This study examined the development of rapid automatised naming (RAN) components (i.e. articulation time and pause time) in English and Chinese, and their relations to English reading comprehension, in Chinese English immersion students at Grades 2, 4 and 6. Results indicated that pause time rather than articulation time was highly correlated with total time in both English and Chinese in all three grades. English and Chinese articulation times and English and Chinese pause times were more related after Grade 2. All component times decreased with grade level, but the decrease in English pause time between Grades 2 and 4 was the greatest. English pause time explained variance in English reading comprehension only in Grade 6. There was little evidence of cross-language transfer from Chinese RAN components to English reading comprehension.

Rapid automatised naming (RAN) speed, defined as how quickly children can name highly familiar visual stimuli, has been found to be a strong predictor of reading comprehension in both alphabetic (e.g. Bowers & Wolf, 1993; De Jong & van der Leij, 1999; Georgiou, Parrila & Papadopoulos, 2008) and nonalphabetic orthographies (e.g. Chow, McBride-Chang & Burgess, 2005; Liao, Georgiou & Parrila, 2008). Importantly, RAN’s effect has survived the statistical control of other known predictors of reading such as letter knowledge (e.g. Kirby, Parrila & Pfeiffer, 2003), phonological awareness (e.g. Manis, Doi & Bhadha, 2000; Parrila, Kirby & McQuarrie, 2004) and orthographic processing (e.g. Georgiou, Parrila, Kirby & Stephenson, 2008).

Although much progress has been achieved in understanding the contribution of RAN to reading (see Kirby, Georgiou, Martinussen & Parrila, 2010, for a review), researchers concur that they do not completely understand how it is related to reading. Several researchers have developed competing theoretical accounts to explain the RAN–reading relationship. Initially, Torgesen and colleagues (Torgesen, Wagner, Rashotte, Burgess & Hecht, 1997; Wagner, Torgesen & Rashotte, 1994) theorised that RAN is an index of the ease of access to stored phonological information in long-term memory and for this
reason its contribution is redundant with phonological awareness. In contrast, Bowers and colleagues (Bowers, Sunseth & Golden, 1999; Bowers & Wolf, 1993) proposed that RAN is distinct from phonological awareness but related to reading through orthographic processing, arguing that children with RAN deficits are less sensitive to commonly occurring orthographic patterns. Finally, Kail and colleagues (Kail & Hall, 1994; Kail, Hall & Caskey, 1999) argued that RAN may be related to reading because both naming and reading depend on general processing speed. Although it is not clear why RAN is related to reading, the idea of analysing RAN performance into its constituent components may provide some insights into the relationship between RAN and reading, particularly when this is done in bilingual children learning to read in two languages that do not share linguistic features.

To measure RAN, most studies have used a single performance time for the whole test (i.e. the total amount of time it takes an individual to name the entire series of stimuli). However, some researchers have argued that the total naming time fails to provide the precision needed to adequately determine the nature of RAN and its relation to reading, and have proposed that the overall RAN time should be analysed into components (e.g. Neuhaus, Foorman, Francis & Carlson, 2001; Neuhaus & Swank, 2002). The two components that have been proposed are the pause times between the named stimuli and the articulation times to name the stimuli. Neuhaus et al. (2001) defined articulation time as the sum of all times for correctly articulated items and pause time as the sum of the intervals between the correctly sequenced articulations.

Articulation time represents the actual production of speech; it has been shown to be influenced by stimulus familiarity (Hulme, Newton, Cowan, Stuart & Brown, 1999), and can be conceptualised as an index of response automaticity (Neuhaus et al., 2001). Pause time represents the elapsed time between articulations and has been described as an index of the automaticity of the retrieval of phonological codes (Neuhaus et al., 2001; Obregon, 1994). We suggest that pause time measures the automaticity of the stimulus recognition process, and includes any time required to shift attention. Existing studies have shown that both articulation time and pause time are associated significantly with reading (e.g. Clarke, Hulme & Snowling, 2005; Georgiou, Parrila & Kirby, 2009; Neuhaus & Swank, 2002). Variability in naming speed is predominately attributable to pause time rather than to articulation time (e.g. Cobbold, Passenger & Terrell, 2003; Georgiou, Parrila & Kirby, 2006; Neuhaus et al., 2001).

To date, most of the research on RAN components has focused on their relationship with word recognition or reading fluency. However, the ultimate goal of reading is comprehension. A connection between RAN and reading comprehension has been found in several studies (e.g. Arnell, Joanisse, Klein, Busseri & Tannock, 2009; Georgiou, Manolitis, Nurmi & Parrila, 2010; Johnston & Kirby, 2006; Neuhaus et al., 2001). For example, Arnell et al. (2009) found that RAN shared 10% and 17% of the variance with reading comprehension and reading fluency, respectively.

