Journal of Research in Reading

Journal of Research in Reading, ISSN 0141-0423 DOI: 10.1111/j.1467-9817.2011.01500.x
Volume 36, Issue 2, 2013, pp 202–222

General auditory processing, speech perception and phonological awareness skills in Chinese–English biliteracy

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This study focused on the associations of general auditory processing, speech perception, phonological awareness and word reading in Cantonese-speaking children from Hong Kong learning to read both Chinese (first language [L1]) and English (second language [L2]). Children in Grades 2–4 ($N = 133$) participated and were administered measures of IQ, word reading, phonological awareness, speech perception and auditory processing in both L1 and L2. Auditory processing uniquely explained both L1 and L2 word reading. While L1 speech perception accounted for unique variance in L1 word reading, L2 phonological awareness explained unique variance in L2 word reading. In cross-language comparisons, L1 phonological awareness and speech perception were uniquely associated with L2 word reading, suggesting cross-language transfer from L1 to L2 only. Results underscore the importance of auditory processing for reading across variable learning contexts.

A large body of research has demonstrated the importance of early sensitivity to the phonological structure of words for children learning their first language (e.g. Wagner, Torgesen & Rashotte, 1994). However, very little is known about how the phonology of a second language is acquired and the way first (L1) and second language (L2) sound systems develop and interact. Reading in L1 and L2 may involve different, multifaceted phonological representations that are built from phonological awareness, speech perception and general auditory processing (e.g. Boets, Wouters, van Wieringen & Ghesquière, 2006; Schulte-Körne, Bartling, Deimel & Remschmidt, 1999). Zhang and McBride-Chang (2010) hypothesised a developmental model of word reading in which general auditory processing precedes and helps shape speech perception, which in turn

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influences metalinguistic skills such as phonological awareness. In that model, the importance of auditory processing and speech perception for word recognition is primarily via phonological awareness itself, in addition to other reading-related skills (e.g. verbal memory, morphological awareness), across orthographies. This model focuses both on rhythmic and temporal processing as well as suprasegmental and segmental speech. In the present study, we tested part of this model by focusing on the development of Chinese (L1) and English (L2) word recognition among Chinese children in relation to temporal processing, segmental speech and phonological awareness in both Chinese and English. A focus on all three skills may be important both in relation to development and cross-linguistically. Below, we begin by highlighting previous research on phonological awareness, speech perception and temporal processing in relation to reading development in children. We then explore different models of word reading acquisition across these three levels.

Phonological awareness, which is the ability to reflect on, analyse and manipulate the sounds of language, is essential for learning to read as it facilitates awareness of the relationship between the sound and the printed word (Adams, 1990; Gottardo, Stanovich & Siegel, 1996; Muter & Snowling, 1998; Olofsson & Neidersoe, 1997; Share, 1995; Stanovich, 1994; Wagner & Torgesen, 1987). Many studies have demonstrated that phonological awareness uniquely explains children's reading over and above general intelligence and other linguistic variables (e.g. Adams, 1990; Comeau, Cormier, Grandmaison & Lacroix, 1999; Manis & Freedman, 2001; Muter, Hulme, Snowling & Taylor, 1998; Sprenger-Charolles, Siegel & Bechennec, 1998). A similar association has also been found in Chinese (e.g. McBride-Chang & Kail, 2002; So & Siegel, 1997; Wang & Geva, 2003). Some argue that phonological awareness reflects the development of phonological representations, which are also required in reading and listening to speech (Brady, 1997; Goswami, 2000; Metsala & Walley, 1998; Snowling, 2001). Thus, some researchers have focused on speech perception itself in relation to word recognition (e.g. McBride-Chang, 1995; McBride-Chang & Ho, 2000; Metsala, 1997).

Studies examining the role of speech perception at the segmental levels including isolated vowels and stop consonants (e.g. /p/, /g/) and the suprasegmental levels (e.g. awareness of stress in words across stress-focused or lexical tone in tonal languages such as Chinese) have found that both of these levels may contribute to the development of phonological representations, thereby influencing the acquisition of reading (e.g. Goswami, 2000, 2002; Holliman, Wood & Sheehy, 2008; McBride-Chang, 1995; Wood, 2006; Zhang & McBride-Chang, 2010). In the present study, we focused only on the segmental level of speech perception for two reasons. First, studies in both Chinese (e.g. Cheung et al., 2009; Liu, Shu & Yang, 2009; McBride-Chang & Ho, 2000) and in English (e.g. Manis, McBride-Chang, Seidenberg & Keating, 1997; Mody, Studdert-Kennedy & Brady, 1997; Werker & Tees, 1987) have demonstrated individual differences in segmental speech relevant to word recognition in children. Second, testing of such contrasts across L1 Chinese and L2 English seemed to us more achievable than did simultaneous testing of suprasegmental speech in these languages, which might involve lexical tone sensitivity in Chinese and sensitivity to stress in English, two arguably similar but distinct processes (e.g. Zhang & McBride-Chang, 2010).

