Why Does Rapid Naming Predict Chinese Word Reading?

Kathy Kar-man Shum

Terry Kit-fong Au

University of Hong Kong

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Abstract

Rapid automatized naming (RAN) robustly predicts early reading abilities across languages, but its underlying mechanism remains unclear. This study found that RAN associated significantly with processing speed but not with phonological awareness or orthographic knowledge in 89 Hong Kong Chinese second-graders. RAN overlaps more with processing speed (18% of individual variation) in predicting word reading fluency, than with phonological (4%) or orthographic awareness(3%), suggesting that processing speed contributed more strongly to the RAN-reading fluency relation in Chinese. Nonetheless, RAN remained significant in predicting Chinese word-level reading fluency when all other cognitive tasks were taken into account, suggesting that no single construct can fully explain RAN's relation to reading, but that multiple components influence this relation. Moreover, when reading abilities in second language English were considered, the association between RAN and word reading fluency was marginally stronger in Chinese than in English. Implications for mechanisms underlying the RAN-reading relation are discussed.

Dysfluent readers often have reading comprehension difficulties. Interactive models of reading propose that readers use lower- and higher-level cognitive skills interactively. Slow processing of individual words forces dysfluent readers to spend a disproportionate amount of attentional resources on word recognition, taking attentional resources from text comprehension (LaBerge & Samuels, 1974; Perfetti, 1998). Other models of reading have also highlighted the important role of reading accuracy and reading fluency—the ability to read text accurately and quickly—in reading development. Carver's causal model of reading achievement (Carver, 1998; Carver & David, 2001) proposes that general reading ability is proximally predicted by reading accuracy and reading rate, which in turn are predicted by decoding ability and naming speed. This causal model underscores the contribution of naming speed to reading development via its effects on reading fluency.

Naming speed is commonly assessed using rapid automatized naming (RAN) tasks (Denckla & Rudel, 1976), which measure the ability to quickly name a series of highly familiar visual stimuli, such as colors, objects, digits, and letters. The simplicity of these tasks belies their power. They robustly predict reading development in many languages (e.g., English: Blachman, 1984; Dutch: de Jong & van der Leij, 1999; Greek: Georgiou, Parrila, & Papadopoulos, 2008; Finnish: Lepola, Poskiparta, Laakkonen, & Niemi, 2005; Chinese: McBride-Chang & Ho, 2005; Japanese: Kobayashi, Haynes, Macaruso, Hook, & Kato; 2005). RAN significantly predicts reading performance even when other reading-related measures such as IQ (Badian, 1993; Cornwall, 1992), articulation rate (Bowey, McGuigan, & Ruschena, 2005), phonological awareness (Manis, Doi, & Bhadha, 2000), orthographic processing (Georgiou, Parrila, Kirby, & Stephenson, 2008), and processing speed (Georgiou, Parrila, & Kirby, 2009), as well as demographic variables such as age (Cornwall, 1992) and socioeconomic status (Swanson, Trainin, Necoechea, &

Hammill, 2003) are taken into account. In line with Carver's causal model (Carver, 1998; Carver & David, 2001), stronger associations are generally observed between RAN and reading fluency, as compared to reading accuracy (Kirby, Georgiou, Martinussen, & Parrila, 2010). Norton and Wolf (2012) have crowned RAN tasks as "one of the best, perhaps universal, predictors of reading fluency across all known orthographies" (p.430).

Despite the plethora of evidence supporting the robust relation between naming speed and reading, why RAN predicts reading fluency remains unresolved. This question has theoretical as well as practical significance because a better understanding of naming speed, and consequently its deficits, can have important educational implications. Due to the strong predictive power of RAN in reading development, remediation efforts have been targeted at improving RAN, in hopes of enhancing reading performance. Nevertheless, the question as to whether RAN can be improved through training remains controversial. The trainability of RAN and the possibility of knock-on effects on reading directly hinge on the nature of the relation between RAN and reading. Three major hypotheses have been proposed to explain this relation: 1) the phonological processing theory; 2) the orthographic processing theory; and 3) the speed of processing theory.

Hypotheses on the RAN-Reading Relation

The phonological processing theory posits that both RAN and reading tap the rate of lexical—or mental vocabulary—access and retrieval of phonological representations from long-term memory (Wagner & Torgesen, 1987). Hence, RAN is just part of phonological processing, along with phonological awareness and phonological memory. Indeed, confirmatory factor analysis revealed a good fit with empirical data for a model with phonological awareness, phonological memory, and phonological lexical access (measured by RAN) as three distinct but significantly correlated factors (Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). Meta-analyses have revealed that rapid naming correlates moderately (*r*=.3 to .4) with phonological awareness (Swanson et al., 2003; Vukovic & Siegel, 2006). Moreover, alphanumeric naming speed seems to influence word reading in fourth-grade children via phonological awareness and phonological memory (Bowey et al., 2005).

On the other hand, counterevidence has accumulated. RAN displays unique effect on reading beyond phonological awareness, phonological memory, and isolated naming—purportedly a more precise measure of lexical access than rapid serial naming (Logan, Schatschneider, & Wagner, 2011), and RAN does not seem to be subsumed under a phonological processing factor in structural equation modeling (Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007). Some other extraphonological factors, then, may matter in the relation between RAN and reading.