An explanation for the relation between RAN and reading comprehension could be that RAN has a direct effect on word identification or reading fluency, which, in turn, influences reading comprehension. In their review paper on the relation between RAN and reading, Bowers and Ishaik (2003) stated that RAN’s contribution to reading comprehension was explained through its association with latency of word recognition. RAN is generally considered as one cognitive process underlying skilled word recognition which is an essential aspect of reading comprehension (Scarborough, 1998). Therefore, there would be an indirect effect of RAN on reading comprehension.
Tracking children from kindergarten to Grade 5, Kirby et al. (2003) reported that RAN had significant effects on both word reading and reading comprehension. They attributed the relationship between RAN and reading comprehension to reading fluency. Because RAN is a precursor of fluency and fluency is required for reading comprehension, a certain level of reading speed is required for adequate comprehension.

An alternative explanation could be that the processes involved in RAN are associated with the processes involved in reading comprehension (Kirby et al., 2003). RAN may be an index of how much and how quickly information may be stored in working memory. Because comprehension depends on the integration of information held in working memory (e.g. Kintsch, 1998), students with slower RAN may not be able to comprehend more difficult material, even if they can identify the words. The possible connection between RAN and working memory was recently proposed by Amtmann, Abbott and Berninger (2007), who argued that RAN is a measure of the time-sensitive phonological loop, because it involves time-sensitive cross-code integration (orthographic sub-lexical letter representations and phonological lexical representations of names) and overt articulation of familiar phonological word forms for strings of unrelated letters (stored in the episodic buffer). Just as reading requires the coordination of orthographic and phonological information over time, RAN requires the sustained involvement of the naming of symbols in a working memory system.

To evaluate the mediated-by-word-reading and comprehension-specific interpretations of the relation between RAN and reading comprehension, one would need to control word-reading skills in predicting reading comprehension. To our knowledge, this has not been done yet. Thus any relationships found between RAN and reading comprehension cannot discount that this effect may be mediated by word reading skills.

The two studies that have examined the relationship between RAN components and reading comprehension have provided mixed findings (Li et al., 2009; Neuhaus et al., 2001). Working with Chinese children aged 8–14 years, Li et al. (2009) found that greater digit and letter RAN pause time variability, which is the degree to which the pauses varied for the individual on a RAN task, was significantly associated with lower scores in reading comprehension. In other words, greater pause time variability was associated with lower scores in comprehension. In contrast, Neuhaus et al. (2001) found that only letter RAN pause time, but not digit or object RAN pause time, was significantly related to reading comprehension in native English-speaking first and second graders.

An important gap in the literature (relevant to the focus of this special issue) is the examination of the cross-language transfer from RAN to reading comprehension in bilingual children. Most existing studies have focused on the cross-language transfer of phonological awareness (e.g. Chow et al., 2005; Comeau, Cormier, Grandmaison & Lacroix, 1999; Gottardo, Yan, Siegel & Wade-Woolley, 2001), or morphological awareness (e.g. Deacon, Wade-Woolley & Kirby, 2007; Wang, Cheng & Chen, 2006). Only a few studies have examined the cross-language transfer of RAN to reading comprehension and these have primarily focused on transfer from one alphabetic orthography to another (e.g. Gholamain & Geva, 1999; Morfidi, van der Leij, de Jong, Scheltinga & Bekebrede, 2007). For example, in a study with bilingual Farsi–English elementary school students, Gholamain and Geva (1999) found that RAN in Farsi (L1) significantly explained variance in English (L2) reading tasks after accounting for RAN in English. Morfidi et al. (2007) also found that RAN in Dutch (L1) explained additional...
variance in English (L2) reading accuracy after accounting for L1 vocabulary. These findings may be due to the association of RAN with orthographic processing because both require the formation of automatic visual-verbal codes (Wolf & Bowers, 1999). In the above studies, both English and Farsi or English and Dutch are alphabetic languages, which may make cross-language transfer more possible. There is one study, which reported cross-language transfer of RAN between alphabetic and nonalphabetic languages. McBride-Chang and Ho (2005) found that Chinese RAN predicted English word reading for Hong Kong Chinese bilingual children after controlling for Chinese (L1) vocabulary and mathematics although Chinese (L1) and English (L2) belong to different orthographies.

Examining the effects of RAN components in bilingual children is important for both theoretical and practical reasons. In terms of theory, if RAN is related to reading because skilled performance in both naming and reading depends, in part, on the rapid execution of the underlying processes (see Kail et al., 1999) or because both processes require the sustained involvement of the naming of letters in a working memory system (Amtmann et al., 2007), then RAN in L1 should predict reading in L2 and RAN in L2 should predict reading in L1. Such a finding would be more consistent with the general processing speed interpretation of RAN (e.g. Kail et al., 1999) than with the orthographic interpretation (e.g. Wolf & Bowers, 1999), which is necessarily more orthography specific. In terms of practical implications, cross-language transfer of RAN to reading would alert educators that children with slow RAN in L1 entering bilingual programmes would be at risk of having the same problems in their second language.