Because we focused on segmental speech contrasts in the present study, we also focused only on temporal processing as a representation of auditory processing, following Zhang and McBride-Chang (2010). This aspect of auditory sensitivity, which employs the use of tone order judgement ability task (Tallal, 1980), has been found to be associated

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with word reading across both Chinese and English (e.g. Wang, Anderson, Cheng, Park & Thomson, 2008; Wang, Perfetti & Liu, 2005). In this temporal order judgement (TOJ) task, two tones using either high or low frequency are presented in pairs at various inter-stimulus intervals (ISIs) and the listener responds with two button presses to identify the order of the stimuli presented. Tallal (1980) found that children with dyslexia had more difficulties in discriminating and sequencing pairs of stimuli with short ISIs compared with their typically developing peers, and concluded that the dyslexics had specific problems processing stimuli that are brief and occur in rapid succession. Difficulty in auditory processing may cause problems in speech perception and phonological development (Farmer & Klein, 1995; Tallal, 1980). The resulting auditory processing problem may subsequently disrupt the normal development of the phonological system and lead to problems learning to read. Indeed, deficits in the TOJ test have been found in some dyslexic children (e.g. Ahissar, Protopapas, Reid & Merzenich, 2000; Boets, Wouters, van Wieringen & Ghesquière, 2007). Performance on the auditory TOJ test has also been found to be linked with word reading, phonological awareness and receptive language from childhood through adulthood (e.g. Hood & Conlon, 2004; Walker, Hall, Klein & Phillips, 2006). Wang et al. (2008) reported that auditory TOJ was found to predict word reading in Chinese and English for both Chinese–English and Korean–English bilingual children, suggesting auditory sensitivity may be an important skill for cross-language differences in bilingual reading acquisition. However, it is worth noting that the relations among auditory sensitivity measured by TOJ, phonological awareness and word reading have been questioned and challenged by several studies (e.g. see Bretherton & Holmes, 2003; Share, Jorm, Maclean & Matthews, 2002 for different results and arguments).

While the pattern of development of phonological representations may result from individual differences in phonological awareness, speech perception and auditory sensitivity in monolingual speakers, the relations among these metalinguistic skills in bilingual children have seldom been investigated. Is there a general factor, an auditory processing skill, underlying all other language skills? Or do two or more metalinguistic skills contribute independently to reading in L1 and L2? The answers to these questions are likely further complicated by differences in the learning contexts of the two languages, that is, by potential differences in the ways in which the phonological systems of the two languages may interact. Whereas L1s are typically acquired through everyday verbal social interaction right from birth, L2s could be learned in a natural social interaction in bilingual communities, in a formal classroom situation that is more biased towards print than speech, in immersion programmes, from domain-specific contact (e.g. trading) between speech groups that do not share a common language, and so on. In the present study, the children learned English in a formal classroom situation with relatively little access to native speakers of English. Given this context, the extent to which phonological representations would likely play a central role in reading was unclear.

According to psycholinguistic grain-size framework, the sequence of phonological development is essentially universal across languages. However, the ways in which sounds are mapped to letters or other orthographic symbols appears to be language specific (Ziegler & Goswami, 2005). Consequently, there is an unanswered question as to whether researchers should focus on language – universal explanations based on central processing or language-specific explanations based on script and phonological representations of L1 (e.g. Geva & Siegel, 2000). For example, research conducted with bilingual readers of French and Spanish found evidence for cross-language transfer

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of phonological processing skills and reading performance. They showed that L1 phonological awareness skills transferred to L2 reading, thus providing more evidence in support of the hypothesis that phonological processing skills transfer across languages (Comeau et al., 1999; Durgunoglu, 2002; Durgunoglu, Nagy & Hancin-Bhatt, 1993). Durgunoglu et al. (1993) also demonstrated that phonological processing in Spanish distinguished native Spanish-speaking children's reading performance in English and Spanish, although oral proficiency in Spanish did not. Studies among Spanish speakers learning to read English showed that phonological awareness in Spanish predicted the ability to learn to read new words in English (Durgunoglu et al., 1993; Gottardo, 2002). Furthermore, both Chiappe and Siegel (1999) and Chiappe, Glaeser and Ferko (2007) reported similar patterns of phonological ability predicting reading in English across native and non-native speakers, thus suggesting the involvement of L1 phonological skills in the latter group, because otherwise their relatively weak English phonological representation would have produced a pattern departing from that of the native speakers. Researchers (Wang et al., 2005; Wang, Park & Lee, 2006) similarly demonstrated in Chinese and Korean learners that L1 phonological skills predicted corresponding L2 skills.

At the same time, different phonological sensitivity skills may explain reading in different languages differently (e.g. Cho & McBride-Chang, 2005; McBride-Chang & Ho, 2005; McBride-Chang et al., 2008). Moreover, little is known about speech perception itself in relation to Chinese and English word reading in the same children. The contrast between Chinese (L1) and alphabetic languages such as English (L2) is of particular interest due to phonological, syntactic and orthographic differences between the two languages. Chinese, which is analytic, tonal and non-inflected, differs from English, a synthetic, atonal, inflected language, in linguistic properties. Given that speakers learning to read in L2 may have phonological representations that differ from their L1, the question then arises how cross-linguistic differences in phonological representations influence reading acquisition in L1 and L2 among Chinese children learning English as an L2 in a Chinese-speaking environment. In particular, we wondered whether Chinese children would show a pattern in which native speech perception was more strongly associated with word recognition in both Chinese and English than English speech perception or, rather, whether speech-specific perception of English would uniquely explain word reading in English. We also wondered whether general auditory processing skill would explain word recognition in Chinese and English similarly.

In the model from Zhang and McBride-Chang (2010), auditory processing influences word reading via the speech perception route, which, in turn, is associated with metalinguistic skills such as phonological awareness. However, the present study only tested part of this model, that is, pathways of auditory processing as temporal processing to segmental speech perception and phonological awareness. Given this model, we made the following predictions. First, we expected that temporal processing skill would be significantly associated with segmental speech perception in both Chinese and English. Second, we hypothesised that word reading in each language would be uniquely predicted by phonological awareness in the same language and general auditory processing but not speech perception in that language. Our reasoning was that phonological awareness is a strong correlate of word reading in each language and, in the model, its proximal link to word reading is clear. At the same time, however, general auditory skills extend across languages, so some of the variance that is more general to all speech might not be accounted for by the language-specific phonological awareness measure.

