers, meanwhile, also agree with the point of view that orthographic knowledge in Chinese composes of several aspects including the knowledge of specific locations, structures, and functions of semantic and phonetic radicals in Chinese characters. Relative to the positional knowledge acquired easily and early, more specific orthographic knowledge, e.g., internal structure of radicals, positional frequency knowledge, was acquired gradually based on the children's reading experience (McBride-Chang, Lin, Fong, & Shu, 2010; Shu & Anderson, 1999). Hence, the direction of changes about the contribution of orthographic knowledge to reading possibly depends on the tasks that used to measure orthographic processing and reading. Further studies are needed to compare different levels of orthographic processing (Anderson et al., 2013) and also different reading tasks (Barker, Torgesen, & Wagner, 1992).

In alphabetic languages, MA has been thought to play a more important role in the development of later reading skills, because it helps children to access the meaning of unfamiliar words by using morphemic clues (e.g., prefix, suffix) and familiar morphemes. In our study, we found that MA's contribution to reading (oral reading accuracy and fluency, silent reading speed) was significant across reading proficiency levels and increased substantially in intermediate and advanced readers on oral reading accuracy and silent reading speed. This is in line with the findings of previous studies in Chinese (e.g., Hu, 2013; Ku & Anderson, 2003; Li et al., 2012; McBride-Chang et al., 2003, 2005; Shu et al., 2006; Xue et al., 2013; Yeung et al., 2011) and suggests that MA is fundamental to reading acquisition in Chinese. Notice that the way MA has traditionally been measured in Chinese children diverges from the focus on inflectional or derivational morphology examined in studies with children learning to read alphabetic scripts (e.g., Deacon, Wade-Woolley, & Kirby, 2007; Kirby et al., 2012; Nagy, Berninger, & Abbott, 2006). Given the many homophones and extensive lexical compounding of Chinese, two corresponding types of measures usually have been used – homophone discrimination, similar to that used in present study, and compound word construction (Liu & McBride-Chang, 2010; Wu et al., 2009). The ability to distinguish homophones and building words from morphemes was found in the present study to be crucial, especially for proficient readers. The task of MA in our study requires children to accurately access the meaning of compound words and then distinguish the characters that shared the same sound as quickly as possible. However, these two (homophone discrimination and building compounding words with morphemes) are not too distinct from each other, because the children usually disambiguate these diverse meanings across homophones with the utility of compounding context. In addition, we found that the relative effect of MA was much stronger on oral reading accuracy and silent reading, although its contribution was also significant on oral reading fluency. The words used to assess oral reading fluency (measured by One-Minute Reading) are relatively easier and more familiar than those in the other two reading measures, and less meaning access is thought to be involved when pronouncing familiar than unfamiliar words (e.g., Harm & Seidenberg, 1999; Yang, Shu, McCandliss, & Zevin, 2013). These findings, hence, suggest that MA exerts a larger effect when more involvement of meaning access is needed in the word reading task. In general, the processing route from orthography to meaning appears to be more important in reading Chinese (e.g., Liu, Shu, & Li, 2007; Yang et al., 2013; Zhao et al., 2014; Zhou & Marslen-Wilson, 1999), whereas the processing route from orthography to phonology appears to be more important in alphabetic orthographies (e.g., Harm & Seidenberg, 1999).

