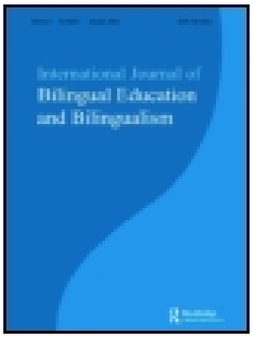

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Simultaneous acquisition of English and Chinese impacts children's reliance on vocabulary, morphological and phonological awareness for reading in English

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ABSTRACT
The developmental process of reading acquisition is frequently conceptualized as a self-organizing mental network consisting of lexico-semantic, phonological and orthographical components. The developmental nature of this network varies across languages and is known to impact second-language learners of typologically different languages. Yet, it remains largely unknown whether such cross-linguistic differences interact within young bilingual learners of two typologically different languages. In the present study, we compared Chinese–English bilinguals and English monolinguals (ages 6–12, $N = 134$) born and raised in the US on their English language and reading skills including vocabulary, phonological and morphological awareness, and word reading. We conducted whole group and subgroup analyses on younger participants to examine the extent of the effect. In monolinguals, phonological abilities directly predicted English word reading. In contrast, in bilinguals, both phonological and morphological abilities made an indirect contribution to English literacy via vocabulary knowledge, even though bilinguals had monolingual-like language and reading abilities in English. These findings offer new insights into the flexibility of the phonological and lexical pathways for learning to read.

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Bilingualism; simultaneous bilingualism; metalinguistic knowledge; language acquisition

Bilingual children frequently face the challenge of learning to *speak* and *read* in two languages. Researchers who focus on children's spoken language acquisition have discovered that early exposure to two languages may result in an interaction between children's two linguistic systems, leading to a different course of language acquisition relative to their monolingual peers for both of their respective languages (c.f., Hoff et al. 2012). More specifically, researchers have found that bilinguals process word sounds and meanings in each of their languages differently, when compared to monolinguals (Byers-Heinlein and Werker 2009). In the current study, we expand this idea to written language and ask: how does exposure to two languages impact children's *reading acquisition?* Does exposure to two writing systems result in different paths to literacy for bilingual children, relative to those of monolingual children? Here we explore the role of bilingualism in reading acquisition by comparing Chinese–English bilingual and English monolingual children.

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Theories of word reading in cross-linguistic contexts

Spoken words are comprised of units of sound (phonemes) and meaning (morphemes, the smallest units of meaning and grammar, e.g. *foot-ball, un-do*). There is now a wealth of developmental evidence demonstrating that children's phonological and morphological language abilities are important for reading acquisition in both English and Chinese (Carlisle 2000; Ziegler and Goswami 2005).[1] Nevertheless, at the earliest stage of learning to read, English-speaking children already show relatively greater reliance on phonological awareness (PA), whereas Chinese speakers show relatively greater reliance on morphological awareness (MA) for learning to read (McBride-Chang et al. 2005). These differences may be driven by the fact that, in Chinese, most syllables are morphemes (i.e. syllables that have meaning), and morphemes map onto individual orthographic representations, known as characters (Perfetti, Liu, and Tan 2005). The strong relationship between syllables and morphemes in Chinese makes morphemes the salient units of processing in speech and in print, emphasizing the role of morphological representation in children's overall semantic representation (McBride 2015). As a result, this yields stronger sound-to-meaning and meaning-to-print interconnections in monolingual speakers of Chinese than English (McBride-Chang et al. 2005; Perfetti, Liu, and Tan 2005). This is in contrast to the prominence of phonemes and the sound-to-print interconnections in English. Across languages, the relations between phonological, semantic and orthographic units form the underlying basis for word knowledge (Perfetti and Hart 2002; Plaut et al. 1996). Nonetheless, we do not know whether exposure to two languages with differing dependences on the relationships between phonology, semantics and orthography would affect the manner in which young bilinguals apply their language skills to literacy development.

Theoretical dilemmas in bilingual reading acquisition

It is generally acknowledged that for children learning to read in two languages simultaneously, literacy skills acquired in one language can 'transfer', or have a significant effect on their acquisition of the other language (Cummins 2012; D'angiulli, Siegel, and Serra 2001; Geva and Wang 2001). Theories of transfer postulate that transfer is most likely to happen when there are shared features across the bilinguals' two languages and when these shared features are more salient in one of the languages than in the other (Kuo et al. 2016). In the case of Chinese–English bilingualism, both English and Chinese are languages with low sound-to-print predictability and with relatively large phono- or morpho-syllabic units mapping onto print (relative to Spanish or Italian, which have greater sound-to-print predictability and more fine-grained sound-to-print mappings; Ziegler and Goswami 2005). Yet, while compound morphology and morpheme-to-print mapping are salient features of Chinese, they are not as common in Indo-European languages like English or Spanish, languages that predominantly use derivational morphology. In fact, past literature has found that English monolinguals and Spanish–English bilinguals have stronger derivational MA in English than Chinese–English bilinguals (Ramirez et al. 2011).

In addition to examining Chinese–English bilinguals' and English monolinguals' MA skills, we also seek to investigate whether Chinese–English bilinguals form stronger meaning-to-print associations than English monolinguals. Although MA has been shown to be important for reading acquisition in different languages, the onset and prominence of its contribution may be dependent upon the language's orthography. Given that Chinese is considered to have a deeper orthography than English has, the contribution of MA in Chinese is stronger than that in English for monolingual beginning readers. Hence, provided with the difference between the orthographies of Chinese and English as opposed to the similarities that language pairs in prior work share (i.e. Spanish–English or Italian–English), we seek to further explore whether this characteristic of Chinese has a cross-linguistic effect on bilingual children's English reading acquisition.

