

Lexical Prosody beyond L1 Boundary: Chinese Lexical Tone Sensitivity

Predicts English Reading Comprehension

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Abstract

This 1-year longitudinal study examined the role of Cantonese lexical tone sensitivity in predicting English reading comprehension, and the pathways underlying their relation. Multiple measures of Cantonese lexical tone sensitivity, English lexical stress sensitivity, Cantonese segmental phonological awareness, general auditory sensitivity, English word reading and English reading comprehension were administered to 133 Cantonese-English unbalanced bilingual second graders. Structural equation modeling analysis identified transfer of Cantonese lexical tone sensitivity to English reading comprehension. This transfer was realized through a direct pathway via English stress sensitivity and also an indirect pathway via English word reading. These results suggest that prosodic sensitivity is an important factor influencing English reading comprehension and that it needs to be incorporated into theoretical accounts of reading comprehension across languages.

Keywords: Lexical prosody, Cantonese lexical tone, English lexical stress, reading comprehension, lexical quality hypothesis, bilingualism

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In recent years, a relation between Mandarin Chinese lexical tone sensitivity and English word reading among Chinese-English bilingual readers has been discovered (Wang, Perfetti, & Liu, 2005; Wang, Yang, & Cheng, 2009). Such a relation may be accounted for by the prosodic transfer hypothesis, proposed by Wang and colleagues, in which English lexical stress sensitivity mediates the relation between Mandarin Chinese lexical tone sensitivity and L2 English word reading.

Prosody typically refers to suprasegmental information such as intonation, accent and pause. It has been conceptualized as an essential component of fluency that facilitates reading comprehension (Kuhn, Schwanenflugel, & Meisinger, 2010). In this study, we examine the role of Cantonese lexical tone sensitivity in predicting L2 English reading comprehension in unbalanced Cantonese-English bilingual children who are learning to read Chinese and English in parallel. From a theoretical point of view, investigating the relation between Cantonese lexical tone sensitivity and English reading comprehension sheds light on the cross-language skills that are critical to reading comprehension, and the underlying pathways driving prosodic transfer.

Prosody and Reading Comprehension: Direct Prosodic Transfer

Lexical tone is a specific type of prosody that uses the pitch variation to

convey differences in word meaning. In Cantonese¹ there are six contrastive tones: High level (55, T1), high rising (25, T2), mid level (33, T3), low falling (21, T4), low rising (23, T5), and low level (22, T6) (Fok Chan, 1974). For example, a Cantonese syllable /si/ can represent six different meanings when carrying different tones: f 師 /si1/ (*teacher*), 史/si2/ (*history*), 試/si3/ (*test*), 時/si4/ (*time*), 市/si5/ (*city*), 事/si6/ (*matter*). Lexical stress in English is a type of prosody, specifically a variation of a suprasegmental feature, which can also be used to distinguish meanings, for example, OBject /ˈabdʒɪkt/ (a solid thing) versus obJECT /əbˈdʒɛkt/ (go against). The possible relation between Cantonese lexical tone sensitivity and English reading comprehension may arise from the linguistic and acoustic similarities of lexical prosody between Chinese (i.e., lexical tone) and English (i.e., lexical stress) (Chrabaszcz, Winn, Lin, & Idsardi, 2014; Wang, 2008).

Tone and stress share similarities in the acoustic dimension, in addition to lexical function. Acoustically, lexical tones are variations of fundamental frequency (i.e., F0; the lowest frequency of a periodic sound wave) in dimensions of contour,

¹ Cantonese is a dialect of Chinese spoken mainly in Southern China and Hong Kong, with an estimation of 80 million speakers (Grasso, 2009). The six Cantonese lexical tones were transcribed using a numerical notational system developed by Chao (1930). The number 1 (lowest) to 5 (highest) indicates relative height, shape and duration of pitch contour. High, Middle and Low are the descriptions of pitch ranges while Level, Rising, Falling are the specifications of the slopes of the pitch contours.

height or even onset (Gandour, 1981, 1983; Khouw & Ciocca, 2007; Tong, McBride, & Burnham, 2014; Tsang, Jia, Huang, & Chen, 2011). Lexical stress is also signaled by fundamental frequency, as well as duration, intensity and vowel quality (Chrabaszc et al., 2014; Wang, 2008; Yu & Andruski, 2010; Zhang & Francis, 2010).