Our study also examined if RAN makes an independent contribution to word-reading accuracy and fluency over and above the effects of PA, OK, and MA. RAN was a significant predictor of Character Recognition (with one exception in beginning readers) and One-Minute Reading, and its effects increased across reading proficiency levels. Notably, the correlations between RAN and Character Recognition are similar to those reported in recent *meta*-analyses (e.g., Araújo, Reis, Petersson, & Faísca, 2015; Song, Georgiou, Su, & Shu, 2015). Our findings are also in line with those of previous studies reporting an increasing effect of RAN on reading fluency across grades (e.g., Batnini & Uno, 2015; Kirby, Parrila, & Pfeiffer, 2003; Landerl & Wimmer, 2008; Moll et al., 2014; Park & Uno, 2015; Vaessen & Blomert, 2010; Vaessen et al., 2010). We have shown here that RAN predicts oral reading fluency when PA and OK were controlled statistically, and even when the other linguistic skills are assessed with speeded measures. This challenges the argument put forward by Ziegler et al. (2010) that RAN accounts for unique variance in reading when the phonological awareness tasks are either not sensitive enough or suffer from ceiling effects. Obviously, our phonological awareness task did not suffer from ceiling effects. However, we should note that the children in Ziegler et al. (2010) were young (Grade 2) and were assessed in only RAN objects (a non-alphanumeric RAN task). A natural follow-up question would then be why RAN significantly contributes to reading fluency and its effects increase with reading proficiency. A possible explanation may be that as children become skilled readers, many words become "sight words" and are recognized and pronounced as automatically as symbols in the RAN tasks (e.g., Georgiou, Parrila, & Kirby, 2009; see also Georgiou, Papadopoulos, & Kaizer, 2014). An alternative explanation may be that as children become more proficient readers they become better in processing multiple symbols at a time (see Altani et al., 2016; Protopapas, Altani, & Georgiou, 2013, for the cascaded processing hypothesis), which further helps in reading fluency.

Some potential limitations of the present study are worth mentioning. First, all of our processing skills were assessed with a single measure. Although this was done to control for differences in the format of the tasks that could account for some of the observed differences in their contribution to reading, it may have reduced the power of our constructs. Future studies should try to replicate these findings using two or more tasks per construct. For example, OK tests could measure not only radical position knowledge tested (as in the present study), but also more specific knowledge, like internal structure of radicals and positional frequency knowledge (McBride-Chang et al., 2010; Shu & Anderson, 1999). Likewise, PA in Chinese could be tested not only with an onset awareness task, but also with measures of rime and lexical tone awareness (e.g., Tong & McBride-Chang, 2010; Xue et al., 2013). MA could also include a measure of compounding sensitivity to distinguish different types of compound words (Shu & Anderson, 1999; Tong & McBride-Chang, 2010). Second, the phonological and morphological awareness tasks were tested with visually-presented stimuli, which deviates from the traditional way of assessing these skills (the tasks are presented orally). This may have influenced the relationships of these skills with reading (particularly in Grade 1, when children are still learning to read). Notice though that the items selected in these tasks were familiar to Grade 1 children (at least based on our previous pilot studies using the same items). But it should also be noted that the role of PA and MA in the present study was not confounded with OK, since their overlap with NCR had been regressed out before running the path analyses (see Statistical analysis section). Third, we chose Word Chains as opposed to other measures of silent reading fluency (e.g., Sentence Verification, Maze Task), because it assesses fluency at the word level and not at the sentence or text level. This way, our results using Word Chains would be comparable to those with Character Recognition and One-Minute Reading since they also tap word-level reading. However, we acknowledge that sentence level reading fluency must be assessed in future studies as well because it has been shown to be more strongly related to comprehension (see Kim, Wagner, & Lopez, 2012). Finally, because our study was cross-sectional, we cannot argue that any of our predictor variables are causally related to word reading, which is not the purpose of this study. As Vaessen and Blomert (2010) have argued, when investigating developmental changes across different proficiency levels in the relationship between cognitive skills and reading, the cross-sectional study is preferred. In contrast, if the purpose of a study is to investigate the causality of the relationship between cognitive predictors and reading, the longitudinal design is better.

To conclude, the findings of our study complement those of previous studies conducted in alphabetic orthographies showing that the role of phonological awareness, orthographic knowledge, and morphological awareness changes across grades in a rather predictable manner. The contribution of phonological awareness to Chinese reading decreased across grades and the contribution of morphological awareness increased across grades. This likely reflects variations in the linguistic units that are favored by each writing system. In alphabetic orthographies, where letters correspond to phonemes, phonological awareness is the dominant predictor of reading (e.g., Kirby et al., 2012). In contrast, in Chinese, where characters correspond to morphemes, morphological awareness is the most important predictor of word reading (e.g., McBride-Chang et al., 2003, 2005). Our findings also suggest that orthographic knowledge is equally important to word reading, especially for silent reading fluency. Finally, RAN was a particularly strong predictor of oral reading fluency and its effects increased across grades. This establishes RAN as a key predictor of reading fluency across languages whose effects are independent of phonological awareness, orthographic knowledge, and morphological awareness.

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