A competing theoretical view is that RAN reflects the automaticity of orthographic symbol processing, and hence it may influence reading via the efficiency of orthographic processing rather than phonological processing. Bowers and Wolf (1993) suggested that slow letter identification—reflected by subpar rapid letter naming—may undermine associations between letters within a word, thereby undermining the detection and learning of common orthographic patterns in print, leading to lower automaticity in reading. Another variant of the automaticity account is that words are often processed in fluent reading as single units, not unlike the processing of individual symbols in RAN tasks (Georgiou et al., 2009). So, RAN could be correlated with reading fluency because both measure whole-unit lexical access.

Consistent with the automaticity account, Manis, Seidenberg, and Doi (1999) argued that, for reading, what can be uniquely explained by RAN may have to do with the arbitrary mappings of print to sound. This hypothesis predicts that RAN should be more strongly related to irregular word reading than to regular word reading, since the former involves more arbitrary mappings between orthography and phonology. This account, however, has been challenged empirically. Moll, Fussenegger, Willburger, and Landerl (2009) found that RAN correlated with reading fluency for nonwords as strongly as for real words in German. Since nonwords are unfamiliar words that presumably cannot be automatically recognized as orthographic units but rely instead on phonological decoding in reading, these results pose a serious challenge to the hypothesis that RAN is a measure of automaticity in orthographic processing. Moreover, RAN remained a significant predictor of word reading fluency even when orthographic spelling was controlled for but not when nonword reading fluency was controlled for, further challenging the view that RAN and reading are linked by orthographic processing (Moll et al., 2009).

A third view is that RAN taps the global cognitive speed of processing; RAN and reading fluency are correlated because both involve rapid sequential processing of information (Kail & Hall, 1994). Increase in naming speed with age may reflect age-related improvement in global processing speed. Indeed, Kail, Hall, and Caskey (1999) found that RAN was predicted by general processing time (measured by visual matching and cross-out tasks)—thereby supporting the global processing speed view—but not by reading experience (measured by author recognition and book title recognition). These findings therefore contradict the view that RAN has to do with the automaticity of orthographic codes being processed and retrieved from memory, as automatic processing is presumably a product of accumulated reading experience. Catts, Gillispie, Leonard, Kail, and Miller (2002) further showed that normal-IQ poor readers performed significantly worse than good readers on rapid object naming and on response time tasks across linguistic and non-linguistic domains. Importantly, RAN failed to explain reading beyond and above what could be explained by IQ and response time measures. On the other hand, some studies revealed that RAN significantly predicted reading ability, accounting for 12-17% of unique variance, even after controlling for global processing speed (Bowey et al., 2005; Bowey, Storey, & Ferguson, 2004; Powell et al., 2007). Hence, it remains unclear how much of the power of RAN in predicting reading fluency can be credited to domain-general processing speed.

Possible Implications on Educational Interventions

These different views of naming speed have direct implications for how interventions are to be carried out to remediate reading problems, as they provide clue to whether RAN should be the target of intervention. If RAN shares a higher degree of commonality with either phonological or orthographic processing—versus processing speed—in predicting reading, then RAN is likely to improve when phonological or orthographically-based interventions are delivered. By contrast, if RAN is indeed largely an index of global speed of processing, it may not be easily modifiable via practice, and intervention effort should then be targeted elsewhere.

Prior research has used a variety of training paradigms, but results were mixed and inconclusive. Assuming that RAN reflected the quality and accessibility of orthographic representations stored in the mental lexicon, Conrad and Levy (2011) showed that speeded letter recognition improved only when the letter naming training was preceded by training in orthographic pattern recognition, but not when the letter training occurred alone. Their results suggested that naming speed can be improved, possibly by strengthening orthographic representations. Fugate (1997), by contrast, showed temporary improvement in RAN and oral reading fluency in a letter-trained group relative to the control group at immediate post-test, though not at follow-up seven weeks later. Other studies explored the effects of phonological interventions on increasing naming speed, but found no significant gains in RAN after training in phonological analysis and blending (Lovett, Steinbach, & Frijters, 2000; Regtvoort & van der Leij, 2007). Broad-based interventions addressing multiple literacy skills also showed inconsistent results with respect to RAN improvement (Nelson, Benner, &

Gonzalez, 2005; Nelson, Stage, Epstein, & Pierce, 2005). Hence, it is still unclear whether RAN can be enhanced through training.

RAN and Reading in Chinese

The picture is further complicated by some findings suggesting that RAN is more strongly associated with reading in orthographically consistent languages (e.g., Dutch, German, and Italian), than in orthographically inconsistent languages (e.g., English) (de Jong & van der Leij, 1999; Di Filippo et at., 2005; Landerl & Wimmer, 2000; Mann & Wimmer, 2002). However, this view fails to explain why RAN is a robust predictor of reading in Chinese (Chow, McBride-Chang, & Burgess, 2005; Hu & Catts, 1998; McBride-Chang & Ho, 2005; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Pan et al., 2011)—a nonalphabetic writing system often regarded as extremely opaque in orthography-to-phonology mappings.