The purpose of the current study was twofold: (a) to explore the development of RAN components in English and Chinese, and (b) to examine the development of their relations to English reading comprehension and look for cross-language transfer, in Chinese English immersion students. English immersion programmes in which 40% of the curriculum is taught in English and the other 60% in Chinese, modelled after French immersion programmes in Canada, were established in elementary schools in several major Chinese cities 10 years ago (see Cheng, Li, Kirby, Qiang & Wade-Woolley, 2010, for details).

Although there is an abundance of research on French immersion programmes, few studies of immersion programmes in the Chinese context have been conducted. We were interested in examining whether the relation between RAN components and reading for English-speaking children also applies to these Chinese bilingual children and whether the developmental changes in RAN components of English-speaking children in previous studies are similar to those of Chinese bilingual children. Furthermore, none of the previous studies of RAN components considered children beyond Grade 5. The examination of the contribution of RAN to reading beyond the early grades is important given the discrepancy in the literature regarding the strength of the relationship between RAN and reading across time. Whereas some studies have found that the relative contribution of RAN to word reading increased with age (e.g. Kirby et al., 2003; Landerl & Wimmer, 2008; Liao et al., 2008; Scarborough, 1998), others have found that RAN had its primary influence on reading in earlier grades and that its influence diminished in later grades (e.g. Georgiou, Parrila, Kirby et al., 2008; Roman, Kirby, Parrila, Wade-Woolley & Deacon, 2009; Torgesen et al., 1997). What may be the key in this controversy is the time when RAN is first measured. When measured early, RAN may contribute more to later reading than when it is measured later, perhaps due to reduced variability. Therefore, the participants in the present study were chosen from the Grades 2, 4 and 6 levels.
The present study aimed to address three questions:

1. How are RAN components in English and Chinese related in Grades 2, 4 and 6?
2. How do RAN components develop across time?
3. How well do RAN components predict English reading comprehension in Chinese English immersion students at the three grade levels?

Method

Participants

A total of 124 students (43, 46 and 35 in Grades 2, 4 and 6, respectively) with parental permission participated in this study. Students were recruited from English immersion programmes in three schools in three Chinese cities, Dongguan, Guangzhou and Xi’an. Students were randomly selected from classes in each school, with approximately equal numbers of males and females selected. There were 23, 25 and 20 males in Grades 2, 4 and 6, respectively.

Measures in English

English reading measures (Cambridge Young Learners English [YLE] Reading and Writing). The Cambridge YLE test for Reading and Writing was employed to assess English reading comprehension. The YLE is a paper and pencil group-administered test that lasts 20 minutes (Starters, Grade 2), 30 minutes (Movers, Grade 4) or 40 minutes (Flyers, Grade 6). Reading texts are short and constrained by a specified set of words and structures. Students perform operations such as selecting and colouring, writing words and phrases in gaps, or writing answers to open-ended questions (Cambridge ESOL, 2007). The score was the number of correct answers, with one point for each correct test item. The maximum score for Grades 2, 4 and 6 was 25, 40 and 50 points, respectively. The internal consistency reliability coefficients in Grades 2, 4 and 6 were .80, .85 and .85.

English rapid automatised naming digits. Naming performance in English was measured using a continuous digit-naming task adapted from Wolf and Denckla (2005). There was one practice task and one test task. The practice task consisted of five randomly arranged digits (i.e. 1, 2, 4, 5 and 8) in one row, and the test task consisted of 40 items, with five rows and eight columns of the same five randomly arranged digits. Students were asked to recognise all five digits in the practice task from left to right before starting the test. Once they were familiar with this procedure and had demonstrated that they knew the names of the digits, they were asked to read all the digits in English as fast as possible without making mistakes, from left to right and top to bottom. Students’ responses were recorded on a digital MP3 recorder for verification and sound analysis at a later time. The split-half reliability coefficients of English articulation time in Grades 2, 4 and 6 were .95, .92 and .88. The split-half reliability coefficients of English pause time in Grades 2, 4 and 6 were .97, .93 and .94.

Measures in Chinese

Chinese reading achievement. School-issued reading achievement tests in Chinese from three different schools were employed to measure students’ L1 proficiency. Although
there were different tests in different schools, the content of the tests was similar at each grade, including pinyin identification, writing Chinese characters and phrases and reading comprehension. The percentage for each section varied across grades. All students’ scores were marked out of 100.

*Mathematics achievement in Chinese.* School-issued achievement tests in mathematics in the three schools were employed to assess and control the group differences. The content of the mathematics tests was similar across schools in each grade. All of the grades had sections on addition, subtraction and logic but the percentage for each section varied across grades. All students’ scores were marked out of 100.