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The language-specific speech perception, however, was not expected to be a unique predictor of word reading with all variables included because of its primary role in this model as a direct link to phonological awareness rather than word reading. Third, given the directionality of the model, we hypothesised that both speech perception and general auditory processing would uniquely explain phonological awareness in each language, respectively.

Method

Participants

Three groups of 133 Cantonese-speaking children participated. The two older groups from primary schools consisted of second graders (10 boys, 36 girls; mean age = 98.89 months; *SD* = 10.1 months) and fourth graders (18 boys, 25 girls; mean age = 118.63 months; *SD* = 7.1 months), respectively. The youngest group (31 boys 13 girls; mean age = 69.25 months; *SD* = 3.9 months) consisted of children in their third (last) kindergarten year. In Hong Kong, kindergarten lasts 3 years, beginning when the children are 3 years old. These children were native speakers of Cantonese-Chinese and learners of logographic written Chinese. In addition, they had learned rudimentary English, both oral and written, for about 2 years, as is usual in Hong Kong kindergartens. Nevertheless, Hong Kong remains a monolingual community in that very little English is spoken outside of the classroom.

Design, materials and procedures

The children were administered 10 tasks including a standardised test of nonverbal intelligence, auditory processing, word reading, phonological awareness and speech perception for both Chinese and English. Except for the nonverbal intelligence test, all other tasks were administered individually. The parents' or guardians' consents for children's participation were obtained before testing. All assessments were conducted in Cantonese by trained experimenters. The details of each test are described below.

Nonverbal intelligence. Raven's Colored Progressive Matrices (RCPM; Raven, Court & Raven, 1995) and Raven's Standard Progressive Matrices (RSPM; Raven, Court & Raven, 1996) were administered for kindergarteners and school children, respectively. The RCPM consisted of 36 coloured items while the RSPM consisted of 60 black-and-white items. These tests required the child to select one patch from six to eight alternatives that fit best into a geometric design. Although local norms were established for RSPM by the former Hong Kong Education Department in 1986, no norms were available for RCPM. Hence, instead of deriving IQs, we reported the raw test scores and used them in subsequent analyses. The maximum scores for RCPM and RSPM were 36 and 60, respectively.

Auditory processing. This test was constructed based on the tests devised by Tallal and Piercy (1974, 1975), Tallal (1980) and Bretherton and Holmes (2003). Tallal's tone judgement task was frequently employed for measuring children's basic auditory processing skill. This task paradigm has been used to investigate the relationship between general auditory processing and reading skills. The low tone had a frequency of 250 Hz

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while the high tone had a frequency of 500 Hz. Both tones were 75 ms in duration. There were four possible pair sequences: High–High (HH), Low–Low (LL), High–Low (HL) and Low–High (LH) and they were presented in random order. These pair tones were presented at each of ISIs of 8, 15, 30, 60, 150 and 305 ms separated presentation of the first and second tone. The tones were presented to participants via Logitech premium stereo headsets and responses were recorded on the IBM ThinkPad notebook computer via DMDX program. The children were seated at a distance of 50 cm from the computer screen. They were instructed to press the assigned keys on the keyboard and response orders were recorded by DMDX program. There were four possible tone pair sequences: HH, LL, HL and LH, corresponding to the button presses: red–red, green–green, red–green and green–red. The D, K, F and J keys in the keyboard were labelled in red–red, green–green, red–green and green–red, respectively. There were eight practice trials with feedback followed by 24 experimental trials consisting of four trials per ISI. No feedback was given for experimental trials. The dependent measure was the number of trials, collapsed across ISI, on which the response was correct (accuracy). This measure has been used in previous work (Chung et al., 2008; Farmer & Klein, 1993; Marshall, Snowling & Bailey, 2001).

Chinese word reading. This was assessed using a combination of two Chinese character recognition tasks. The first task consisted of 34 two-character words arranged in increasing difficulty (Ho & Bryant, 1997). The test was stopped if the child failed to read aloud 10 consecutive items. Children who progressed beyond this task were additionally presented with items adapted from the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD) (Ho, Chan, Tsang & Lee, 2000). This test consisted of 150 two-character Chinese words arranged in increasing difficulty. These children were asked to read aloud from the beginning of this task and stopped when they failed to recognise 15 consecutive items. The maximum possible score for accomplishing both reading tests was 184. The split-half reliability of HKT-SpLD was 0.96, and the internal reliability of the 34-word test was 0.96 (Cronbach's α).

English word reading. Because there is no standardised English word reading test in Hong Kong, 80 single English word items were constructed based on the item occurrence frequency in major textbooks designed for the local English curriculum. All of these words were initially piloted with children of the same age, and they were arranged in ascending order of difficulty with reference to the pilot testing data. Basal and ceiling rules were applied: if the children erred in more than two-thirds of the items in a set, they did not progress to the next difficulty level (ceiling); if they erred in fewer than 11 items in a set, they progressed onto the next level (basal). The children were required to read the words aloud one by one. Each word was worth one mark. This measure has been used in previous studies (Cheung et al., 2010; Tong & McBride-Chang, 2010).