A standard approach to investigating bilingual transfer is to test the strength of associations between children's individual spoken language skills (e.g. phonological, morphological and

vocabulary skills) and reading abilities (Pasquarella et al. 2015; Uchikoshi 2014) using data modeling tools such as hierarchical regression and other statistical methods. For example, a study of Spanish–English bilinguals demonstrated that bilinguals' literacy in English was best predicted by their alphabetic knowledge and listening comprehension in English, as well as vocabulary knowledge in both English and Spanish (Proctor et al. 2006). This constitutes evidence of *direct* transfer, with children's Spanish vocabulary supporting English reading. Such direct transfer is often found for typologically similar languages (i.e. Indo-European languages that share lexical items, morpho-syntactic features and alphabetic forms; see recent meta-analysis by Prevoo et al. 2015 as well as work by Cisero and Royer 1995; D'angiulli, Siegel, and Serra 2001; Durgunoğlu, Nagy, and Hancin-Bhatt 1993) or those aspects of linguistic processing that are maximally similar across languages (e.g. syllable awareness in English and Chinese; see meta-analyses by Simos et al. 2002 as well as work by Geva and Siegel 2000; Wang, Perfetti, and Liu 2005).

However, the transfer of linguistic processing can also be *indirect* and therefore manifest differently in more typologically distant languages. For instance, researchers have found that Chinese–English bilinguals' PA in English makes a direct contribution to their English literacy (Koda, Lü, and Zhang 2014). Moreover, bilinguals' PA in both English and in Chinese made direct contributions to their reading of pinyin (a phonetic transcription system for Mandarin Chinese). Yet, neither of these PA abilities made a direct contribution to Chinese character reading. Researchers have thus suggested that while cross-linguistic transfer is possible for learners of distal languages, the language skill being transferred is 'transformed' or otherwise modified to fit the constraints of the host language (i.e. indirect contribution to Chinese character reading via the support of pinyin, Koda, Lü, and Zhang 2014).

Relative to English, Chinese has a much higher proportion of homophonous morphemes (e.g. 'I' vs. 'eye', 求, to beg [*qiu2*] vs. 球, ball [*qiu2*]). Therefore, Chinese-speaking children's understanding of the existent ambiguity and their ability to use morphology to solve this ambiguity is a significant predictor of learning to read in Chinese (Shu et al. 2006). In other words, the necessity to consider multiple possible meanings for similar-sounding syllables promotes stronger *morpheme-based* meaning-to-sound association in Chinese speakers than what is typically found for native speakers of English (Perfetti, Liu, and Tan 2005). Unlike Chinese, English builds upon mono-morphemic words that have unique phonetic, semantic and orthographic forms (*dog, foot, ball,* etc.). Not surprisingly then, learning to read in English is largely dependent on children's vocabulary knowledge and this has now been found across both bilingual and monolingual learners of English (Kieffer and Lesaux 2007; Oller, Pearson, and Cobo-Lewis 2007; Quinn et al. 2015). Nevertheless, structural characteristics of English vocabulary permit the formation of strong sound-to-meaning, or more specifically, stronger phonology-to-vocabulary associations (Lervåg and Aukrust 2009). The meaning-bearing unit in English is more likely to be a vocabulary-based word instead of a morpheme-based suffix like 're-' or '-ly'. Developmental research finds that children whose vocabulary includes larger numbers of similar-sounding words develop better PA, which in turn supports further vocabulary growth as well as learning to read (Metsala 1999). Therefore, it is likely that, through exposure to the structural characteristics of both Chinese and English, Chinese–English bilingual children may transfer from *morpheme-based* meaning-to-sound and meaning-to-print associations in Chinese (Perfetti, Liu, and Tan 2005) to *vocabulary-based* meaning-to-sound and meaning-to-print associations in English.

New look at bilingual Chinese–English literacy

The present study was carried out in an effort to establish the extent to which bilinguals' phonological, morphological and vocabulary skills are associated with word reading in both bilingual and monolingual children. Prior studies examining bilingual literacy showed that Chinese–English bilingual children's compound awareness in one language makes a significant contribution to their learning to read in another language (Wang, Lin, and Yang 2014; Zhang et al. 2014). Yet, there is ambiguity in the data with regard to derivational morphology (Zhang et al. 2014). For instance, some have found

that Chinese–English bilinguals might have lower derivational morphology skills than English monolinguals or even Spanish–English bilinguals, likely because the derivational morphology structure of English is more similar to Spanish than Chinese (Ramirez et al. 2011). Therefore, the present investigation focused on the role of derivational morphology, phonology and vocabulary on bilingual children's literacy.

We predicted that previously observed cross-linguistic differences for reading skills between Chinese and English stem, at least in part, from the underlying differences in lexico-semantic processing for each of these languages. To test this hypothesis, we examined the relationships between three core skills of oral languages: vocabulary, MA and PA across English and Chinese. In particular, we hypothesized that bilingual experience with Chinese, which relies more on MA during their lexico-semantic processing in speech and in print (Perfetti, Liu, and Tan 2005), would change children's literacy network, as well as the associations of oral language skills. Given their bilingual exposure to Chinese, we expected to observe a stronger emphasis on bilingual children's lexico-semantic processing skills (*i.e. the associations between vocabulary and MA and their individual contribution to reading*) as compared to their monolingual counterparts. In contrast, we also expected a weaker sound-to-print association (*the contribution from PA to reading*) in bilingual children, given that in the Chinese language, the phoneme-to-print mapping is more irregular and less transparent when compared to English.