*Chinese rapid automatised naming digits.* This test was essentially identical to English Rapid Automatised Naming Digits, with the exceptions that the instructions were given in Mandarin and the participants were required to respond in Mandarin. The same practice digits used in the English version were used in the Chinese version (i.e. in Arabic numerals) but in a different order. The same procedure as in the English RAN test was used here. The split-half reliability coefficients of Chinese articulation time in Grades 2, 4 and 6 were .89, .95 and .89. The reliability coefficients of Chinese pause time in Grades 2, 4 and 6 were .87, .94 and .97.

**Procedure**

The school-issued achievement tests in Chinese and mathematics were administered at the end of the last term of the previous academic year, at the beginning of July. The other tests were administered in October. The Cambridge YLE for Reading and Writing was administered to all students before the individual RAN tests. English and Chinese RAN digits tests were administered by four testers who were fluent in both English and Chinese.

**Manipulation of sound files**

RAN responses for each participant were digitally recorded on a portable digital recorder. The sound files of English and Chinese digit naming responses for each participant were transferred to a computer, and separate audio wave files were created for each participant using GoldWave v.5.25 (GoldWave Inc., 2008). The sound files were manipulated using the same procedures as described in detail in Georgiou et al. (2006). The background noise of each sound file was then removed using the hiss-removal function of GoldWave. To establish the onset and offset of articulation time and pause time, a volume level of .15 of the absolute value of the sound file amplitude was used as a cut-off. Both articulation time and pause time were calculated in milliseconds. Four types of data cleaning procedures were used. First, if a digit was named incorrectly, the previous pause time, the articulation time for the error and the following pause time were removed. Second, if a self-correction was made, then the pause time between the two correct articulations was removed. Third, if a stimulus was skipped, then the pause time between the two correct articulations and the articulation time that followed the skipped digit were removed. Finally, if off-task behaviours (e.g. coughing, talking to the tester, self-encouragement) occurred, the specific pause time was removed.

Therefore, articulation time in this study refers to the mean of the articulation times of the correctly named digits. The maximum number of articulation times was 40 for both
English and Chinese RAN tasks, if no mistakes were made. Smaller numbers of articulation times indicate that cleaning procedures had been used. There were 10 instances of articulation time cleaning in Grade 2, 12 in Grade 4 and 1 in Grade 6 in Chinese and 35 instances of articulation time cleaning in Grade 2, 33 in Grade 4 and 4 in Grade 6 in English. Pause time refers to the mean of the pause times, which are the intervals between correctly articulated digits. The maximum number of pause times was 39 for both English and Chinese RAN tasks. Smaller numbers of pause times indicate that cleaning procedures were used. There were 27 instances of pause time cleaning in Grade 2, 25 in Grade 4 and 2 in Grade 6 in Chinese and 90 instances of pause time cleaning in Grade 2, 92 in Grade 4 and 29 in Grade 6 in English. RAN total time refers to the sum of total articulation time and pause time before cleaning. It is worth noting that the number of cleaning in English sound files was greater than in Chinese, indicating fewer errors in students’ native language.

Results

Descriptive statistics

The means and standard deviations of the RAN total times and components in both English and Chinese, English reading comprehension, Chinese reading achievement and mathematics achievement in Grades 2, 4 and 6 are shown in Table 1. Measures whose skewness or kurtosis values fell outside the acceptable range (i.e. the absolute value of skewness/SE or kurtosis/SE > 3.09) were transformed according to the guidelines in Tabachnick and Fidell (2007). Square root transformation was applied to Chinese pause time in Grades 2 and 4, English pause time in Grade 4, Chinese total time in Grade 4, English reading comprehension in Grades 2 and 4 and Chinese reading and mathematics achievement in Grades 2 and 4. Logarithmic transformation was applied to Chinese pause time in Grade 6 and Chinese total time in Grade 6. All transformed measures had

<table>
<thead>
<tr>
<th>Table 1. Descriptive statistics of the rapid automatised naming (RAN) total times and components across languages.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 2 ($N = 43$)</td>
</tr>
<tr>
<td>--------------------</td>
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<tr>
<td></td>
</tr>
<tr>
<td>English</td>
</tr>
<tr>
<td>Total time</td>
</tr>
<tr>
<td>Articulation time</td>
</tr>
<tr>
<td>Pause time</td>
</tr>
<tr>
<td>Reading</td>
</tr>
<tr>
<td>Chinese</td>
</tr>
<tr>
<td>Total time</td>
</tr>
<tr>
<td>Articulation time</td>
</tr>
<tr>
<td>Pause time</td>
</tr>
<tr>
<td>Chinese reading</td>
</tr>
<tr>
<td>Maths</td>
</tr>
</tbody>
</table>

*Measured in seconds. Measured in milliseconds.
distributions within the acceptable range. All subsequent analyses were performed with the transformed data.