Chinese phonological awareness. Phonological awareness was tested using a measure similar to the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen & Rashotte, 1999) in that it tapped different phonological units with increasing difficulty. Phonological awareness was assessed by the three tests, namely syllable deletion, onset deletion and rhyme production. This measure was used in previous studies (Cheung et al., 2009; Chung et al., 2008). All stimuli were presented orally. There were 15 three-syllable real and 14 pseudowords in the Syllable Deletion test. On each trial, the

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children were then required to take away either the first, second or third syllable and say aloud what was left. For example, the children were asked to say/din6/ /daan1/ /ce1/ without /din6/. The correct answer is /daan1/ /ce1/. In the Onset Deletion test, 10 real and 12 pseudo one-syllable words were used. The children were asked to drop the first consonant of each item and say aloud what was left. For example, say /so1/ without the initial sound would be /o1/. These stimuli strictly measured onset deletion only, rather than phoneme deletion more globally, because in Cantonese, there are no consonant clusters and too few final consonants to consider asking children to delete phonemes anywhere within the syllable except the onset position. However, our task of English phoneme deletion (described below under English phonological awareness) differed somewhat from this task because of the nature of English. There were 16 trials in the Rhyme Production test, which had three reference syllables sharing the same rhyme and tone on each trial. The children were to come up with and say aloud a Cantonese syllable having the same rhyme and tone as the references. For example, 'say a Chinese syllable which had the same rhyme and tone as ''侵'' (侵 /cam1/ meaning ''invade''). One acceptable answer would be ''心'' (心 /sam1/ meaning ''heart'')'. A composite phonological awareness score was calculated by summing the scores from the three tests. The maximum composite score was 67.

English phonological awareness. Syllable and phoneme deletion were used to measure English phonological awareness, as done in previous work on Cantonese-speaking children (Cheung et al., 2010; Chow, McBride-Chang & Cheung, 2010). Syllable deletion required the child to drop one syllable from a three-syllable phrase. For example, the item 'one teapot' was presented and the child was required to omit 'one' and produce 'teapot'. Sixteen trials were used for syllable deletion; half of the items were real words or phrases and half of them were pseudowords. Of the 16 items, four required deletion of the first syllable, four required deletion of the last syllable and eight involved deleting the middle syllable. Each item was worth 1 mark. Phoneme deletion required the child to omit either the initial or final phoneme of a word and produce what was left. Fifteen initial phoneme deletion items (7 words and 8 pseudo-words) and 14 final phoneme deletion items (7 words and 7 pseudo-words) were used. Each item was given 1 mark. The maximum English phonological awareness composite score was 45. Practice trials were administered before actual testing.

Cantonese speech perception. In the Cantonese syllable discrimination task, the children had to tell whether two successively presented syllables were the same or different, by pressing one of two designated keys on the keyboard. For the 'different' pairs, the syllables differed only in their initial consonants, along the articulation manner, place and aspiration dimensions. Test syllables are shown in Table 1. This test has been used as an index of speech perception examining the relationships between speech perception, phonological awareness and word reading in Hong Kong students (Cheung et al., 2010).

The tokens were said and recorded by a female native speaker, using the carrier phrase 'I say ____ again (/ngo5 zoi3 gong2 ____ jat1 ci3/)'. Sound recording for the construction of speech stimuli was done in a sound-attenuated room using the following equipment: two condenser microphones connected to a Tascam DA-30 MK II DAT tape recorder, feeding sound information into the editing software CoolEdit Pro v.2. Recordings were stored in a 44,100 Hz, 16-bit format. Syllable editing was handled by CoolEdit Pro v.2. The mean and standard deviation (*SD*) of token durations were 427.1

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Table 1. Stimuli of the syllable discrimination task.

	Onset	Rhyme	Character	Onset	Rhyme	Character
Chinese Pair						
1	/t	ou2/	土	/d	ou2/	賭
2	/g	aa1/	加	/k	aa1/	卡
3	/b	aau1/	包	/p	aau1/	拋
4	/m	iu5/	秒	/n	iu5/	鳥
5	/w	an1/	溫	/j	an1/	因
6	/f	an4/	焚	/h	an4/	痕
7	/d	aai3/	帶	/p	aai3/	派
8	/b	ong1/	幫	/m	ong1/	芒
9	/d	it6/	秩	/l	it6/	列

	Onset	Rhyme	Spelling	Onset	Rhyme	Spelling
English Pair						
1	/t	u/	Two	/d	u/	Do
2	/f	æn/	Fan	/v	æn/	Van
3	/p	eɪ/	Pay	/b	eɪ/	Bay
4	/s	u/	Sue	/ʃ	u/	Shoe
5	/w	ɛt/	Wet	/j	ɛt/	Yet
6	/d	eɪt/	Date	/g	eɪt/	Gate
7	/n	ɛt/	Net	/l	ɛt/	Let
8	/b	ɔl/	Ball	/m	ɔl/	Mall
9	/j	æm/	Yam	/r	æm/	Ram

and 59.5 ms, respectively. Four actual presentations were created out of each pair of syllables. For example, the '土–賭' pair was arranged into two 'same' ('土–土' and '賭–賭') and two 'different' presentations ('土–賭' and '賭–土'), so that stimulus order was balanced in actual testing. The ISI was 500 ms. Results from a pilot test showed that the 'same' presentations were too easy for the children. We suspected that it was because in the 'same' condition the sound recordings were simply repeated, and hence irrelevant acoustic cues could have been used by the child. We therefore produced another set of the 'same' syllables and used one token from each set to create the 'same' presentations, so that the child was listening to different tokens of the same syllables. A higher false alarm then resulted, which enhanced the discriminatory power of the task.

Children were instructed to press the key labelled with '=' for 'same' and that with '≠' for 'different' judgements. Stimuli were presented via DMDX and Logitech premium stereo headsets. Twelve practice trials were administered with feedback before testing, which involved 36 test trials. Discrimination was reported as d', which was calculated as the difference between the z score for hits and that for false alarms.