Unlike reading alphabetic scripts which relies heavily on decoding letters within a word, reading Chinese characters depends primarily on acquiring arbitrary associations between symbols and sounds. Although about 80% of Chinese characters contain a phonetic component offering clues to the sound (Ho, Ng, & Ng, 2003), pronunciation can only be correctly inferred in about 25% of the Chinese characters when lexical tone is also taken into consideration (Shu, Chen, Anderson, Wu, & Xuan, 2003). Hence, a Chinese character is typically recognized as a unit quite holistically. As such, automaticity in orthographic processing—rather than phonological processing—may well turn out to mediate the RAN-reading relation in Chinese. On the other hand, phonological sensitivity does predict Chinese character recognition longitudinally (Pan et al., 2011), and RAN was found to overlap more with phonological sensitivity tasks than with orthographic processing tasks in predicting both reading accuracy and reading fluency in Chinese children in Grades 2 and 4 (Liao, Georgiou, & Parrila, 2008). With both phonological processing and orthographic processing as plausible mediators for the relation between RAN and reading ability, Chinese will be a good test case for sorting out how various cognitive components may contribute to this relation.

Research Aims

To do so, we examined correlations among RAN, phonological awareness, orthographic knowledge, speed of processing, and both Chinese word reading accuracy and fluency in a sample of Grade 2 children in Hong Kong. Hierarchical regression analyses were conducted to explore the common variance shared between RAN and the other cognitive measures in predicting word reading accuracy and fluency, offering clues to the relative importance of various cognitive components in mediating the RAN-reading relation in Chinese.

We also assessed the children's word reading accuracy and fluency in English as a second language (ESL), and compared the RAN-reading correlations in English with those obtained in Chinese as the first language. Existing studies on Chinese speakers (Hu & Catts, 1998; Liao et al., 2008) have reported stronger RAN-reading correlations than the median correlation obtained by Scarborough's (1998) meta-analysis of English-speaking samples. By contrast, Georgiou, Parrila, and Liao (2008) found no significant differences in the RAN-reading correlations across languages—Chinese, English, and Greek—that vary in orthographic consistency. The results are mixed for studies among Chinese-speaking ESL children: some studies have reported significant relations between word reading and rapid naming in both languages (Chung & Ho, 2010), while others found significant correlation in L1 Chinese but not in L2 English (Keung & Ho, 2009). These findings suggest that different cognitive components may underlie the association between RAN and reading across languages. We set out to evaluate these competing theories on the robust but as yet not well understood relation between RAN and reading, using Chinese and English as the test cases.

Method

Participants

Eighty-nine native Cantonese-speaking Grade 2 children in Hong Kong (41 boys and 48 girls; mean age = 7.48 years; *SD* = 0.47) from two public elementary schools participated in the study. In Hong Kong, English as a second language exposure typically begins around age 4 to 5 years. By Grade 2, children typically have attained some vocabulary knowledge in English. Parental written consent and child oral assent were obtained prior to testing.

Measures

Nonverbal Intelligence Task

Raven's Standard Progressive Matrices. Children's nonverbal intelligence was assessed using the full version (Sets A, B, C, D and E) of this standardized written test, with 60 items arranged in ascending order of difficulty. Each item consisted of a pattern with a missing part, and children chose from either 6 (for Sets A and B) or 8 (for Set C, D and E) alternatives to complete the pattern. Raw scores were converted into standard scores based on local norms obtained by the Hong Kong Education Department (Raven, 1986).
Test-retest reliability was reported to be .88 in the original version of this test. Cronbach's alpha reliability coefficient for this sample was .92.

Reading Accuracy Tasks

Chinese word reading. This word reading accuracy test was adopted from the *Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary School Students* (HKT-P(II); Ho et al., 2007)—a standardized test battery for assessing children (aged 6-12) for developmental dyslexia. In this untimed task, children read aloud from a set of 150 two-character Chinese words listed in increasing level of difficulty. A child scored one point for pronouncing both characters of a word correctly. The test was discontinued when a child scored 0 on 15 consecutive words. Ho et al. (2007) reported split-half reliability of .98 for this subtest for children at age 7. Cronbach's alpha obtained in this study was .98.

English word reading. Word reading accuracy in English was assessed by asking children individually to read aloud, without any time limit, 80 English words selected from the most widely used local English textbooks. The words ranged from 2 to 10 letters (1 to 4 syllables) and were presented in ascending order of difficulty. Children were asked to attempt all items on the word list, and one point was given for each word read correctly. Cronbach's alpha coefficient for this task was reported to be .98 in previous work (Chung & Ho, 2010) and was .97 for the current sample.

Reading Fluency Tasks

Chinese one-minute word reading. This timed task from the HKT-P(II) measured reading fluency (Ho et al., 2007), with 90 simple two-character Chinese words displayed in 9 rows containing 10 words each. Children read aloud as many words as they could in one minute, earning one point every time they read both characters correctly, and the total number of points was the score. If they finished reading the 90 words within the time limit, the completion time for the task was recorded, and their final score as follows: (Number of words correctly named) x 60 / (Completion time in seconds). According to Ho et al. (2007), test-retest reliability at age 7 was .99. We obtained a reliability coefficient of .94 for this subtest.

English one-minute word reading. This reading fluency test consisted of 90 simple monosyllabic English words, 2 to 5 letters in length, arranged in 9 rows with 10 words each. Children were given one minute to read aloud sequentially as many words as possible. The score was the number of words correctly read within the time allowed. Scores were calculated as in the Chinese one-minute word reading if children finished reading all items within the time limit. The reliability coefficient was .95 for this task.