There is empirical support that that lexical tone and stress share fundamental frequency as a common acoustic cue: In a recent study, Cantonese-English bilingual children used the F0-related acoustic parameters, such as average F0 and F0 onset, to perceive both Cantonese lexical tone and English lexical stress (Tong, Lee, Lee, & Burnham, 2015).

Together, the similarities in both linguistic and acoustic dimensions for Cantonese lexical tone and English lexical stress raise the possibility of direct prosodic transfer in which L1 Cantonese lexical tone sensitivity facilitates L2 English lexical stress sensitivity, which in turn predicts English reading comprehension. We refer to this as the direct prosodic transfer pathway hereafter. Such a direct prosodic transfer pathway has empirical support from studies demonstrating the role of prosody in English reading comprehension. Miller and Schwanenflugel (2006) reported a significant contribution of pitch variations to reading comprehension after controlling for word decoding. In a related longitudinal study, Miller and Schwanenflugel (2008) further demonstrated that different prosodic parameters such as pauses and intonation

(variation of pitch at phrase/sentence level) significantly predicted reading comprehension development in native English readers.

Prosody and Reading Comprehension: Indirect Prosody Transfer

The possible relation between reading comprehension and aspects of lexical prosody such as Cantonese lexical tone and English lexical stress also arises from the connection that prosody has with automaticity of word reading, which is subsumed within reading fluency. Kuhn et al. (2010) proposed a prominent link between reading comprehension and reading fluency, in which reading fluency constituted automaticity, prosody and accuracy. The automaticity component can be best illustrated by the automaticity theory (LaBerge & Samuels, 1974). This posits that the facilitation of word retrieval will lead to fast, efficient (or automatic) word recognition, enabling readers to allocate cognitive resources away from low-level word decoding to the higher-level processes required for reading comprehension, such as inferencing and retrieval of world knowledge.

Perfetti's lexical quality hypothesis offers an explanation for the process by which word retrieval could become automated (Perfetti, 2007; Perfetti & Hart, 2001; Perfetti & Stafura, 2014). According to the lexical quality hypothesis, the quality of lexical representations is related to the specificity and redundancy of orthographic, phonological and semantic constituents of word representations, and their

interconnections. Quality of these representations can vary from high to low. Skilled readers are believed to have higher quality representations of words whilst low skilled readers have lower quality representations. As a result, skilled readers have greater automaticity of word decoding (Perfetti, 2007).

To date, the phonological representations of words have been considered in relation to segmental information (vowel and consonant) only (e.g., Swingley & Aslin, 2000; 2007). There has been a lack of emphasis on lexical prosody, another essential structural element of phonological representations (Goswami, Huss, Mead, Fosker, & Verney, 2013; Tong, Tong, & McBride, 2015). However, the importance of Cantonese lexical tone sensitivity in word reading was shown in a study in which Cantonese lexical tone sensitivity predicted unique variance in Chinese word reading in Cantonese-English bilingual children (McBride-Chang et al., 2008). In relation to this finding, a recent eye-tracking study reported that oculomotor measures sensitive to lexical processing were influenced by tonal changes (Luo, Yan, Yan, Zhou, & Inhoff, 2015). Specifically, this study found lower re-fixation probabilities and shorter first pass viewing durations for neutral tone targets compared to full tone targets. These eye movement findings suggest that Chinese readers attend to lexical tones during written Chinese word processing. Consistent with the eye tracking studies, Goh et al. (2014) found evidence for early appreciation of lexical tone. Using a

mispronunciation paradigm, they found that Mandarin Chinese toddlers treated tonal variations as mispronunciations. Collectively, these studies suggest that Cantonese lexical tone plays a key role in Chinese word reading. In relation to these findings, Tong et al. (2015) proposed that Cantonese lexical tones and segmental information should be regarded as important aspects of the representation of a Chinese word.