English speech perception. The English syllable discrimination task followed the same procedure as the Cantonese task. The mean and *SD* of the English syllables were 409 and 76.9 ms, respectively. Syllable lengths were not significantly different across the two languages ($p > .05$). The English test syllables are shown in Table 1. d' scores were

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calculated using the same method as in Cantonese syllable discrimination to indicate discrimination sensitivity.

Results

In the statistical analyses, we first standardised the distributions of children's responses and then calculated multiple analyses of variance. The analyses of variance (ANOVA) were employed to investigate the developmental trend of the various variables. The correlations between different tests were computed. Finally, hierarchical linear regressions were conducted to assess the contributions of phonological awareness, speech perception and auditory processing to children's word reading for Chinese (L1) and English (L2). For each analysis, a level of statistical significance of $p < .05$ was used.

Mean performance

All inferential developmental tests except for nonverbal intelligence were conducted by one-way ANOVA, followed by Tukey's honestly significant difference test to examine differences among the groups of children at 6, 8 and 10 years of age. Nonverbal intelligence was measured by different tests for the three groups, and therefore no direct group comparisons were made. The means, *SD* and *F*-values for all tests are presented for the three age groups in Table 2. Overall group differences were significant for all the

Table 2. Descriptive statistics and analysis of variance for all measures by grade level.

	A Kindergarteners (n = 43–44)[a]	B Second graders (n = 45–46)	C Fourth graders (n = 42–43)	F-value (dfs)	Post hoc by Tukey
Age in month	69.25 (3.90)	98.89 (10.12)	118.63 (7.02)	477.07*** [2, 130]	A < B < C
Nonverbal intelligence	22.16 (22.16) [out of 36]	32.43 (28.32) [out of 60]	43.19 (23.56) [out of 60]	/	/
Auditory processing	86.57 (22.16)	94.50 (28.32)	120.28 (23.56)	21.81*** [2, 130]	A = B < C
Chinese variables					
Character reading (maximum = 184)	45.05 (25.46)	126.33 (17.35)	163.58 (11.62)	443.21*** [2, 130]	A < B < C
Phonological awareness (maximum = 67)	19.86 (7.42)	34.98 (8.86)	50.44 (8.64)	146.23*** [2, 130]	A < B < C
Syllable discrimination (d')	− 1.13 (1.75)	0.18 (1.62)	1.33 (.60)	31.76*** [2, 128]	A < B < C
English variables					
Word reading (maximum = 80)	16.34 (13.19)	37.87 (18.02)	69.70 (7.14)	168.02*** [2, 130]	A < B < C
Phonological awareness (maximum = 45)	14.20 (8.06)	26.54 (8.54)	36.09 (5.07)	95.24*** [2, 130]	A < B < C
Syllable discrimination (d')	− 0.88 (1.73)	0.23 (1.20)	0.52 (1.07)	13.01*** [2, 130]	A < B = C

Note: *SD*s are in parentheses.
[a]Range of numbers of participants contributing to the various test means.
***$p < .001$.

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measures. Developmental improvement was evident. Post hoc analyses showed that the fourth graders performed at a higher level than the second graders who in turn outperformed the kindergarteners in all the tasks except the auditory processing, which differed only between fourth graders and the other ages, and in English speech perception, in which the second and fourth graders performed at similar levels. These results suggest that overall, the tasks were developmentally appropriate and showed some growth with age.

Partial correlations

The correlational analyses were conducted by pooling the scores from the three age groups, which had between 42 and 46 children in each group. By pooling the data from different age groups, more statistical power could be obtained to detect the relations among them. Moreover, correlations among variables were similar across the three groups. Correlation coefficients of various English and Chinese measures after partialling out children's age and Raven's scores as nonverbal intelligence are shown in Table 3. Because nonverbal intelligence was assessed by two different tests, one of which lacked a local norm so that no IQs could be derived, the raw scores from each group were converted into standard scores using the respective group mean and *SD*, having a possible range from −1 to 1 with a mean of 0. Results showed that reading in L1 and L2 was intercorrelated ($r = 0.51$). Performance on Tallal's auditory processing task was correlated with the word reading in both L1 ($r = 0.33$) and L2 ($r = 0.44$). Auditory processing was closely associated with phonological awareness ($r = 0.41$ and 0.25 for L1 and L2) and speech perception ($r = 0.25$ and 0.19 for L1 and L2). These results focused on associations of general auditory processing and speech were in line with our first hypothesis, that is, that these variables should be associated for both languages. Interestingly, however, while L1 speech perception appeared to be generally related to L1 reading ($r = 0.30$), L2 speech perception was not correlated with reading either in the L1 or L2. Speech perception tended to be associated with phonological awareness in L1 ($r = 0.25$) and L2 ($r = 0.20$). Finally, phonological awareness was correlated with Chinese ($r = 0.29$) and English ($r = 0.34$) word reading.

Regressions

Multiple hierarchical regression analyses were performed to examine whether phonological awareness, speech perception and auditory sensitivity might have unique

Table 3. Partial correlations controlling for age and nonverbal intelligence.

	1.	2.	3.	4.	5.	6.
Chinese variables						
1. Character reading	–					
2. Phonological awareness	.29**	–				
3. Syllable discrimination	.30***	.25**	–			
English variables						
4. Word reading	.51***	.40***	.31***	–		
5. Phonological awareness	.30**	.56***	.29**	.34***	–	
6. Syllable discrimination	.07	.14	.42***	.15	.20*	–
7. Auditory processing	.33***	.41***	.25**	.44***	.25**	.19*

*$p < .05$; **$p < .01$; ***$p < .001$.