RAN Tasks

Chinese rapid digit naming. Naming speed was measured using the Digit Rapid

Naming subtest from the HKT-P(II) (Ho et al., 2007). Children were presented with a 5x8 array made up of 5 digits (2, 4, 6, 7, 9) arranged in random sequence in each row, and asked to name all the digits in serial order both as quickly and as accurately as they could. Children were given two trials each, and their average completion time across the trials was their score. A lower score on this task signified better performance in RAN. Median test-retest reliability for children aged 7 was reported to be .86 (Ho et al., 2007). We obtained a reliability coefficient of .85 in this study.

English rapid letter naming. The structure and format of this test was similar to the RAN tasks developed by Denckla and Rudel (1976) and expanded by Wolf and Denckla (2005). This test was composed of 5 English uppercase letters (A, D, L, M, S) repeated 8 times each, and arranged in quasi-random order to create 4 rows of 10 letters. Prior to the actual timed test, children were first asked to name the 5 letters to ensure that they knew the stimulus items. They were then asked to name the letters sequentially as quickly and as accurately as they could, and the score was their average completion time across two trials. The lower the score on this task, the better was the performance. Test-retest reliability was .84 for the current study.

Other Cognitive Tasks

Rhyme awareness. Shu, Peng, and McBride-Chang (2008) have shown that accuracy in syllable awareness reached 80% or above in preschool Chinese children aged 3 to 6; such early competence may be due to the salience of syllables in Chinese. To avoid ceiling performance in Grade 2 children, we therefore used the more challenging rhyme detection instead to assess children's phonological awareness (Shu et al., 2008). For each test item in this HKT-P(II) task (Ho et al., 2007), children listened to digital sound tracks of three Chinese syllables (e.g., [saa]^1 (sand "沙")、[haa]^1 (shrimp "蝦")、[jin]^1 (smoke "煙")), each illustrated with a picture to reduce memory load. Children were asked to indicate which two syllables rhymed by pointing to the corresponding pictures. Three demonstration trials were presented, followed by 18 test trials. One point was given for each correct response. Split-half reliability for this subtest was .75 for children at age 7 (Ho et al., 2007). Cronbach's alpha for our sample was .73.

Lexical decision. This subtest from the HKT-P(II) assessed children's orthographic processing and their ability to distinguish legitimate orthographic layouts of Chinese characters from illegitimate ones (Ho et al., 2007). The test consisted of 30 rare characters (e.g., "攢") and 30 non-characters (e.g., "月舟"), each containing two radicals displayed in a left-right position. The non-characters were constructed by putting together either two semantic radicals, two phonetic radicals, or a semantic and a phonetic radical placed in illegitimate positions. All items were printed in a fixed random order on two sheets of paper. Children were asked to cross out all the non-characters without time limit. The test was scored on the number of characters and non-characters correctly identified, with a maximum score of 60. Ho et al. (2007) reported a median split-half reliability of .75 for children at age 7. We obtained a Cronbach's alpha coefficient of .69 for this subtest in our study.

Cross-out. Cross-out tasks are often used for measuring general speed of processing (Georgiou et al., 2008a). The test adopted here consisted of 10 rows of digits (0-9). Each row contained one target digit on the left and another 10 digits on the right with 3 identical to the target. Children were given 30 seconds to cross out the 3 digits identical to the target, randomly dispersed in each row (e.g., 6 // 8 1 4 6 7 6 2 3 5 6), as quickly as possible. Two practice trials were given prior to the actual timed test. The score was the number of items correctly crossed out within the time limit. Test-retest reliability for this task was .66.

Procedure

Children were tested in two sessions lasting about 30 minutes each. In the first session, children were individually assessed with the reading tasks and all the cognitive tasks except for Raven's Progressive Matrices, which was administered in the second session in a group setting. Testing sessions were conducted on separate days to minimize fatigue. All assessments were carried out in the participating schools by trained experimenters during school hours.

Results

Table 1 presents the means and standard deviations for all measured variables. Raven's Standard Progressive Matrices raw scores were converted into standard scores (Raven, 1986), based on a mean of 100 and a standard deviation of 15, and the nonverbal IQ standard scores were above 80 for all participants.

Correlations among RAN and Other Cognitive and Reading Measures in Chinese

Table 2 presents the Pearson correlation coefficients among all tasks. Reading accuracy in Chinese (as measured by untimed Chinese word reading) correlated strongly with word reading fluency (as measured by timed Chinese one-minute word reading). Untimed Chinese word reading also correlated significantly with all the reading-related cognitive measures, with rhyme awareness showing the strongest correlation (r=.37, p<.001). Chinese word reading fluency by contrast correlated most strongly with rapid digit naming and rapid letter naming (rs>-.66, ps<.001), moderately with digit cross-out (r=.44, p<.001), and only weakly although still significantly with rhyme awareness and lexical decision.