Similarly in English, it has been suggested that lexical stress is an important aspect of lexical representations (e.g., Arciuli, Monaghan, & Seva, 2010; Ashby & Clifton, 2005; Goswami et al., 2013; Quam & Swingley, 2014). In an early eye tracking study, Ashby and Clifton (2005) found longer fixation time on words with one stressed syllable than those with two stressed syllables, even after controlling for the alphabetical length, number of syllables and word frequency. Quam and Swingley (2014) further demonstrated that children as young as 2.5 years old exploited lexical stress during word recognition. Arciuli et al. (2010) found that English children aged 5 to 12 years were sensitive to the probabilistic cues of morphemes being stressed or un-stressed, for example ‘-ing’ is usually unstressed. They proposed that stress is “a property of lexical representations”. In addition to the eye tracking studies, there is also empirical research showing that English lexical stress contributes to word acquisition (Curtin, 2010). Specifically, Curtin (2010) showed that English infants were able to identify words that had contrasting stress patterns and positions,

indicating that lexical stress is lexically encoded during word learning. Collectively, these studies suggest that, during word reading, information about stress is actively retrieved in addition to segmental information.

Thus, apart from segmental information, aspects of lexical prosody such as Cantonese lexical tone and English lexical stress may fit into the lexical quality hypothesis and automaticity theory, giving rise to possible indirect prosodic transfer pathways. Indirect prosodic transfer pathways refer to the pathways in which the contribution of prosodic sensitivity to English reading comprehension is mediated through English word reading. There are three possible indirect prosodic transfer pathways as depicted in Figure 1: (1) Cantonese lexical tone sensitivity → English lexical stress sensitivity → English word reading → English reading comprehension; (2) Cantonese lexical tone sensitivity → Chinese segmental phonological awareness → English word reading → English reading comprehension; (3) Cantonese lexical tone sensitivity → English word reading → English reading comprehension.

Empirical support for the first indirect prosodic transfer pathway comes from recent cross-language research on the perception of lexical prosody (Choi, Tong, & Singh, 2015; Tong et al., 2015). For example, Tong et al. (2015) reported a moderate correlation between Cantonese lexical tone perception and English lexical stress perception for Cantonese-English bilingual children and English monolingual adults.

Similar results were obtained by Choi, Tong, and Singh (2015), who found that Cantonese lexical tone sensitivity significantly correlated with English lexical stress sensitivity even after controlling for measures such as acoustic pitch sensitivity and working memory. Further support for this tone-stress association pathway comes from cross-language psychoacoustic studies of Chinese listeners who attend to the acoustic cue used predominantly in L1 Chinese lexical tone perception (i.e., F0), when perceiving English stress (Wang, 2008; Yu & Andruski, 2010). In addition, there is empirical evidence showing that English lexical stress sensitivity longitudinally predicts English word reading in English children (e.g., Holliman, Wood, & Sheehy, 2010).

These previous findings can be placed in the framework of the lexical quality hypothesis and automaticity theory in the following way. Well-formed suprasegmental phonological representations facilitate word retrieval, and more efficient or even automatized word retrieval aids English reading comprehension by sparing cognitive resources for higher level comprehension processes such as syntactic processing, inference making and retrieval of world knowledge (LaBerge & Samuels, 1974). Thus, it seems highly probable that Cantonese lexical tone sensitivity predicts English lexical stress sensitivity and, in turn, predicts English reading comprehension via English word reading.