The descriptive statistics in Table 1 indicate that there is considerable variability in children’s pause time and total time in both English and Chinese across grades. There is comparatively little variability in articulation time.

**Language and grade differences in RAN components**

To examine whether there were significant differences in English and Chinese across grade levels, 3 (grade) \( \times \) 2 (language) mixed ANOVAs with language as the repeated measure were performed. For pause times, the results showed a Language effect, \( F(1, 121) = 243.43, \ p < .001 \), a Grade effect, \( F(2, 121) = 40.92, \ p < .001 \) and an interaction effect, \( F(2, 121) = 19.40, \ p < .001 \). The main effects indicated that pause times were shorter in Chinese than in English and that they decreased with grade. The interaction is illustrated in Figure 1. To examine it further, post hoc paired samples t-tests were conducted between languages at the three grade levels. The differences between English and Chinese pause times were all significant at the three grade levels (\( p < .001 \)).

The difference between English and Chinese pause times in Grade 2 was almost four times the \( SD \) of the Chinese pause times, whereas in Grades 4 and 6 it was closer to two times the Chinese \( SD \). English pause time decreased with grade more quickly than Chinese pause times, especially from Grades 2 to 4. Removing the Grade 2 data from the analysis resulted in a nonsignificant interaction term. Therefore, it was the substantial decrease in English pause times from Grades 2 to 4 that was responsible for the interaction effect. For articulation times, also shown in Figure 1, there were language, \( F(1, 121) = 59.17, \ p < .001 \) and grade, \( F(2, 121) = 24.45, \ p < .001 \), effects but no interaction effect, \( F(1, 121) = 1.13, \ ns \).

**Figure 1.** English and Chinese articulation and pause times at three grade levels (error bars are standard errors).

*Note: RAN components are measured in milliseconds.*
Correlations between components

The correlations among English and Chinese RAN components, RAN total times and English reading comprehension at the three grade levels are shown in Tables 2–4. Both English and Chinese pause times were highly correlated with the corresponding total times, ranging from .71 to .94 for English, and .81 to .96 for Chinese. English articulation time was only moderately correlated with English total time in Grade 6 and Chinese articulation time was only moderately correlated with Chinese total time in Grades 4 and 6.

English and Chinese pause times were significantly related to each other in Grades 4 and 6, as were English and Chinese articulation times, though neither relationship was

Table 2. Correlations between rapid automated naming (RAN) components and English reading in Grade 2.

<table>
<thead>
<tr>
<th></th>
<th>1 English articulation time</th>
<th>2 English pause time</th>
<th>3 English total time</th>
<th>4 English reading</th>
<th>5 Chinese articulation time</th>
<th>6 Chinese pause time</th>
<th>7 Chinese total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–</td>
<td>–</td>
<td>.20</td>
<td>.94**</td>
<td>.16</td>
<td>.14</td>
<td>.23</td>
</tr>
<tr>
<td>2</td>
<td>– .01</td>
<td>–</td>
<td>.20</td>
<td>.94**</td>
<td>.16</td>
<td>.14</td>
<td>.23</td>
</tr>
<tr>
<td>3</td>
<td>.20</td>
<td>.94**</td>
<td>–</td>
<td>.32*</td>
<td>.16</td>
<td>.14</td>
<td>.23</td>
</tr>
<tr>
<td>4</td>
<td>–26*</td>
<td>– .33*</td>
<td>– .40**</td>
<td>–</td>
<td>.16</td>
<td>.14</td>
<td>.23</td>
</tr>
<tr>
<td>5</td>
<td>.16</td>
<td>.14</td>
<td>.23</td>
<td>– .06</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>– .01</td>
<td>.27†</td>
<td>.20</td>
<td>– .11</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>.08</td>
<td>.34†</td>
<td>.32*</td>
<td>– .19</td>
<td>.24</td>
<td>.89**</td>
<td>–</td>
</tr>
</tbody>
</table>

**p <.01; †p <.05; *p <.10.

Table 3. Correlations between rapid automated naming (RAN) components and English reading in Grade 4.