The relative importance of various cognitive abilities for reading seemed to depend on whether accuracy or fluency was in question. We used Hotelling's t tests (Glass & Hopkins, 1984) to examine whether the correlations of each cognitive task with untimed Chinese word reading differed significantly from their correlations with Chinese one-minute word reading. The two RAN tasks were related to both reading measures, but more robustly so with word reading fluency than with word reading accuracy in Chinese (ts(86)>5.95, ps<.001). General processing speed measured by the cross-out task correlated significantly more strongly with Chinese word reading fluency than with reading accuracy ($t(86)=-2.89$, $p<.01$). By contrast, the difference between correlations with the two Chinese reading measures—accuracy versus fluency—was not significant for either rhyme awareness ($t(86)=1.66$, $p=.10$) or lexical decision ($t(86)=.00$, $p=1.00$). Lastly, both RAN measures correlated significantly more strongly with Chinese word reading fluency than the cross-out task did ($ts(86)=-8.77$, $ps<.001$).

Between RAN and the other cognitive variables, only the digit cross-out task correlated significantly with both rapid digit naming and rapid letter naming ($rs>-.33$, $ps<.01$). Rhyme awareness and lexical decision were significantly correlated, but neither was associated with the RAN tasks. RAN seemed to be related more strongly to general processing speed than to phonological awareness or orthographic processing in this study.

Unique Contribution of RAN and Shared Variance with Phonological Awareness, Orthographic Knowledge, and Processing Speed in Predicting Chinese Word Reading

Hierarchical multiple regression analyses were conducted to investigate whether RAN shared predictive variance on reading with phonological awareness, orthographic knowledge, and processing speed. To reduce error in the measurement of RAN, the average of the scores on rapid digit naming and rapid letter naming was used in the analyses. Separate analyses were run for the prediction of untimed Chinese word reading (i.e., accuracy) and Chinese one-minute word reading (i.e., fluency). In all the regressions, children's age and nonverbal IQ were entered as control variables in the first step of the equations. Initially, RAN was included in the second step as the only predictor to estimate its contribution to Chinese word reading beyond the controlled variables. In subsequent regressions, RAN was entered in the third step following rhyme awareness, lexical decision, or digit cross-out to assess the common variance shared between RAN and each of the cognitive processes, and also the unique variance explained by RAN over and above the other factors in predicting word reading in Chinese. Results are presented in Table 3.

In predicting Chinese word reading accuracy, RAN accounted for 14% of variance in the dependent variable beyond age and IQ. Comparing this with the unique variance added by RAN (11%) after controlling for rhyme awareness, the reduction in RAN's contribution to Chinese word reading accuracy revealed a 3% shared predictive variance with phonological awareness. Similarly, RAN shared 2% and 4% of the variance in Chinese word reading accuracy with the orthographic knowledge and processing speed tasks respectively. Hence, comparable amounts of common variance were shared between RAN and each of the cognitive measures in accounting for the variability in word reading accuracy.

Results for word reading fluency were very different. RAN was a far more robust predictor of Chinese one-minute word reading (ΔR^2=.55, p<.001) than of the untimed word reading task (ΔR^2=.14, p<.001). The reduction in additional variance contributed by RAN was most substantial when cross-out was entered in the previous step of the regression, indicating that RAN shared the largest proportion of variance with processing speed (18%) in predicting word reading fluency in Chinese. Both rhyme awareness (4%) and lexical decision (3%) shared much less common variance with RAN. General speed of processing, when compared to phonological awareness and orthographic knowledge, seemed to matter more in explaining the relation between RAN and word reading fluency.

Significantly, although RAN shared considerable variance with processing speed, RAN also accounted for an additional 37% of variability in predicting Chinese one-minute reading over and above processing speed. These results suggest that RAN is tapping more than just processing speed; other cognitive factors are likely to be involved in mediating the relation between RAN and word reading fluency.

To further explore the unique contribution of RAN to reading beyond phonological awareness, orthographic knowledge, and processing speed combined, RAN was put in the third step of the regression after all the other cognitive measures had been entered in the second step. Significant changes in R^2 were observed when RAN was added, in predicting both untimed Chinese word reading (ΔR^2=.09, p<.01) and one-minute word reading (ΔR^2=.36, p<.001). These results suggested that other processes in addition to phonological awareness, orthographic knowledge, and processing speed are involved in the relation between RAN and word reading—both fluency and accuracy included—in Chinese.

Comparison of RAN-Reading Correlations in Chinese and English

We examined the correlations between RAN and the word reading measures in both Chinese and English to see whether the RAN-reading relations differed across these two languages among Cantonese Chinese-speaking ESL children (Table 4). Similar to the results in Chinese, RAN as measured by rapid letter naming was significantly associated with both untimed English word reading (r=-.44, p<.001) and English one-minute word reading (r=-.56, p<.001). Note that the former correlation was significantly weaker than the latter (t(86)=2.71, p<.01), as revealed by Hotelling's *t* test (Glass & Hopkins, 1984). Hence, in English as well as Chinese, RAN was more strongly related to word reading fluency than to reading accuracy.