With multi-group path analyses, we examined the relative contributions of individual literacy factors to English word reading skills in English monolinguals and Chinese–English bilinguals. We focused on three major domains – PA, MA and vocabulary. As seen in Figure 1, we predicted that bilingual children would show stronger meaning-to-print associations (paths *a* and *b*; MA-word reading and vocabulary-word reading), stronger sound-to-meaning associations (path *e*; PA-vocabulary), and weaker sound-to-print associations (path *c*; PA-word reading) in English reading as compared to English monolingual children.

Method

Participants and procedure

A total of 77 English-speaking monolingual children (36 girls, 41 boys; mean age = 110.88 months; SD = 21.78; range = 72.60–156.10 months; average grade = third grade) and 57 Chinese–English-speaking bilingual children (39 girls, 18 boys; mean age = 104.56 months; SD = 20.95; range = 76.40–152.60 months; average grade = third grade) participated in the study. The groups were similar in terms of age ($t = 1.69$; $p > .05$) and levels of parental education ($t = .82$; $p > .05$), but differed in

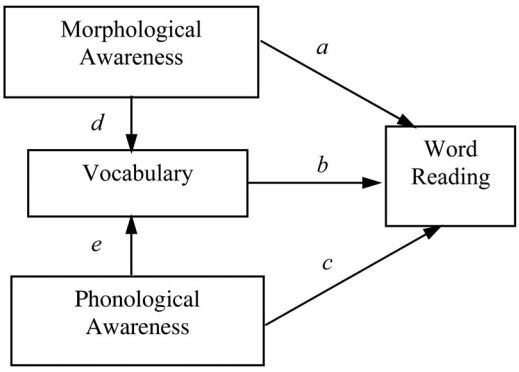

Figure 1. The hypothesized model for examining the direct and indirect contributions of PA, MA and vocabulary to single-word reading.

gender ($t = -2.54$; $p < .01$). Native speakers of English, unfamiliar with Chinese languages, administered assessments in English, while native speakers of Chinese administered assessments in Chinese. The study was approved by the Institutional Review Board. Children received a small gift and monetary compensation for their participation.

All participants were born in the US and had no history of language, hearing or reading delays. All attended regular English-only schools starting at age five. Bilinguals received exposure to Chinese from birth. For 51 bilingual children, both parents were native Chinese speakers, born and raised in a Chinese-speaking country. Children received systematic exposure to English by the age of two, and had at least four years of bilingual exposure prior to testing. The remaining six bilingual children had one native English-speaking parent and one native Chinese-speaking parent. Eighty percent of the children attended Chinese heritage programs with curricula described in detail by Lu and Koda (2011), including an hour of age-appropriate literacy instruction, an hour of Chinese culture instruction and a choice of activity lesson (dance, ping-pong, etc.). All instruction was delivered in Mandarin Chinese by teachers who were native speakers of the language.

The screening criteria for the bilingual children were (1) a minimum of 65% accuracy in a Chinese receptive vocabulary and (2) greater than 85 standard score performance for English receptive vocabulary task (see the Method section for measure description). Therefore, while the sample size may appear relatively small and wide in its age range, we applied rigorous selection criteria to arrive at an early exposed and highly proficient bilingual sample that was maximally matched to their monolingual peers in terms of English language proficiency and experiences of living in the same neighborhoods and attending the same schools.

Language and literacy assessment methods

Language Background and Use Questionnaire (LBU). Participants' parents completed a questionnaire (also used in Kovelman, Baker, and Petitto 2008) detailing their child's history of language and literacy development in each of their languages. The questionnaires allowed us to determine the age of first bilingual exposure, language(s) of reading instruction and language(s) used during/throughout schooling and in the home environment. The frequency of book reading activities at home was measured on a scale from 1 to 5 (1 = never, 5 = always). All parents reported reading to their child, and most bilingual parents read to their children both in English ($M = 3.53$, $SD = 1.09$) and in Chinese ($M = 3.02$, $SD = .99$). With regard to the home conversational activities, parents reported speaking to their children in Chinese ($M = 4.11$, $SD = .92$) more often than in English ($M = 3.20$, $SD = .94$). All parents reported that English was their child's dominant language.

All bilingual children received Chinese literacy instruction with their parents or in after-school programs that included either pinyin (81%) or zhuyinfuhao (19%) phonetic script instruction (age-controlled comparisons of Chinese and English literacy between pinyin and zhuyinfuhao-educated children did not reveal any significant differences, $p > .05$). Participants were equated across monolingual and bilingual groups for level of parental education ($p > .05$).

Selection criteria for the PA and MA measures. PA and MA measures were chosen based on the following criteria: (1) measures a child's sensitivity to both their spoken and written language's linguistic structures, (2) has been shown to be a predictor of children's literacy based on prior research and (3) the task demands are maximally comparable in each language.

Derivational morphology in English and compound morphology in Chinese best predict children's literacy success in each of their respective languages (Carlisle 2000; McBride-Chang et al. 2005). While the tasks tap into seemingly different types of morphemic computations (derivation in English and compound in Chinese), the two tasks are comparable in their demands for computing morphological structures by applying rules of lexical morphology. Both tasks are indicative of the structural features of each language.

English language and literacy measures

Vocabulary. Children completed the vocabulary subtest of the Kaufman Brief Intelligence Test, Second Edition (KBIT-2; 60 total items; for detail on test scoring and reliability see Kaufman and Kaufman 2004). Children heard a word or phrase and their task was to select one out of four pictures that corresponded to the word or phrase.

Reading. Children completed the Word Identification subset of the Woodcock Reading Mastery Tests – Revised/Normative Update (Woodcock 1998). Children were presented with a list of 106 words and were asked to read each word aloud.

PA. Children completed the elision subset of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, and Rashotte 1999; 20 items), in which they were asked to pronounce a word while omitting a phonetic unit from a word, starting with simple items such as syllables and then moving to smaller phonetic units with greater complexity and different positioning within the word.