In the second indirect prosodic transfer pathway, Cantonese lexical tone sensitivity predicts Cantonese segmental phonological awareness, which then predicts English word reading and hence English reading comprehension. The rationale for this pathway comes from the interactive relation between suprasegmental and segmental phonological awareness, in which the former has been proposed to enhance the later through facilitated phoneme identification (Wood et al., 2009; Zhang & McBride-Chang, 2010). This theoretical claim is supported by a recent study showing that Cantonese lexical tone sensitivity predicts Cantonese segmental phonological awareness, which in turn predicts English word reading (Zhang & McBride-Chang, 2014). Thus, the model we test in the current study will take into account the possible mediating role of Cantonese segmental phonological awareness in the relation between Cantonese lexical tone sensitivity and English reading comprehension.

The third possible indirect prosodic transfer pathway that we consider is that Cantonese lexical tone sensitivity directly predicts English word reading, in turn predicting English reading comprehension. Evidence to support this pathway comes from studies demonstrating that Mandarin Chinese lexical tone sensitivity predicts unique variance in English pseudoword (Wang et al., 2005) and real word reading (Tong et al., 2015; Wang et al., 2009). Moreover, the prediction persists even when performance on measures of segmental phonological awareness and vocabulary is

controlled (Wang et al., 2005; 2009). Taking into account the possible association between Cantonese lexical tone and English lexical stress described previously, these somewhat surprising results might in fact be accounted for by English lexical stress sensitivity, which has not been controlled in previous research. To test further the plausibility of a direct route between Cantonese lexical tone sensitivity and English word reading, and ultimately English reading comprehension, we include this pathway in the models we test.

Additionally, in the pathways that involve English lexical stress sensitivity, the prosodic transfer between lexical tone and lexical stress may be mediated by general auditory sensitivity. As noted, Chinese listeners predominantly attend to fundamental frequency when perceiving Chinese lexical tone and English lexical stress (e.g., Khouw & Ciocca, 2007; Tong et al., 2014; Tsang et al., 2011; Wang, 2008; Yu & Andruski, 2010). With the common use of fundamental frequency as an acoustic cue, the possibility arises that auditory pitch sensitivity mediates prosodic transfer. A recent study found that lexical stress perception correlated with music perception after controlling for working memory (Hausen, Torppa, Salmela, Vainio, & Sarkamo, 2013). In a neurophysiological study of lexical tone and pitch perception by Chinese listeners, both types of information processing were lateralized in the same hemisphere, suggesting a relation between lexical tone and pitch perception (Gu, Zhang, Hu, &

Zhao, 2013). The association found between tone-pitch and stress-pitch sensitivities is suggestive of a mediating role of pitch sensitivity in the tone-stress interaction. The current study will test this by adding an alternative route for tone-stress interaction in the pathways that involve the prosodic transfer between Cantonese lexical tone and English lexical stress.

The Present Study

To extend theories of reading comprehension and cross language transfer from the segmental to the suprasegmental domain, the current study evaluated the role of Cantonese lexical tone sensitivity in predicting English reading comprehension. Of particular interest were the possible pathways underlying the relation between Cantonese lexical tone sensitivity and English reading comprehension. We tested a model with one direct prosodic transfer pathway and three indirect prosodic transfer pathways from Cantonese lexical tone sensitivity to English reading comprehension (see Figure 1).

As shown in Figure 1, the direct prosodic transfer pathway (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English reading comprehension) evaluates whether Cantonese lexical tone sensitivity contributes to English reading comprehension at the prosodic dimension independent of word reading. In the direct prosodic transfer and the first indirect prosodic transfer pathways (as described below),

the possible role of general auditory sensitivity in mediating prosodic transfer is also tested.

The three indirect prosodic transfer pathways posit that Cantonese lexical tone sensitivity influences English reading comprehension via English word reading. Specifically, the first indirect prosodic transfer pathway tests the prosodic transfer hypothesis which proposes a mediating role of English lexical stress sensitivity in the relation between Cantonese lexical tone sensitivity and English word reading (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English word reading → English reading comprehension). The second indirect prosodic transfer pathway examines the possibility that Cantonese segmental phonological awareness plays a role in bridging Cantonese lexical tone sensitivity and English word reading (Cantonese lexical tone sensitivity → Cantonese segmental phonological awareness → English word reading → English reading comprehension). The third indirect prosodic transfer pathway tests the claim that there is a direct route from Cantonese lexical tone sensitivity to English reading (Cantonese lexical tone sensitivity → English word reading → English reading comprehension).