<table>
<thead>
<tr>
<th></th>
<th>1 English articulation time</th>
<th>2 English pause time</th>
<th>3 English total time</th>
<th>4 English reading</th>
<th>5 Chinese articulation time</th>
<th>6 Chinese pause time</th>
<th>7 Chinese total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–</td>
<td>–</td>
<td>.27†</td>
<td>.71**</td>
<td>.46**</td>
<td>.17</td>
<td>.37†</td>
</tr>
<tr>
<td>2</td>
<td>– .33*</td>
<td>–</td>
<td>.27†</td>
<td>.71**</td>
<td>.46**</td>
<td>.17</td>
<td>.37†</td>
</tr>
<tr>
<td>3</td>
<td>.27†</td>
<td>.71**</td>
<td>–</td>
<td>–</td>
<td>.46**</td>
<td>.17</td>
<td>.37†</td>
</tr>
<tr>
<td>4</td>
<td>.06</td>
<td>– .22</td>
<td>– .18</td>
<td>–</td>
<td>.46**</td>
<td>.17</td>
<td>.37†</td>
</tr>
<tr>
<td>5</td>
<td>.46**</td>
<td>.17</td>
<td>.37†</td>
<td>– .24</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>– .34*</td>
<td>.56**</td>
<td>.33†</td>
<td>– .10</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>– .09</td>
<td>.54**</td>
<td>.42**</td>
<td>– .25</td>
<td>.41**</td>
<td>.81**</td>
<td>–</td>
</tr>
</tbody>
</table>

**p <.01; †p <.05; *p <.10.

Table 4. Correlations between rapid automated naming (RAN) components and English reading in Grade 6.

<table>
<thead>
<tr>
<th></th>
<th>1 English articulation time</th>
<th>2 English pause time</th>
<th>3 English total time</th>
<th>4 English reading</th>
<th>5 Chinese articulation time</th>
<th>6 Chinese pause time</th>
<th>7 Chinese total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>–</td>
<td>–</td>
<td>.40*</td>
<td>.92**</td>
<td>.49**</td>
<td>– .02</td>
<td>– .05</td>
</tr>
<tr>
<td>2</td>
<td>.15</td>
<td>–</td>
<td>.40*</td>
<td>.92**</td>
<td>.49**</td>
<td>– .02</td>
<td>– .05</td>
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<tr>
<td>3</td>
<td>.40*</td>
<td>– .32†</td>
<td>– .37†</td>
<td>–</td>
<td>.49**</td>
<td>– .02</td>
<td>– .03</td>
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<tr>
<td>4</td>
<td>–25</td>
<td>– .32†</td>
<td>– .37†</td>
<td>–</td>
<td>.49**</td>
<td>– .02</td>
<td>– .03</td>
</tr>
<tr>
<td>5</td>
<td>.49**</td>
<td>– .02</td>
<td>.05</td>
<td>– .03</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>.04</td>
<td>.48**</td>
<td>.38†</td>
<td>– .02</td>
<td>.16</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>7</td>
<td>.18</td>
<td>.43†</td>
<td>.36*</td>
<td>– .03</td>
<td>.44**</td>
<td>.96**</td>
<td>–</td>
</tr>
</tbody>
</table>

**p <.01; †p <.05; *p <.10.
significant in Grade 2. Therefore, English and Chinese RAN components were more related after Grade 2. However, Chinese articulation time was not significantly correlated with Chinese pause time at any grade, and English articulation time was not significantly correlated with English pause time in Grades 2 and 6.

In terms of the correlations between RAN components and English reading comprehension, only English pause time and total time were correlated significantly with English reading comprehension, and this occurred in Grades 2 and 6, but not in Grade 4. There were no significant correlations between Chinese RAN components and English reading comprehension.

**Prediction of English reading**

To determine how RAN components in English and Chinese were related to English reading comprehension, two sets of regression analyses were employed; these analyses are done separately by grade because the outcome measure was different at each grade. The first set of regression analyses examined the unique contribution of English pause time and articulation time to English reading comprehension (see Table 5). Chinese reading achievement and mathematics achievement scores were entered in the first step to control L1 proficiency and general cognitive ability. Next English articulation time was entered in the regression equation (at step 2) followed by English pause time (entered at step 3). The results indicated that English articulation time did not contribute significantly to English reading comprehension in any grade. English pause time explained 14% of the variance in English reading comprehension in Grade 6, but was not significant in any other grade. When the order of entry of English articulation and pause times was reversed, similar results were found.

The second set of regression analyses investigated the unique contribution of English or Chinese RAN components to English reading comprehension (see Table 6). When Chinese and mathematics were controlled (entered at step 1), after entering Chinese articulation time in step 2, English articulation time had no significant effect in step 3. However, English pause time (see step 3) and total time (see step 3) each significantly

![Table 5. Summary of regression analyses predicting English reading from English rapid automatised naming (RAN) components.](image)

<table>
<thead>
<tr>
<th>Step predictor</th>
<th>Grade 2 (N = 43)</th>
<th>Grade 4 (N = 46)</th>
<th>Grade 6 (N = 35)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β^a</td>
<td>β^b</td>
<td>ΔR^2</td>
</tr>
<tr>
<td>1 Chi</td>
<td>.18</td>
<td>.14</td>
<td>.21**</td>
</tr>
<tr>
<td>Maths</td>
<td>.38*</td>
<td>.32*</td>
<td></td>
</tr>
<tr>
<td>2 English AT</td>
<td>-.13</td>
<td>-.15</td>
<td>.02</td>
</tr>
<tr>
<td>3 English PT</td>
<td>-.17</td>
<td>-.17</td>
<td>.03</td>
</tr>
<tr>
<td>2 English PT</td>
<td>-.16</td>
<td>-.17</td>
<td>.02</td>
</tr>
<tr>
<td>3 English AT</td>
<td>-.15</td>
<td>-.15</td>
<td>.02</td>
</tr>
</tbody>
</table>

Note: Chi = Chinese Reading Achievement; Maths = Maths Achievement; AT = Articulation Time; PT = Pause Time.