MA. Children completed a derivational morphology task modeled after Carlisle's (2000) Test of Morphological Structure and were asked to add a morpheme to the given word in order to complete the sentence correctly. The task consisted of 12 trials and 2 practice sentences. To best predict literacy in each of the children's languages, children completed the MA task that best fit the orthographic and linguistic structure of each language. Specifically, derivational morphology taps into children's sensitivity to the structure of English and is best at predicting English literacy (Carlisle 2000), while compound morphology taps into children's sensitivity to the structure of Chinese and is best at predicting Chinese literacy (McBride-Chang et al. 2005; Newman et al. 2011). The study did not include compound morphology in English because unlike derivational morphology in English or compound morphology in Chinese, compounding in English is governed pragmatically rather than structurally.

Chinese language and literacy measures

Since there are no standardized language and literacy assessments in Mainland China, the Chinese tasks for this study were obtained from previous studies that used assessments modeled after standardized English tasks to study Chinese language monolinguals (Cheung, Lee, and Lee 1997; Lei et al. 2011; Newman et al. 2011). For comparison, we present findings from the available and maximally (albeit not ideally) similar age groups for each of the tasks.

Vocabulary. To compare bilingual children's vocabulary knowledge in Chinese and English, a receptive vocabulary task was used as a vocabulary measure to maintain a consistent testing format across languages. The Chinese receptive vocabulary task was adapted from the Cantonese Receptive Vocabulary Test (CRVT) designed by Cheung, Lee, and Lee (1997) and has been used in a longitudinal study of native Chinese speakers' language and literacy development and includes phonological and semantic distractors that are appropriate to the Chinese language (Song et al. 2015). Similar to the English task, during this Chinese task the children heard a word or phrase and their task was to select one out of four pictures that corresponded to the word or phrase (the shortened version was administered; 64 total items). Each item included a phonetic, semantic and neutral distractor that was appropriate for Chinese-speaking children.

Only 2 out of 57 participants had ceiling performance. Participants' Chinese language vocabulary score distribution (Table 1) was similar to the one found by Cheung, Lee, and Lee (1997), who tested younger Cantonese monolinguals (mean age 5.81, $n = 54$), finding a similar mean accuracy of 91.72 (±5.73) and suggesting that the children in our sample were about 3 years behind their monolingual peers in terms of Chinese vocabulary development. This finding is consistent with reports for Chinese–English bilinguals raised in the US, showing a marked slowing in their Chinese vocabulary development, especially at the onset of English schooling (Sheng 2014).

Reading. Children completed the Character Recognition task used in previous study (Newman et al. 2011) to assess children's Chinese reading and literacy skills (120 total items). To ensure that

Table 1. English and Chinese language and literacy measures in monolingual and bilingual children.

	Bilingual		Monolingual		
English	Reliability	Mean standard score (SD)	Reliability	Mean standard score (SD)	*t*/*F*
Language & literacy measures					
Vocabulary (KBIT)	.94	110.70 (12.55)	.93	113.90 (11.55)	1.53
Reading (Woodcock)	.96	120.61 (11.91)	.98	115.01 (10.87)	−2.83**
PA (CTOPP-Elision)	.90	12.16 (2.45)	.87	11.95 (2.44)	−.49
Morphological awareness (+)	.76	9.07 (2.15)	.72	9.53 (2.02)	.59
	Bilingual				
Chinese	Reliability	Mean raw score (SD)			
Language & literacy measures					
Vocabulary (Picture Identification)	.84	56.23 (5.18)			
Reading (Character Recognition)	.96	22.93 (11.78)			
PA	.76	34.86 (9.54)			
Morphological awareness	.84	19.08 (3.96)			

Note: *t*-values were reported for all standardized tasks except (+) MA, where raw scores and *F*-value for ANCOVA age-controlled were reported.
*$p \leq .05$.
**$p \leq .01$.
***$p \leq .001$.

children's Chinese reading performance was not affected by the choice of Chinese characters (traditional vs. simplified), we used two versions of the task and administered the one that corresponded to children's reading experiences. Children who attended school with traditional written instruction completed the traditional character version, while children who attended school with simplified written instruction completed the simplified version. Children saw characters with ascending order of difficulty and were asked to read each character aloud. Newman et al. (2011) administered this task to 41 monolingual children (mean age 7.19) and found a mean accuracy of 54.60 (±25.73). This mean greatly exceeds that of the bilinguals (see Table 1).

PA. Children completed a Chinese syllable deletion task used in previous studies (Newman et al. 2011; total items = 54) to measure Chinese PA. Similar to the elision subset of CTOPP in English, during this Chinese language task the children were asked to pronounce a word while omitting a phonetic unit from a word, starting with simple items such as syllables and then moving to smaller phonetic units with greater complexity and different positioning within the word. Thus, both the English and the Chinese measures tapped into children's ability to segment spoken words into the phonological components that map onto their respective orthographies (syllables, rimes, phonemes, etc. – progressively decreasing in the phonological unit size and increasing in unit complexity) and have nearly identical task requirements across the two languages.

Further, this measure has been successfully used to predict literacy acquisition in monolinguals in English (e.g. Nakamoto, Lindsey, and Manis 2007) and in Chinese (e.g. Newman et al. 2011). Newman et al. (2011) administered this task on 41 monolingual children (mean age 7.19) and found a mean accuracy of 22.34 (±7.86), which was comparable or even lower than that of the younger bilingual group within the same age range (see the Discussion section for more details). None of the participants reached ceiling performance on this task, but two children were considered to be outliers at the lower bound and were removed from the subsequent statistical analyses that included this task.