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roles in predicting children's word reading in L1 and L2. These analyses were performed on the combined data from the three age groups, thereby enhancing statistical power. To do so, we calculated a series of hierarchical regression analyses to test the ability of phonological awareness, speech perception and auditory processing to predict performance after controlling for age and nonverbal intelligence. In these regressions, age and Raven's scores were entered at the first step so that their contributions were removed before the critical predictors were examined. Phonological awareness, speech perception and auditory sensitivity were entered at separate steps so that the unique contribution of either with the other controlled for could be evaluated in a more stringent way at the last step, as they were highly correlated.

There were three regressions in Set 1, using Chinese reading as the dependent variable and each of the following as the last entered independent variable: Chinese phonological awareness, speech perception and auditory sensitivity. In the first regression, Chinese phonological awareness, speech perception and auditory processing were entered at steps

Table 4. Hierarchical regressions predicting character and word reading in the L1 and L2.

Step	Independent variable	Final βs	*df*s	$R^2\Delta$	$F\Delta$
Set 1: predicting Chinese character reading					
1.	Age	.69***	128	.78	231.27***
	Intelligence	− .06			
2.	Chinese phonological awareness	.14	127	.02	12.89***
3.	Chinese syllable discrimination	.12*	126	.01	8.27**
4.	Auditory processing	.11*	125	.01	4.85*
1.	Age	.69***	128	.78	213.27***
	Intelligence	− .06			
2.	Chinese syllable discrimination	.12*	127	.02	12.81***
3.	Auditory processing	.11*	126	.01	9.33**
4.	Chinese phonological awareness	.14	125	.01	3.90
1.	Age	.69***	128	.78	231.27***
	Intelligence	− .06			
2.	Auditory processing	.11*	127	.02	14.35***
3.	Chinese phonological awareness	.14	126	.01	5.55*
4.	Chinese syllable discrimination	.12*	125	.01	6.16*
Set 2: predicting English word reading					
1.	Age	.42***	130	.59	94.18***
	Intelligence	.13*			
2.	English phonological awareness	.23**	129	.04	14.12***
3.	English syllable discrimination	.03	128	.00	1.04
4.	Auditory processing	.27***	127	.05	19.05***
1.	Age	.42***	130	.59	94.18***
	Intelligence	.13*			
2.	English syllable discrimination	.03	129	.01	2.82
3.	Auditory processing	.27***	128	.06	24.44***
4.	English phonological awareness	.23**	127	.02	7.23**
1.	Age	.42***	130	.59	94.18***
	Intelligence	.13*			
2.	Auditory processing	.27***	129	.07	27.04***
3.	English phonological awareness	.23**	128	.02	7.88**
4.	English syllable discrimination	.03	127	.00	0.20

*$p < .05$; **$p < .01$; ***$p < .001$.

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2, 3 and 4, respectively; in the second regression the entry order was auditory processing, phonological awareness and speech perception at steps 2, 3 and 4. For the third regression, speech perception, auditory processing and phonological awareness were entered at steps 2, 3 and 4. The results of the regression analyses on L1 and L2 word reading are summarised in Table 4. Set 2 was treated the same as Set 1 except the English, rather than the Chinese, skills were included. Age and nonverbal intelligence clearly contributed a significant amount of variance to learning to read in both languages when entered first. Auditory processing and speech perception were found to be significant predictors of Chinese word reading after controlling for the effects of other reading related skills. For English, auditory processing and phonological awareness predicted significant unique variance in English word reading but speech perception failed to explain additional variance in word reading performance. These results were in line with our hypotheses. We had expected that both auditory processing and phonological awareness, but not speech perception itself, would be uniquely associated with word reading across languages. Although this was true in English, in Chinese, speech perception itself was an additional unique correlate of word recognition.

The next stage in the analysis explored the extent to which auditory sensitivity and speech perception explained variability in phonological awareness for both L1 and L2. In the first order, both auditory sensitivity and speech perception were predictors of phonological awareness after controlling for age and Raven's scores. However, after controlling for auditory processing, speech perception was no longer a significant predictor. These results are shown in Table 5.

To assess the first part of the hypothesised model from Zhang and McBride-Chang (2010) further, two regression analyses were also then performed for speech perception in L1 and L2, as shown in Table 6. Auditory processing contributed to speech perception for both languages after controlling for age and nonverbal intelligence.

Finally, in a broader exploration, our hierarchical regression analyses focused on examining cross-language predictors as displayed in Table 7. These analyses were conducted to investigate whether the three metalinguistic skills could be 'transferred'

Table 5. Hierarchical regressions predicting phonological awareness.

Step	Independent variable	Final βs	*df*s	$R^2\Delta$	$F\Delta$
Set 1: predicting Chinese phonological awareness					
1.	Age	.62***	128	.66	122.98***
	Intelligence	.12*			
2.	Chinese syllable discrimination	.11	127	.02	7.85**
3.	Auditory processing	.24***	126	.04	17.63***
2.	Auditory processing	.24***	127	.05	22.77***
3.	Chinese syllable discrimination	.11	126	.01	3.32
Set 2: predicting English phonological awareness					
1.	Age	.65***	130	.62	104.53***
	Intelligence	.11			
2.	English syllable discrimination	.11	129	.02	5.37*
3.	Auditory processing	.16*	128	.02	6.23*
2.	Auditory processing	.16**	129	.02	8.19***
3.	English syllable discrimination	.11	128	.01	3.51

*$p<.05$; **$p<.01$; ***$p<.001$.