We further examined whether RAN-reading correlations in Chinese were significantly different from their correlations in English, using Raghunathan, Rosenthal, and Rubin's (1996) modification of Pearson and Filon's *z* test (ZPF) to compare non-overlapping correlations. As it turned out, correlation between rapid digit naming and untimed Chinese word reading was not significantly different from the correlation between rapid letter naming and untimed English word reading (z=1.49, p=.14), whereas the correlation between rapid digit naming and Chinese one-minute word reading was marginally different from that between rapid letter naming and English one-minute reading (z=-1.73, p=.08). When the average of the two rapid naming tasks was used to assess RAN performance, similar results were obtained based on Hotelling's *t* tests (Glass & Hopkins, 1984) for comparing overlapping correlations: RAN's correlation with Chinese one-minute word reading was marginally stronger than its correlation with English one-minute word reading ($t(86)=-1.85$, $p=.07$), but no difference was found between Chinese and English in terms of RAN's correlation with untimed word reading ($t(86)=.99$, $p=.32$). In other words, RAN appeared to relate more strongly with word reading fluency in Chinese as compared to English, although this trend failed to reach statistical significance at the level of $p<.05$.

Discussion

We set out to examine why RAN predicts reading. We used word reading in a nonalphabetic orthography—Chinese—as a test case because it relies considerably on both: (1) automatizing many arbitrary script-sound associations, and (2) phonological decoding of phonetic cues in Chinese characters. Based on the three major theoretical views on the RAN-reading relationship, we focused on how RAN was related to phonological awareness, orthographic knowledge, and speed of processing, as well as their common variance in predicting word reading accuracy versus word reading fluency in the Chinese language.

Theoretical Implications on the RAN-Reading Relation in Chinese

Firstly, RAN as measured by rapid digit naming and rapid letter naming did not correlate well with phonological awareness and orthographic knowledge. Our results corroborate Keung and Ho's (2009) findings that RAN (rapid picture naming) did not correlate significantly with either Chinese rhyme detection ($r=-.08$) or lexical decision ($r=.13$) in Grade 2 Hong Kong Chinese children. Among Mandarin speakers in Taiwan (Liao et al., 2008), naming speed of digits and colors likewise did not correlate significantly either with orthographic processing in Grade 2, or with phonological sensitivity and orthographic processing in Grade 4. In Swanson et al.'s (2003) meta-analysis on 49 independent English-speaking samples (N = 2,257), mean correlations weighted for sample size were in the low-to-moderate range (.36 to .41) between RAN and phonological awareness and between RAN and orthographical awareness. Moreover, these three kinds of measure were found to load on different factors in a five-factor model in exploratory factor analysis. The non-significant correlations observed in our study between RAN and these two constructs suggest that what underlies RAN in predicting reading is probably quite independent of what underlies phonological awareness and orthographic knowledge in predicting reading.

By contrast, both rapid digit naming and rapid letter naming correlated moderately with the digit cross-out task. It might seem questionable whether the association between the digit naming and cross-out tasks would have largely been due to the use of numbers in both measures. Nevertheless, the moderate correlation similarly observed between rapid letter naming and the processing speed task provided evidence against this postulation. Moreover, other studies using geometric figures instead of digits in cross-out tasks have shown even stronger correlations between RAN and cross-out (Kail et al., 1999). For instance, Kail and Hall (1994) observed that both visual matching of digits and cross-out of geometric figures correlated strongly with naming speed of digits, letters, and colors (*r*s ranging from .61 to .75). Powell et al. (2007) found significant correlations not only between RAN and speed of processing as measured by cross-out of geometric figures, but also between RAN and simple reaction time tasks that required appropriate key-presses when target stimuli appeared on screen. Our results are in line with these findings, providing support to the hypothesis that RAN is a significant index of processing speed.

Our hierarchical regression analyses revealed further that although shared variance between RAN and each of the other three cognitive measures (i.e., phonological awareness, orthographic knowledge, processing speed) was comparable (ranging from 2% to 4%) in predicting word reading accuracy, RAN shared much more variance with processing speed (18%, as measured by digit cross-out) than with phonological awareness (4%) and orthographic knowledge (3%) in predicting Chinese word reading fluency. Hence, among the three constructs assessed, processing speed appeared to contribute most strongly to the relation between RAN and fluent word reading.

Prior research on Chinese reading has mostly focused on how well RAN, phonological sensitivity, orthographic processing, and other variables such as short-term memory, morphological awareness, and vocabulary knowledge, predicted Chinese reading accuracy and reading fluency (Chung & Ho, 2010; Keung & Ho, 2009; Liao et al., 2008; McBride-Chang et al., 2003; Pan et al., 2011; Shu et al., 2008). The potential mediating effects of general processing speed have largely been overlooked. This study makes a new contribution by documenting that processing speed emerged as the strongest mediator among the three constructs examined here in accounting for the robust correlation between RAN and Chinese word reading fluency. This account fits well with the exploratory model proposed by Cutting and Denckla (2001), postulating that processing speed contributes to RAN performance, which in turn uniquely predicts word reading, independent of phonological awareness and orthographic knowledge.

Another major finding of our study was that RAN still emerged as a significant predictor of both untimed Chinese word reading and one-minute word reading when all other cognitive tasks in this study had been controlled for, accounting for respectively an additional 9% and 36% of unique variance in the two reading measures. Results here are consistent with prior studies showing that rapid naming contributed significantly to reading beyond the effects of phonological processing (Logan et al., 2011), orthographic processing (Moll et al., 2009), and global processing speed (Bowey et al., 2004; Powell et al., 2007). Given RAN’s unique contribution over and above these factors combined, our findings argue against those theories that posit any of these constructs as the single major factor mediating the association between RAN and reading, even though those constructs individually shared a portion of variance in word reading with RAN. Were such theoretical views valid, RAN should no longer significantly predict word reading once their respective favored determining factor has been controlled for. Quite the contrary, our data supported the hypothesis that multiple constructs are involved in the relation between RAN and reading at the word level. The unique contribution of RAN in predicting word reading accuracy and fluency strongly suggests that other component skills, besides those included in the analyses, underlie the relations.