^aStandardised beta coefficient for the step at which the predictor first entered the model.

^bStandardised beta coefficient for the final step of the model.

**p < .01; *p < .05.
predicted English reading comprehension in Grade 6 after controlling their Chinese counterparts. English pause time explained 15% of the variance in reading in Grade 6 and total time accounted for 12%.

In order to examine the unique contribution of Chinese RAN components to English reading comprehension and look for cross-language transfer, Chinese and mathematics were entered in step 1. In step 2A, English RAN components were entered to control L2 skills. In step 3A, Chinese RAN components (L1) did not significantly predict English reading comprehension (L2) at any grade, but there was a trend ($p<.10$) for Chinese articulation time to predict English reading comprehension in Grade 4.

**Discussion**

*How are RAN components related?*

We considered how the pause and articulation time components were related to each other and to RAN total times within and across languages. Within languages, we found that pause time was highly related to RAN total time for both English and Chinese, whereas articulation time was less strongly and less consistently related. Pause and articulation times were not significantly correlated with each other in English or Chinese (with the exception of Grade 4 in English and even then the correlation was small). This lack of correlation is consistent with the results of previous studies with monolinguals (e.g. Cobbold et al., 2003; Georgiou et al., 2006; Neuhaus et al., 2001). Thus in each
language pause and articulation times are largely independent components of RAN. Across languages, English and Chinese articulation times and English and Chinese pause times were more related after Grade 2. This pattern suggests that the L2 (English) components begin to resemble their L1 (Chinese) equivalents as L2 proficiency increases.

**Developmental change in RAN components**

In agreement with previous studies (e.g. Cobbold et al., 2003; Georgiou et al., 2006; Neuhaus et al., 2001), we found that both English and Chinese articulation times and pause times decreased with development, but pause times decreased faster. Moreover, English pause time decreased much faster than any other RAN component. This dramatic developmental change in pause time appears to reflect increasing familiarity of the Chinese children with English.

We can compare the RAN components of the children in the present study with those of English-speaking children (Georgiou, Parrila, Kirby et al., 2008; Georgiou, Parrila & Liao, 2008), because the research methods were identical. The average RAN-Digit English pause time of Grade 2 English-speaking children in Georgiou, Parrila, Kirby et al.’s (2008) study ($M = 236$ ms) was similar to the average RAN-Digit Chinese pause time of Grade 2 Chinese-speaking children in the present study ($M = 275$ ms). English pause times of the Chinese-speaking Grade 2 children in this study ($M = 724$ ms) lagged behind those of Georgiou, Parrila, Kirby et al.’s (2008) English-speaking Grade 2 children ($M = 237$ ms). The Grade 4 children in the present study ($M = 424$ ms) had longer pause times than Georgiou, Parrila & Liao’s (2008) English-speaking Grade 4 children ($M = 142$ ms). At Grade 6, the RAN-Digit English pause time of children in the present study ($M = 330$ ms) resembles that of Grade 1 English-speaking children in Georgiou, Parrila, Kirby et al.’s (2008) study ($M = 295$ ms). However, it is surprising to find that the English articulation time of Grade 2 Chinese children in the present study ($M = 306$ ms) was faster than that of Georgiou, Parrila & Liao’s (2008) English-speaking Grade 4 children ($M = 391$ ms); this suggests that articulation time indexes something less central to language proficiency, such as the automaticity of the articulatory response.

More broadly, these developmental changes in articulation and pause times suggest that pause time is the more sensitive indicator of language proficiency. Longitudinal studies are required to determine how closely pause time tracks language competence, and more fine-grained studies are needed to determine which aspects of language development it tracks most closely.

**Prediction of English reading comprehension from RAN components**

English pause time and total time, but not articulation time, were related to English reading comprehension in Grade 6, but not in Grades 2 or 4. This result is in line with Cobbold et al.’s (2003) finding that the relationship between the pause time and reading ability develops as children move from a preliterate phase to an early-literate phase, which reflects the development of English language proficiency of Chinese children from Grades 2 to 6 in this study. The Grade 2 students had just started to learn English and therefore may not have had adequate English skills, while the Grade 4 students may have been in a transitional period in which phonological analysis was more salient (Ehri, 1997). Finally, the Grade 6 students who were more skilled in English may have attained the orthographic processing phase (Ehri & McCormick, 1998). Previous research has suggested that RAN is related to holistic or orthographic processing in
reading (e.g. Bowers & Wolf, 1993; Georgiou, Parrila, Kirby et al., 2008; Manis, Seidenberg & Doi, 1999), although it shares variance with phonological skills in reading. It is perhaps only in the orthographic processing phase that RAN becomes predictive of reading.