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Table 6. Hierarchical regressions predicting speech perception (syllable discrimination).

Step	Independent variable	Final βs	*df*s	$R^2\Delta$	$F\Delta$
Set 1: predicting Chinese syllable discrimination					
1.	Age	.41***	128	.30	27.31***
	Intelligence	.09			
2.	Auditory processing	.25**	127	.05	8.65**
Set 2: predicting English syllable discrimination					
1.	Age	.27*	130	.15	11.28***
	Intelligence	.07			
2.	Auditory processing	.20*	129	.03	4.56*

*$p<.05$; **$p<.01$; ***$p<.001$.

Table 7. Hierarchical regressions examining cross-language transfer.

Step	Independent variable	Final βs	*df*s	$R^2\Delta$	$F\Delta$
Set 1: predicting Chinese character reading					
1.	Age	.67***	128	.78	231.27***
	Intelligence	−.06			
2.	Chinese phonological awareness	.09	126	.03	10.95***
	Chinese syllable discrimination	.13*			
3.	English phonological awareness	.09	125	.00	1.12
4.	English syllable discrimination	−.06	124	.00	1.06
5.	Auditory processing	.11*	123	.01	5.31*
Set 2: predicting English word reading					
1.	Age	.33***	128	.58	89.39***
	Intelligence	.11			
2.	English syllable discrimination	−.01	126	.04	7.46**
	English phonological awareness	.11			
3.	Chinese phonological awareness	.20	125	.03	9.36**
4.	Chinese syllable discrimination	.13	124	.01	4.85*
5.	Auditory processing	.22**	123	.03	11.32**

*$p<.05$; **$p<.01$; ***$p<.001$.

from one language to the other in learning to read. To examine the cross-language transfer of these skills from Chinese (L1) to English (L2), we examined whether the unique variance in English word reading could be accounted for by the Chinese reading-related skills. In this regression, control measures including age, Raven's scores, English phonological awareness and speech perception were entered in the first and second steps so that their effects were considered before examining the transfer effects of the Chinese variables. The Chinese metalinguistic skills were unique and significant predictors of English word reading even after the three L2 tasks were taken into consideration (see Table 7). These cross-language results indicate the influence from L1 to L2 and suggest that Chinese reading-related skills facilitate learning to read English. Similarly, in analyses of cross-language skills from L2 to L1, the unique effect of the English reading-related skills on Chinese word reading were investigated. In this important contrast, the English skills explained no unique variance in Chinese word reading, though general auditory processing continued to be unique in the model.

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Discussion

The present study explored relations among phonological awareness, specific-speech discrimination and general auditory processing in Chinese (L1) and English (L2) reading acquisition. To begin with, the cross-sectional results showed an overall trend of development for the three metalinguistic skills and word reading across the three consecutive age groups for both L1 and L2. A developmental pattern in auditory sensitivity, speech discrimination and phonological awareness was generally observed across the three age groups. Given this general developmental pattern and similar associations among all variables tested within each age group, our analyses then centred on results of the combined age groups together.

Our first hypothesis, derived from a proposed model from Zhang and McBride-Chang (2010) positing that general auditory processing should be uniquely associated with speech perception in both Chinese and English was supported. The correlations of these variables were admittedly modest, but they are in line with previous work demonstrating similar associations (e.g. Gibson, Hogben & Fletcher, 2006; Witton, Stein, Stoodley, Rosner & Talcott, 2002). In further regression analyses, auditory processing explained unique variance in both Chinese and English speech perception, even with age and general reasoning skills statistically controlled.

Our second hypothesis focused on correlates of word reading in each language. Originally, we had hypothesised that, in a full model, both phonological awareness and general auditory processing would be unique correlates of word recognition in Chinese and in English. However, we expected that speech perception in the given language would not be uniquely associated with word reading in such a full model because the role of speech perception was expected to be subsumed under general phonological awareness in these analyses. Results showed that speech perception was indeed not a significant contributor to English word reading, though it was to Chinese word reading. We believe that this added direct association of speech perception to Chinese word recognition can be explained by considering the full model proposed by Zhang and McBride-Chang (2010), in which suprasegmental speech perception is also important for metalinguistic skills related to word reading. It is possible that the Chinese speech discrimination task was related to word reading because in this task, each syllable corresponded to a morpheme, marked additionally with lexical tone, in Chinese. At the same time, it is also plausible that children had such limited exposure to spoken English that their phonological representations were not well developed enough to make the discriminations. Future research is needed in order to tease apart these possibilities. Our test of this model was quite incomplete, given our focus only on temporal processing generally and segmental speech. We believe that the findings from Chinese suggest that the speech perception task may have captured other aspects of the model not tested, such as suprasegmental speech, which could be related more strongly to metalinguistic aspects of word reading such as morphological awareness. Future work might test for such associations directly. Furthermore, we do not see these results as indicative of processes that are general to all kinds of L1 versus L2 acquisition contexts, necessarily. Future work should further examine the effects of environmental and language factors including home language, literacy environment and general oral English proficiency on second-language acquisition.

Our third hypothesis was that phonological awareness in each language would be explained both by speech perception and general auditory processing. Given that speech

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perception has been shown to explain first language phonological awareness in previous work in both English and Chinese (McBride-Chang, 1996; McBride-Chang & Ho, 2000), as well as the proximal association of speech perception to phonological awareness in the model we tested (Zhang & McBride-Chang, 2010), we had expected that speech perception would be uniquely associated with phonological awareness. It was indeed associated with phonological awareness across languages with age and general reasoning statistically controlled. However, once temporal processing was included in the model, speech perception was no longer significant. It is possible that the general auditory processing measure encompasses more variability in auditory processing than any single speech measure in the present findings. Moreover, in English, there was no association between phonological awareness and speech perception in the present study, though there was a modest association between speech perception in Chinese and phonological awareness in English. This result may indicate that developmental models of L2 reading acquisition may be influenced more strongly by context of learning than they are in L1.