MA. Children completed a Morphological Construction Judgment task modeled after the Chinese Morphological Construction task (Lei et al. 2011; total items = 24). Children heard two words, the first word was a word they knew and the second word was a pseudo-word that resembled the first real word and either confirmed or violated the structural constraints on morphological compounding in Chinese (24 items). Children were asked to decide if the second word was a 'good' or 'bad' new word (e.g. 'sick-patient [病人] and sick-flower [病花]?' = good and 'snowman [雪人] and catsnow [貓雪]?' = bad). The first example follows Chinese compounding regularities in that the descriptive term ('sick') comes before the noun whereas in the second example, the modifier ('snow') comes after the noun.

Lei et al. (2011) tested 184 monolingual Chinese-speaking children (mean age 6.4), and found a mean accuracy of 10.66 (±3.24), and Cronbach's alpha of .73. The mean obtained for the present study's bilingual children was higher (Table 1); however, the children in our study were also older and there is evidence to suggest that this type of metalinguistic skill increases with age (Goodwin and Ahn 2013).

Statistical analyses

All participants included in the study completed the English single-word reading, PA and vocabulary tasks. Two monolingual children did not complete the English MA task. All bilingual children completed the Chinese single-word reading and vocabulary tasks. Seven bilingual children did not complete the Chinese morphological task and one did not complete the Chinese phonological task due to fatigue. Using the outlier-labeling rule (Hoaglin and Iglewicz 1987), two bilingual children's data from the Chinese PA task were identified as outliers and removed for all analyses on Chinese measures. The skewness and kurtosis values for all English and Chinese measures were within the acceptable range for normal distributions (±2; George and Mallery 2010).

The reliabilities for all measures are reported in Table 1, together with means and standard deviations for both groups of participants. Using ad-hoc *t*-tests, we compared monolingual and bilingual children's English proficiency (using standard scores). Since MA was not a standardized task, an ANCOVA controlling for age was performed on the raw score. Although there were gender differences across the group ($t = -2.539$; $p < .01$), the results remained unchanged when we controlled for gender differences.

The study's core hypothesis was that exposure to Chinese may impact bilingual children's sound-to-print and meaning-to-print associations in English, as compared to the English monolingual speakers. As a first step to testing this hypothesis, two age-controlled Pearson's partial correlation analyses were conducted: (1) within language correlations for monolingual children's English reading and (2) within and between language correlations for bilingual children's English and Chinese reading (Tables 2 and 3). To prevent multi-collinearity effects between age and grade ($r = .95$, $p < .001$), partial correlations were conducted separately by age and grade. Similar results were obtained. Given the foremost importance of age in bilingual acquisition, only age-controlled findings are presented and discussed.

The second step to testing our hypothesis was to conduct a multi-group path analysis (Amos 20; Arbuckle 2011) that tested potential differences in children's associations between sound-to-print (*c*; phonology to reading) and meaning-to-print (*a*; morphology and reading / *b*; vocabulary and reading) associations.

To ensure the power of our model, a priori analysis on effect sizes from prior work (McBride-Chang et al. 2005) was conducted using G*Power 3.1 (Faul et al. 2009). The results indicated that a sample size of 56 Chinese–English bilingual children and 64 English monolingual children would be needed to perform path analyses of interest with 80% power (alpha = .05). This requirement is commensurate with the present sample for English language path analyses, even after excluding the children with the missing data (monolinguals = 77, bilinguals = 57). The Chinese language sample did not reach

Table 2. Partial correlation controlling for age between English measures for English monolinguals.

Variables	1	2	3	4
1. Reading (Woodcock)	–			
2. PA (CTOPP-Elision)	.62***	–		
3. MA	.35**	.25*	–	
4. Vocabulary (KBIT)	.37***	.12	.45***	–

*$p \leq .05$.
**$p \leq .01$.
***$p \leq .001$.

Table 3. Partial correlation controlling for age between Chinese and English measures for Chinese–English Bilinguals.

	English Measures							
Variables	1	2	3	4	5			
1. Reading (Woodcock)	–							
2. PA (CTOPP-Elision)	.33**	–						
3. MA	.43***	.32*	–					
4. Vocabulary (KBIT)	.55***	.42***	.53***	-				
	English measures					Chinese measures		
	1	2	3	4	5	6	7	8
5. Reading (character recognition)	.17	.15	.15	.06	-			
6. PA	.18	.45***	.15	.14	.39**	-		
7. MA	.09	.18	.33*	.34*	.34*	.35*	-	
8. Vocabulary (picture identification)	.06	.12	.20	−.11	.37**	.20	.20	–

*$p \leq .05$.
**$p \leq .01$.
***$p \leq .001$.

this criterion ($n = 50$, after removing outliers and missing data), and therefore we performed a hierarchical regression analysis for the Chinese language measures.

As the power of the path analyses did not allow for an additional variable in addition to the key variables (age, vocabulary, phonology, morphology and reading), we also conducted exploratory hierarchical regression analyses for each of the groups, adding gender and parental education (as a proxy for IQ and the overall motivation for academic achievement) as a factor, separately. However, the addition of this variable did not change the key findings and was not reported here.

Should the path analyses yield differences between the two groups, our plan was to follow up on those differences with hierarchical regression analyses that would allow for a better focus on each individual language group and age sub-group.

Finally, children's Chinese literacy was explored using regression analyses given the limited sample size for bilingual children's Chinese data and therefore lack of power to conduct path analyses as was done for the English literacy data. Age was the first factor in the hierarchical regression models.

Results

Group comparisons of English language and literacy competence

Our first prediction was that bilingual experiences with Chinese would have an impact on bilingual children's morphological and phonological language abilities in English. While we did not find any differences in phonological, morphological or vocabulary competence between the groups, bilinguals showed significantly better single-word reading ability (Woodcock 1998; $t = -2.83$, $p < .01$) than monolinguals after controlling for age (Table 1).