Chinese RAN components did not predict English reading at any grade (with one weak trend as an exception), which suggests there was little cross-language transfer. This is inconsistent with McBride-Chang and Ho’s (2005) finding that Chinese RAN predicted English word reading significantly among bilingual children. The reason for this discrepancy is not clear. McBride-Chang and Ho (2005) used English word reading as the outcome measure, not reading comprehension as in the present study. Also, their participants were kindergarten children in Hong Kong where English and Chinese are both official languages. In the present study, the participants were older students (in Grades 2, 4 and 6) from mainland China where Chinese is the only official language. Further research is required to resolve this inconsistency.

Our results are consistent with the view that the effect of RAN is specific to the automaticity of the actual visual-verbal codes, which are language specific. In Grade 2, English and Chinese RAN times are weakly correlated (see Table 2). But in Grade 4, the correlation between languages is larger (see Table 3), suggesting a potential relation between the two languages when children have learned L2 to a certain level. The correlation stays much the same at Grade 6, when the children are becoming more proficient in English (see Table 4), indicating that the English and Chinese RAN times may be distinct, and not manifestations of a single construct. Our result supports the view that reading is not predicted by general processing speed but instead by speed of processing associated with a specific orthography (Neuhaus & Post, 2003; Neuhaus et al., 2001; Neuhaus, Roldan, Boulware-Gooden & Swank, 2006). However, because the visual stimuli used in the English and Chinese RAN tasks were identical, we can go further to say that the effect is language specific.

English pause time was a better predictor of English reading than articulation time, and only in Grade 6. English articulation time did not predict English reading comprehension at any grade. Therefore, it is of interest to consider what articulation time and pause time reflect in RAN. We argued earlier that articulation time measured response automaticity (i.e. the automaticity of the production of the response, once recognition has occurred), and that pause time measured the automaticity of the recognition process plus other attention-related processes. Pause time, therefore, reflects stimulus familiarity and the quality of the orthographic representation, including the language-specific associations between the visual and verbal codes. Retrieval of the language-specific name to be articulated (and thus speed of access to phonological information) would be part of pause time if retrieval occurs completely before any articulation, but if some retrieval is still occurring after articulation begins, then it will be partly in both. As the prediction only happened in Grade 6, the effect of RAN may turn out to be powerful in reading only after the Chinese students have acquired adequate English proficiency in the orthographic phase, usually in the upper grades. This finding that pause time and total time have language-specific and skill-level-specific effects indicates that they are not measuring the same construct across languages or at different levels of language proficiency. This implies that the processing speed account of RAN cannot be completely true, that the familiarity of the stimuli and associated verbal codes is crucial (Kail et al., 1999; Neuhaus & Swank, 2002). Because the effect only occurred in Grade 6, after the students had become moderately proficient in English, and it occurred for pause and not
articulation times, we suggest that it is due to the improved quality of orthographic representations that the students have acquired at that time.

Limitations, future research and educational implications

Several limitations of this study are worth noting. First, the participants in this study were recruited from Grades 2, 4 and 6, and were not followed longitudinally. Future research following the same children is needed to obtain a better understanding of developmental changes in the RAN components as bilingualism is attained. Second, the sample size was relatively small, especially in Grade 6 \((N = 35)\). A larger sample size would provide more statistical power, especially in the analyses with additional control variables. Third, we did not include age data in this study because children in Chinese schools are all within a 12-month age range. As a result, the effects of small age differences may have been missed; future studies should include age as a variable. Finally, future research on RAN components across languages should consider other processing skills, including phonological awareness, speed of processing, orthographic processing and especially word reading, which may mediate the relations between RAN components and reading in different languages. Without controlling word-reading skills, we cannot conclude that the relationship between RAN and reading comprehension is direct.

Our study found that RAN is a language-specific skill and predicts reading comprehension. Therefore, if we want to improve bilingual children’s English (L2) reading, English (L2) rather than Chinese (L1) RAN should be targeted. Little research has been carried out to show ways to improve RAN, but orthographic pattern training (Conrad & Levy, 2009) or letter naming training (Fugate, 1997) have shown positive effects (see discussion in Kirby et al., 2010). It may also be useful, or even more useful, to target directly the consequences of RAN, that is, the orthographic representations. The results of the current study suggest that this training needs to be specific to the language/orthography in which reading improvements are desired.

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