RAN is sometimes viewed as a microcosm of reading, since they both seem to require the orchestrated execution of similar processes, including early attentional processes and uptake of visual information, visual processing of pattern, lexical access of mental representations, integration of orthographic, semantic and phonological information, and motoric articulation (Wolf & Bowers, 1999). As such, some of these underlying processes may indeed serve to account for the unexplained variance in the RAN-reading association. One plausible candidate is visual perception. Stainthorp, Stuart, Powell, Quinlan, and Garwood (2010) showed that children poor in RAN were significantly slower in judging whether simple visual features were same or different, when compared to controls matched on age, verbal and nonverbal IQ, phonological processing ability, and visual acuity, after partialling out the effect of simple reaction time. Thus this difficulty in visual discrimination could not be due to a deficit in general processing speed. Moreover, when simple reaction time, visual discrimination, and RAN were entered stepwise into the regression equation, visual discrimination was no longer a significant predictor of word reading once RAN was added, revealing common variance shared between them. Importantly, RAN further contributed unique variance in word reading even when entered last in the regression, implying that some other factors apart from speed of processing and visual discrimination are probably involved in mediating the relationship between RAN and reading. The role of other cognitive processes, such as working memory and executive functions, in mediating the RAN-reading relation remains to be explored.

RAN-Reading Correlations in Chinese and English among ESL Children

Our study on Hong Kong Chinese children learning ESL also revealed that the correlations of RAN with word-level reading accuracy and reading fluency in both Chinese (L1) and English (L2) were significant, and the association between RAN and word reading fluency in Chinese was marginally higher than its association with English word reading fluency. Prior studies among Chinese-speaking ESL children have mostly reported RAN's relation with untimed reading measures (Chung & Ho, 2010; Ho & Fong, 2005; Keung & Ho, 2009; McBride-Chang & Ho, 2005; McBride-Chang, Liu, Wong, Wong, & Shu, 2011; Pan et al., 2011), but have seldom contrasted RAN's correlations with speeded reading across the two orthographies. One study thus far has compared correlations of RAN with both reading accuracy and fluency across Chinese, English, and Greek, and found no significant differences in RAN-reading correlations between these languages (Georgiou et al., 2008b). Nonetheless, analyses at the components level revealed that the unique contribution of RAN pause time and RAN articulation time on reading outcomes differed across orthographies, with pause time showing largest contribution to reading in Chinese, followed by English, then Greek, along the continuum of orthographic consistency (Georgiou et al., 2008b). The arbitrariness in print-to-sound mappings might have led to more prominent effects of processing speed in reading Chinese. The difference in strength of RAN-reading correlations observed in our study may well be related to the varying relative contribution of speeded cognitive components in reading Chinese and English.

Further comparison of the correlations among the word reading tasks and other cognitive measures revealed different patterns of relations both within and across languages. For Chinese, word reading accuracy correlated weakly although significantly with all cognitive measures, while word reading fluency correlated most strongly with RAN tasks, moderately with processing speed, and weakly with phonological awareness and orthographic knowledge. Hence, RAN was significantly related to both reading measures in Chinese, but its relation with the timed task (i.e., word reading fluency) was clearly stronger. For English, RAN's correlations with word reading fluency and accuracy were more comparable, although the former was still stronger than the latter. These results are in line with prior findings in English (Kirby et al., 2010). Moreover, rhyme awareness measured in Chinese showed moderately strong correlations with both timed and untimed word reading in English, suggesting a prominent contribution of phonological awareness in reading English as compared to Chinese.

Given the different patterns of correlations observed for untimed and timed word reading, our results suggest that word reading accuracy and fluency are plausibly two distinct constructs, at least among aged 7 children in the current study. Our findings corroborate Carver's causal model of reading achievement that postulates reading accuracy and reading rate as two separate components that predict reading efficiency (Carver, 1998; Carver & David, 2001).

We also speculate that the different relative contribution of RAN and other cognitive tasks in their association with Chinese and English word reading may partly reflect the stages of reading development of children at the time of assessment. Most second graders in Hong Kong probably have not attained the same level of reading proficiency in their L2 English as compared to their L1 Chinese. The stronger association between phonological awareness and word reading in English relative to Chinese might suggest a heavier reliance on phonological decoding in reading English among these emergent L2 readers.