We use structural equation modeling to test the four pathways (Bentler, 2006), for a population of 133 Cantonese-English bilingual second graders. Second graders were chosen because they have acquired all six Cantonese lexical tones, although their

perceptual capacity is not yet at adult levels (Ciocca & Lui, 2003). The second graders in this study had received formal teaching in Chinese and English reading for two years and independent research has shown that second graders' Chinese and English reading proficiencies typically reach an appropriate level (McBride-Chang et al., 2011; Tong et al., 2015). Thus, second graders were tested with measures for Cantonese lexical tone sensitivity, English lexical stress sensitivity, general auditory sensitivity, Cantonese segmental phonological awareness, English word reading and English reading comprehension.

Method

Participants

A total of 133 second graders were recruited from different primary schools in Hong Kong. The same participants were tested approximately one year later. Their mean age was 6 years and 11 months ($SD = 15.2$ months) at Time 1 and 8 years and 1 month ($SD = 10.6$ months) at Time 2. All participants had no reported speech, language or hearing problems or other learning difficulties.

According to the language background questionnaires (Tong et al., 2015) completed by parents, all children were native Cantonese Chinese speakers who learned English as a second language. The mean onset age of English learning was 2.79 years ($SD = 1.54$). The children's mean frequency of use of English at home was

1.83 ($SD = 1.16$) out of 5 points in a Likert scale. At primary schools, Chinese and English had been taught as language subjects since grade 1. The schools offered eight English classes per week, each lasting 40 minutes. Thus, the children had received formal instruction of Chinese and English in primary school for at least one year at Time 1 and two years at Time 2. A majority of the mothers and fathers had graduated from secondary school (61.4% and 55.3% respectively) and a sizeable proportion from university/college (23.7% and 28.1%).

Measures

Cantonese lexical tone sensitivity. A Cantonese lexical tone identification test and a Cantonese lexical tone discrimination test were used to assess the Cantonese lexical tone sensitivity of the participants.

In the Cantonese lexical tone identification test, two monosyllables /ji/ and /fu/ were used throughout to carry the lexical tone contrasts. These monosyllables were chosen because /ji/ and /fu/ both carry lexical meanings across all six tones. For the syllable /ji/, it represented the meanings of /ji1/衣 (*clothing*), /ji2/椅 (*chair*), /ji3/意 (*the first character of spaghetti*), /ji4/兒 (*son*), /ji5/耳 (*ear*), and /ji6/二 (*two*). The six tones of the syllable /fu/ represented the meanings of /fu1/膚 (*skin*), /fu2/虎 (*tiger*), /fu3/褲 (*trousers*), /fu4/符 (*symbol*), /fu5/婦 (*woman*), and /fu6/父 (*father*).

There were originally 15 possible combinations of tone contrasts. We

narrowed this down to eight contrasts to obtain the most information from the smallest set. Based on previous studies that have examined the tonal perceptual capacity of children around this age (Ciocca & Lui, 2003; Tong et al., 2014), we used a total of eight minimal tone contrasts (T3-T6, T2-T5, T1-T3, T1-T6, T5-T6, T4-T6, T4-T5, T1-T2) for each monosyllable, with two repetitions each. Specifically, Ciocca and Lui found systematic variations in the differences in the initial F0 (T1-T2) or final F0 (T5-T2) or both (T6-T3). Among the 15 possible combinations of Cantonese lexical tone contrasts, some tone contrasts (e.g. T1-T4) could easily be discriminated even by 2-year-olds (Lee, van Hasselt, Chiu, & Cheung, 2002). These contrasts were not included as they might not represent the tonal perceptual capacity of children at 7 to 8 years of age. The Cantonese lexical tone identification test has been used successfully in assessing 5- to 11-year-old Cantonese children (Ciocca & Lui, 2003; McBride-Chang et al., 2008; Tong et al., 2014).