Age-controlled partial correlations among language and literacy measures

Our second prediction was that aspects of children's phonological, morphological and vocabulary competence in one language might make an independent and significant contribution to their reading ability in their other language. On the one hand, the data revealed significant cross-linguistic correlations within the individual reading abilities (e.g. PA in Chinese correlated with PA in English, Tables 2 and 3). On the other hand, there were no significant correlations between single-word reading in English and phonological, morphological, vocabulary and other language measures in Chinese, and vice versa. As there were no significant cross-linguistic correlations between bilinguals' single-word reading skills in one and phonological, morphological or vocabulary abilities in the other language, the inter-relationship between Chinese and English language skills was not further examined.

English reading in bilinguals and monolinguals: full sample

These analyses included English language data for 75 monolingual and 57 bilingual children (the entire sample of participants minus 2 bilinguals who did not complete one of the key tasks). The manner in which the variables were compared can be visualized in Figure 2. Specifically, a bootstrap procedure (500 draws) was used for the multi-group analyses to obtain better estimates of standard errors in each model and maximum likelihood estimates of the models were used for fit assessment. The fit statistics are reported and interpreted as suggested by Kline (2005): (1) Pearson chi-square for which non-significant values signify good fit, and a χ^2/df ratio ≤ 3 is acceptable; (2) Comparative Fit Index (CFI; Bentler 1990) >.90 is considered a good fit and (3) Root Mean Square Error of Approximation (RMSEA; Steiger 1990) $\leq .08$ is considered acceptable while $\leq .05$ is considered a good fit. The model for the multi-group analyses was fitted to data in four steps to test the invariance hypothesis across groups:

Step 1 (*Unconstrained model*). The parameter estimates were free to vary across the monolingual and bilingual groups. The unconstrained model showed acceptable goodness of fit: $\chi^2(7) = 11.504$, $p = .118$, $\chi^2/df = 1.643$, CFI = .989, RMSEA = .070, suggesting that the unconstrained model fits each language group individually.

Step 2 (All constrained model). To test whether there are variations across groups, all parameters were constrained to equality across the two language groups, including regression, variance, covariance and mean estimates. If there was no fit deterioration at this step, then the two language groups demonstrate the same paths to reading acquisition. The constrained model showed poor goodness

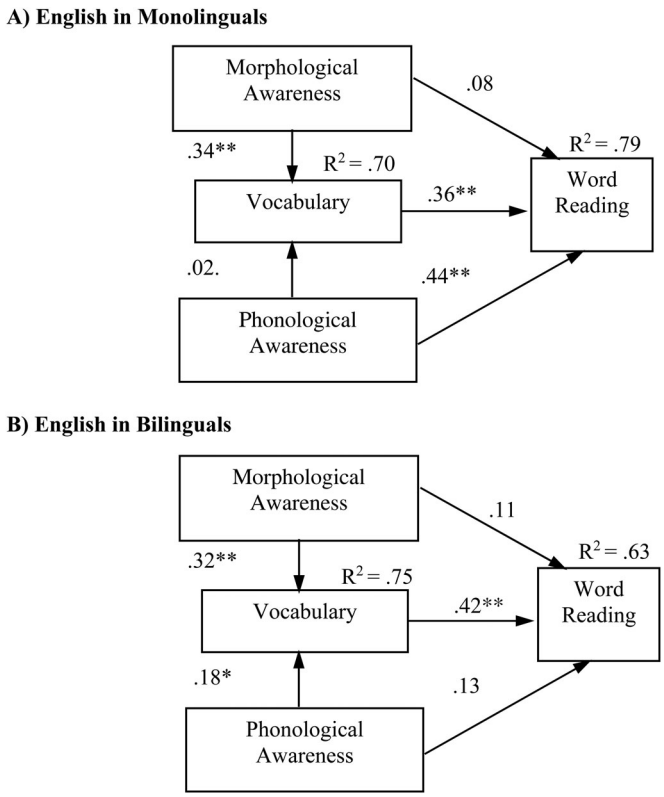

Figure 2. Multi-group analysis models predicting English literacy in (A) English monolinguals ($n = 75$) and (B) Chinese–English bilinguals ($n = 51$). The figure depicts the final Step 4 PA model. Results are age-controlled and standardized regression weights for each path as well as the squared multiple correlations (explained variances; R^2) for dependent variables, vocabulary and reading, are reported (*$p \leq .05$. **$p \leq .01$).

of fit: $\chi^2(16) = 42.992$, $p < .001$, $\chi^2/df = 2.687$, CFI = .936, RMSEA = .114 and deteriorated significantly from the Step 1 model ($\Delta\chi^2(9) = 31.488$, $p < .001$), suggesting that some parameters may differ significantly across groups.

Step 3 (Model allowing differences in MA parameters). To identify whether the paths of MA differ across groups, all paths were constrained to equality except the paths (a) between MA and vocabulary and (b) between MA and reading were allowed to vary. The MA model showed poor goodness of fit: $\chi^2(14) = 37.047$, $p = .001$, $\chi^2/df = 2.686$, CFI = .945, RMSEA = .113 and is a poorer fit when compared to that of the Step 1 model, albeit not significant ($\Delta\chi^2(7) = 25.542$, $p = .058$).

Step 4 (Model allowing differences in PA parameters). To identify whether the paths of PA differ across groups, all paths were constrained to equality except the paths (e) between PA and vocabulary and (f) between PA and reading were allowed to vary. The PA model showed excellent goodness of fit: $\chi^2(13) = 15.763$, $p = .262$, $\chi^2/df = 1.213$, CFI = .993, RMSEA = .040 and is not significantly different from the Step 1 model ($\Delta\chi^2(6) = 4.258$, $p = .642$). This suggests that the PA paths are driving the difference across the two language groups.