Clinical and Educational Implications

Rapid naming deficits are commonly observed in dyslexic readers in spite of the debate on the nature of this deficit. The double-deficit hypothesis proposes that poor naming speed is a second core deficit of dyslexia independent of phonological deficits (Wolf & Bowers, 1999). Deficits in RAN are even ranked the most dominant type of deficits among Chinese dyslexic children (Ho, Chan, Lee, Tsang, & Luan, 2004; Ho, Chan, Tsang, & Lee, 2002). Based on our finding that processing speed is one potential mediator of the robust relation between RAN and word reading fluency, processing speed deficits may underlie the association between poor naming speed and reading difficulties. Prior research has indeed shown that children with problems in rapid naming also performed more poorly than their age-matched counterparts on reaction time tasks, supporting the presence of a domain-general deficit in speed of processing (Catts et al., 2002; Stainthorp et al., 2010). Importantly, speed of processing is also slower in children with specific language impairment (Leonard et al., 2007; Miller, Kail, Leonard, & Tomblin, 2001). Despite the ongoing debate on whether developmental dyslexia and specific language impairment should be regarded as two distinct disorders or different manifestations of the same underlying deficiencies, significant overlap between the two had been found, indicating their comorbidity (Catts, Adlof, Hogan, & Weismer, 2005; Wong, Kidd, Ho, & Au, 2010; Wong et al., 2015). Deficits in processing speed may turn out to be a shared cognitive risk factor that can help explain the comorbidity of these two disorders.

Our finding that RAN was more closely related to processing speed than to phonological or orthographic processing also concurs with existing evidence that RAN is not a construct easily manipulated through training. Age-related change in RAN has been proposed to reflect a general increase in global processing speed governed by maturation (Kail & Hall, 1994; Kail et al., 1999). Therefore, devoting effort and time towards improving other components in the reading achievement model—such as decoding skills that contribute to both reading accuracy and reading rate (Carver & David, 2001)—should be more cost effective than targeting intervention resources on the less malleable RAN despite its robust relation with reading.

Conclusion

Prior research on the nature of the relation between RAN and reading was mixed and inconclusive. The three major theoretical perspectives described earlier have each been challenged. Findings from the present study support a multiple construct model. That is, no single construct—not global processing speed, or phonological awareness, or orthographic skills—can adequately account for RAN's relation to word reading ability. Instead, multiple components are probably involved, among which the general processing speed appears to play an important role in mediating the relation between RAN and word reading (especially word reading fluency) in Chinese. Future studies will do well to examine the developmental changes across the elementary years in the RAN-reading relation beyond the word level, perhaps using text-level reading measures and a longitudinal design. A more systematic investigation into those processes likely underlying both RAN and reading is crucial to understanding why RAN predicts so robustly reading abilities across languages.

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Table 1.
Means and standard deviations (SD) of age and all experimental measures in raw scores (*N*=89).

Variable (*max possible score*)	***Mean***	***SD***
Age (years)	7.48	.47
Raven's Progressive Matrices (60)	34.66	8.31
Chinese word reading (150)	65.75	24.94
Chinese one-minute word reading	50.53	16.13
English word reading (80)	33.74	15.83
English one-minute word reading	29.82	17.78
Rapid digit naming (seconds)	22.95	5.03
Rapid letter naming (seconds)	27.39	7.89
Rhyme awareness (18)	11.84	3.41
Lexical decision (60)	51.02	4.33
Cross-out (30)	20.44	3.67

Table 2.

Pearson correlations among all tasks.

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Chinese word reading	—								
2. Chinese one-min word reading	.74***	—							
3. English word reading	.45***	.48***	—						
4. English one-min word reading	.36***	.58***	.88***	—					
5. Rapid digit naming	-.27**	-.69***	-.35**	-.55***	—				
6. Rapid letter naming	-.33**	-.66***	-.44***	-.56***	.74***	—			
7. Rhyme awareness	.37***	.25*	.54***	.40***	-.07	-.15	—		
8. Lexical decision	.21*	.21*	.32**	.24*	-.15	-.10	.34**	—	
9. Cross-out	.24*	.44***	.34**	.41***	-.43***	-.33**	.28**	.20†	—

†*p*<.01, **p*<.05, ***p*<.01, ****p*<.001.

Table 3.

Hierarchical multiple regression analyses predicting Chinese word reading and Chinese one-minute word reading from RAN, phonological awareness, orthographic knowledge, and processing speed.

	Chinese Word Reading		**Chinese One-Minute Word Reading**	
Step/Variable	R^2	ΔR^2	R^2	ΔR^2
1. Age, IQ	.06	.06†	.01	.01
2. RAN	.20	.14***	.56	.55***
2. Rhyme awareness	.18	.12**	.07	.06*
3. RAN	.28	.11**	.58	.51***
2. Lexical decision	.09	.03†	.05	.04†
3. RAN	.21	.12**	.57	.52***
2. Cross-out	.10	.04*	.20	.20***
3. RAN	.20	.10**	.58	.37***
2. Rhyme awareness, Lexical decision, Cross-out	.19	.14**	.23	.22***
3. RAN	.29	.09**	.59	.36***

†*p*<.01, **p*<.05, ***p*<.01, ****p*<.001.

RAN = average of the scores of rapid digit naming and rapid letter naming.

Table 4.

Pearson correlations and coefficients of determination (in brackets) between RAN and word reading measures in Chinese and English.

	Word Reading Accuracy		**Word Reading Fluency**	
	Chinese	***English***	***Chinese***	***English***
Chinese rapid digit naming	-.27**	-.35**	-.69***	-.55***
	(.07)	(.12)	(.48)	(.31)
English rapid letter naming	-.33**	-.44***	-.66***	-.56***
	(.11)	(.19)	(.43)	(.31)
RAN	-.33**	-.43***	-.72***	-.60***
	(.11)	(.19)	(.51)	(.35)

**p<.01, ***p<.001.

RAN = average of the scores of rapid digit naming and rapid letter naming.