Importantly, in exploratory analyses, results showed that general auditory processing made a significant contribution to both Chinese and English word reading after controlling for age, IQ, phonological awareness and speech discrimination. It has been suggested that auditory processing is a foundation for speech sounds and phonological activities and subsequent reading (e.g. Tallal, 1980; Zhang & McBride-Chang, 2010). Our findings that auditory processing skill contributed to word reading are consistent with findings from previous research studies across languages (e.g. Au & Lovegrove, 2007; Goswami, 2002; Reed, 1989; Wang et al., 2008; Witton et al., 1998, 2002). Auditory sensitivity is a general processing skill that is common for learning to read any script, whereas speech perception and phonological awareness may need to be acquired for each language independently. Although different researchers focus on different aspects of auditory sensitivity (e.g. Goswami, Gerson & Astruc, 2009), such results are important to pursue in future work, particularly work focused on bilingual reading development.

With respect to the question of language transfer from one language to another, our results have shown that speech perception and phonological awareness in Chinese predicted English word reading after controlling for age, IQ, English speech perception and phonological awareness. However, there was no additional cross-language contribution for Chinese word reading from English speech perception and phonological awareness. This transfer of speech perception and phonological awareness is only observed in the direction from L1 to L2 but not from L2 to L1. We argue that children who were educated in a Chinese-speaking environment with L1 as the primary language of communication in the home may continue to use their L1 knowledge and strategies to learn L2. In instances in which L2 does not attain the same proficiency as L1 in early development, there is a possibility that the development of L2 phonological activities can be parasitic on L1. Because bilingual children may have limited L2, they may rely on their L1 to acquire L2. However, as children's L2 proficiency increases, L2 may exert an influence on the development of L1 processing skills and the bidirectional transfer effects may be detected as found in Comeau et al.'s (1999) study. Nevertheless, the present findings suggest that the early L1 spoken language experience and limited L2 proficiency may have an impact on the development of L2 phonological representations such that L1 transfer effects on L2 have been observed. The present findings are in line with previous research (Cheung, Chen, Yip, Wong & Hills, 2001; Denton, Hasbrouck, Weaver &

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Riccio, 2000; Durgunoglu et al., 1993; Hernandez, Li & MacWhinney, 2005), in which L2 is dependent upon L1.

Contributions and limitations

There are some aspects of the present findings that should be extended and improved upon in future work. First, it should be noted that the present study only reported correlational data; all tasks were administered simultaneously. Therefore we could not test the directionality of the relations among auditory processing, speech perception and phonological awareness in relation to bilingual literacy acquisition. To better understand this relationship, future research should address the issue of bidirectional relationships and examine the predictive power of metalinguistic skills in reading acquisition in biliteracy acquisition over time. Second, to test the generality of our findings, additional measures of speech perception and auditory processing should be included for future studies. Having multiple measures of speech perception and auditory processing would provide a more comprehensive view of development of phonological representations that might be informative about reading performance. Perhaps the use of frequency discrimination and amplitude-modulated tasks could be used to examine an additional aspect of auditory processing (Goswami et al., 2009; Menell, McAnally & Stein, 1999; Rocheron, Lorenzi, Füllgrabe & Dumont, 2002; Stein & McAnally, 1995). These two tasks, which might be able to tap into a perceptual deficit in P-centre processing as well as temporal and spectral variations, were correlated with phonological processing skills in previous work (e.g. Goswami et al., 2002). In speech perception, tone and aspiration perception or onset-rime segmentation measures (Cheung et al., 2009), which were found to be associated with Chinese word reading, could be used to determine the extent to which they are linked to auditory sensitivity and phonological awareness. Inclusion of these measures could help to test the full model proposed by Zhang and McBride-Chang (2010). Third, to facilitate better attention and understanding, the auditory processing tasks might be more clearly presented in a video game format that could be understood by younger children as suggested by Wightman, Allen, Dolan, Kistler and Jamieson (1989).

Nonetheless, there are several ways in which this study contributes to our current understanding of reading development in L1 and L2. First, this work has helped to refine understanding of a model of word reading acquisition in which auditory processing is linked to speech perception and then to metalinguistic skills and word reading with development (Zhang & McBride-Chang, 2010). Findings from the present study suggest some support for the model but particularly emphasise the role of general auditory processing for L2 reading acquisition. This result may have practical implications for early testing and training for those learning a second language. Those with higher scores on these types of tasks may have an easier time of learning various L2 skills than those with lower scores on them. At the same time, these results suggest that testing for speech perception in an L2 for young children may not be particularly helpful in predicting reading performance in that L2. L2 learning likely includes broader speech sensitivity than does L1 learning; it also likely draws more strongly on L1 phonological sensitivities for learning. Cross-language differences in the relations among auditory processing, speech perception, phonological awareness and reading are attributable to variations in learning context and the nature of the script of the two languages. Overall, the present findings suggest that auditory processing underpins the acquisition of reading through the

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development of auditory information into the formation of speech perception and phonological awareness for L1 and L2.

Acknowledgements

This study was supported by Hong Kong government RGC grant 840308 to Kevin K.H. Chung. We thank all research assistants, the children and their parents for their participation.

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Received 5 February 2010; revised version received 19 May 2011.

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