These results indicated that both Step 1 and 4 models were adequate representations of the data. However, Step 4 models showed better fit, which were considered as final and are reported in Figure 2 with standardized coefficients for each path across groups.

English reading in beginning bilingual and monolingual readers (ages 6–8)

Given that the main difference between the monolinguals and bilinguals in the full sample was in sound-to-print associations, we included follow-up analyses of English literacy that only included the younger participants, ages 6–8 (cut-off age, less than 96 month old), to examine whether the results from the path analyses were not driven by the older bilinguals. We conducted two hierarchical regressions for the younger bilingual ($n = 23$) and monolingual children ($n = 21$). There was no significant group differences in gender (bilinguals: 14 females, 9 males; monolinguals: 12 females, 11 males; $\chi^2 = .354$, $p > .05$) or age (bilinguals mean age in months = 85.32 ± 6.53; monolinguals mean age in months = 86.69 ± 6.80; $t = .70$, $p > .05$). The variables were entered in the following order: age, vocabulary, PA, MA, see Table 4.

Monolinguals: English. The final betas were significant for vocabulary and PA and the explained variances for English reading were 5% and 50%, respectively.

Bilinguals: English. The final beta was significant for vocabulary only and the explained variance for English reading was 77%.

The power analysis suggested that these regression models had an effect size ranging from 2.39 to 5.76 with a power of 1. These analyses are conceptually important, even if they were to have had lower power levels, as they address an important issue of a wide age range variation in our sample and demonstrate that the effects found for the full sample are also true of the younger bilinguals.

Table 4. Hierarchical regression analyses predicting reading in younger monolinguals and bilinguals (age: 6–8).

	Monolingual English ($n = 21$)		Bilingual English ($n = 23$)	
Steps & predictors	ΔR^2	Standardized final beta	ΔR^2	Standardized final beta
1. Age	.32**	.03	.25*	−.26
2. Vocabulary	.05	.28*	.42***	.77**
3. PA	.50***	.78***	.002	−.14
4. MA	.01	.10	.04	.38

Note: PA = Phonological awareness; MA = Morphological awareness.
*$p \leq .05$.
**$p \leq .01$.
***$p \leq .001$.

Discussion

Theories of reading acquisition suggest that children's single-word reading abilities build upon a strengthening network of phonological, semantic and orthographic knowledge (Perfetti, Liu, and Tan 2005; Verhoeven, Leeuwe, and Vermeer 2011). Yet, the nature of these associations differs between monolingual learners of English and Chinese (McBride-Chang et al. 2005). Therefore, the present study examined whether the structural characteristics of Chinese impact the manner in which Chinese–English bilinguals form meaning-to-print and sound-to-print associations in English, as compared to English monolinguals. Consistent with our hypothesis, the findings revealed that Chinese–English bilinguals showed low sound-to-print association but a significant sound-to-meaning association in English in contrast to their English monolingual counterparts. These differences were consistent across the entire age range (ages 6–12; Figure 2) including the younger learners (ages 6–8; Table 4), reflecting the possible impact of bilingual learning experiences with Chinese. The present findings offer new insights for developing a comprehensive model for how bilingual language experiences can influence children's reading acquisition.

English in bilinguals

Past research on English learners often finds that as children become better readers, they depend less on their PA and more on MA and vocabulary knowledge for learning to read (Carlisle 2000). In the present study, Chinese–English bilinguals showed evidence of weaker sound-to-print associations as compared to English monolinguals, across the entire age range (ages 6–12) and among the youngest participants (ages 6–8). The results may have stemmed from bilinguals' exposure to the Chinese language, where PA did not show significant correlation with word reading after taking into account other language skills such as MA and orthographic skills (Yeung et al. 2011).

To help explain the role of vocabulary in emergent literacy, lexical restructuring hypothesis suggests that the nature of children's vocabulary knowledge, such as knowing a lot of similar-sounding words, improves children's PA, which in turn improves both vocabulary and learning to read (Metsala 1999). Chinese bilinguals are especially accustomed to working with similar-sounding lexical units that are disambiguated through MA and morpheme-to-character mappings. This yields stronger sound-to-meaning and meaning-to-print associations in Chinese. Therefore, we had hypothesized that bilingual experiences with Chinese might yield stronger sound-to-meaning and meaning-to-print associations in bilinguals' English.

Interestingly, the difference in the contribution of MA on reading was not observed when comparing bilinguals' and monolinguals' English reading, after accounting for both vocabulary knowledge and PA. The result may be due to the fact that the meaning-bearing unit in English is more likely to be a vocabulary-based word such as 'foot-ball' or 'snow-man'. Therefore, learning to read in English relies on children's foundation of vocabulary knowledge. It is likely that bilingual children experienced this pathway to English literacy as well. In fact, results from the regression analyses on the youngest bilingual children showed greater dependence on vocabulary than their monolingual peers (Table 4). Evidence from our young bilingual children suggests that they may be on a developmental trajectory to mimic the English monolingual children's development of vocabulary-based meaning-to-print association. Collectively, the findings suggest that bilingual experience with both Chinese and English may incur an early-emerging impact on the way bilingual children form sound-to-print and meaning-to-print association.

Consistent with the lexical restructuring hypothesis, our results of a stronger sound-to-meaning association found in the bilingual group suggested that with Chinese language exposure, bilingual children's ability to explicitly segment words phonologically and morphologically enhanced their vocabulary growth and subsequently, their reading skills. The fact that a stronger sound-to-meaning association was observed in bilingual children further suggested that the nature of Chinese language impacts children's pathway to English reading acquisition. With more homophones

in Chinese, the bilingual children are exposed to an oral language environment that requires heightened sensitivity to differentiate spoken words based on the semantics and context, resulting in a stronger sound-to-meaning association as compared to their English monolingual counterparts (McBride 2015). Additionally, a subset of our bilingual participants also completed fMRI measures of MA, revealing stronger activation in left middle temporal gyrus region (MTG), an area that is typically associated with lexico-semantic processing, suggesting that bilingual exposure influences the neuro-cognitive architecture of learning to read, as manifested behaviorally and neurologically (Ip et al. 2016). The findings are consistent with this hypothesis and suggest that bilingual exposure to Chinese may help foster stronger relationships between phonological and lexico-semantic representations in young Chinese–English bilingual speakers, thereby also strengthening their meaning-to-print associations in English from an as early as ages 6–8.

Vocabulary growth is known to play an important role in bilingual reading acquisition (August et al. 2005; Oller, Pearson, and Cobo-Lewis 2007). Bilinguals often present with smaller receptive and expressive vocabulary size in each of their languages, as compared to monolinguals (Bialystok et al. 2010). The bilinguals in this study had monolingual-like receptive vocabulary competence in English (though, of course, their Chinese vocabulary competence was lower than what had been reported in studies using our vocabulary task with monolinguals of Chinese, e.g. Cheung, Lee, and Lee 1997). Similar to the previous studies with Spanish–English bilinguals (Proctor et al. 2006), Chinese–English bilinguals' vocabulary was the strongest predictor of their English word reading. Vocabulary was also one of the strongest predictors of English literacy in monolingual controls. English builds upon mono-morphemic vocabulary units, units that often present with phonologically opaque spellings requiring the child to know the specific orthographic form of the given word (Ziegler and Goswami 2005). This feature of English orthography likely drives the tight link between vocabulary and literacy growth regardless of the bilingualism status, heritage language or vocabulary size.

Finally, both bilinguals and monolinguals showed significant associations between MA and vocabulary in English. This finding is also similar to those obtained for Spanish–English bilinguals in previous studies of bilingualism. For instance, Kieffer and Lesaux (2007) found that, similar to English-speaking monolinguals, Spanish–English bilinguals with better MA were better at learning new vocabulary items, and that larger vocabularies made a significant contribution to children's literacy in English. This finding also fits within the lexical restructuring hypothesis which suggests that children with better vocabulary knowledge develop better sensitivity of the sub-lexical units of sound and meaning, which in turn improves their ability to learn new vocabulary items as well as their progress in learning to read (Metsala 1999).

Chinese in bilinguals

The bilinguals showed somewhat comparable performance on the same PA tasks relative to Chinese monolinguals (Newman et al. 2011: mean age = 7.19 and mean accuracy = 22.32 ± 7.86; our younger bilinguals: mean age = 7.22; mean accuracy = 28.33 ± 10.82). This finding is remarkable, given that bilingual children had rather limited Chinese literacy instruction. Thus, it is possible that experiences with English alphabetic writing may have strengthened bilinguals' PA abilities in Chinese. In sum, while the Chinese language comparisons are qualitative and should be treated with great caution, they nevertheless suggest that bilingual experiences may have a bi-directional effect on children's literacy, from Chinese to English, and from English to Chinese.

There were significant cross-linguistic correlations between bilinguals' phonological and morphological abilities in each of their languages, respectively, confirming that the cross-linguistic measures were tapping into comparable linguistic abilities. The improved word reading abilities in bilinguals, at least in part, were likely to stem from cross-cultural differences of the values placed on academic performance between parents of Asian-American and other US communities (Chen and Stevenson 1995). However, given that the cross-linguistic effect from Chinese–English bilingual children's

English exposure on Chinese reading was not explored in the present study, future studies may consider exploring whether there is a bidirectional cross-linguistic relationship between Chinese and English in bilingual children.

Implications for understanding literacy, limitations and future directions

The limitations of the present work include a broad age range and only one language pairing of English and Chinese. Although the groups were equated for parental education, which plays a significant role in child cognitive and academic development (Dubow, Boxer, and Huesmann 2009), the study did not include cognitive controls. Finally, it is noteworthy that the Chinese language and literacy tasks chosen for the present study were maximally comparable to our English measures. Nevertheless, there was only one measure of phonology, morphology and vocabulary per language and future research may need to include multiple measures per construct so as to better capture the nature of dual-language interaction in the biliterate learner.

At the theoretical level, the present study considered the possibility that early and systematic dual language experience may alter the structural composition of children's word knowledge, with the bilingual literacy skills being 'transformed' (Koda, Lü, and Zhang 2014) or otherwise modified to fit the constraints of the English language. Indeed, the findings suggest that not only do Chinese–English bilingual children show weaker sound-to-print associations as is typical of Chinese literacy, but also stronger sound-to-meaning relations, as is typical of Chinese spoken language. In contrast, findings for Spanish–English bilinguals (Kremin et al., 2016) have shown that Spanish–English bilinguals form stronger sound-to-print interconnections than English monolinguals, as is consistent with the orthographic demands for learning to read in Spanish. Taken together, these findings are commensurate with the perspective that a primary force behind bilingual transfer for learning to read is the transformation or modification of children's metalinguistic awareness abilities to both conform to the demands of the child's other language and to facilitate literacy acquisition in the other language (Koda, Lü, and Zhang 2014). The findings carry implications for bilingual educators, exemplifying that heritage language experiences alter the way bilinguals learn to read, even when these bilinguals are both proficient and dominant in the language of their reading instruction.

Note

1. Note that although cross-linguistic literacy research often emphasizes the phoneme–morpheme dichotomy, word knowledge is multidimensional and includes word form, meaning and use in morpho-syntactic contexts (Nation 2001).

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