The participants were presented with two pictures at a time, for example, /ji1/ (*clothes*) versus /ji5/ (*ear*). They then pointed to the picture corresponding to the audibly presented target stimulus (e.g. /ji1/). Corrective feedback was given for the first three practice trials, only. One point was scored for each correct trial, with a maximum possible score of 48. Cronbach's alpha showed acceptable reliability ($=.69$).

In the Cantonese lexical tone discrimination test, an odd-one-out paradigm was used. The participants were presented with four pictures, e.g., /si1/(*lion*), /sau2/(*hand*), /sam1/(*heart*), and /sing1/(*star*), together with pre-recorded audio stimuli of the four words. They then pointed at the picture illustrating the word that carried a different lexical tone from the other three. The same eight minimal tone contrasts with the tone detection test were used in this test, each with three repetitions. One point was awarded for each correct trial, with a maximum possible score of 24. The split half reliability was .51.

English lexical stress sensitivity. The revised stress mispronunciation task developed by Holliman, Wood, and Sheehy (2010) was used to evaluate the English lexical stress sensitivity of the participants. There was one practice item and 18 test items. All items were disyllabic words.

To ensure word familiarity, we selected commonly used words from English textbooks for grades 1 to 3, and from the Wordlists for the Primary English Language Curriculum for Hong Kong Cantonese-English bilingual children (HKSAR Education Bureau, 2009). Adopting the same design used in Holliman et al. (2010), we administered all items in baseline and experimental conditions. We included the baseline condition to control for the effect of vocabulary knowledge for the test items, because the children were second language learners of English. In each trial under the

baseline condition, a pre-recorded disyllabic word with a correct stress pattern, e.g., /'spaidə/, was presented with four colored pictures illustrating the target and distracters with the same initial phoneme, e.g., *spider*, *swinging*, *snowman*, *sandwich*. The distracters were matched with the target in frequency, $p = .969$. Following the audio and visual presentation, the children then pointed at the picture that represented the word they heard.

In the experimental condition, the target words were mispronounced with a change of lexical stress and vowel quality. For the case of /'spaidə/ (*spider*), the mispronounced stimulus /spə'dɜ:/ involved a change in stress pattern, from strong-weak to weak-strong, and vowel quality with the first vowel reduced and second vowel fully articulated. The children were told that the audibly presented words were not spoken properly. They then identified the referent for the mispronunciation stimuli by pointing to one of four pictures presented. One point was awarded for each correct response in both baseline and experimental conditions. The baseline score measured children's familiarity with the words. The maximum possible score of the task was 18. Cronbach's alpha showed good reliability ($=.79$).

The baseline and experimental conditions were administered at least one month apart, in a counterbalanced order. This was to reduce any memory effects for test items.

General auditory sensitivity. A beat perception in music task was adopted from Goswami, Huss, Mead, Fosker, and Verney (2013) to evaluate participants' general auditory sensitivity. Notes with different beat structure arrangements with a pulse rate of 500 ms were presented aurally to the children in a forced choice paradigm. Each trial consisted of two auditory stimuli. Half of the trials consisted of identical series of notes whilst the other half consisted of slightly different series of notes. The different notes had a longer duration (either 100ms or 166ms) for the accented than the standard note. Ten trials (five same and five different) were set in 3/4 time, and fourteen trials (seven same and seven different) were set in 4/4 time. Among the "different" trials, seven trials had a 100ms delay in rhythm structure and five trials had a 166ms delay. The "same" and "different" trials were presented in pseudo-randomized order. The children's task was to respond whether the two presented stimuli were the same or different. One point was given for each correct item, with the maximum possible score being 24. The Cronbach's alpha reliability was .46.

Cantonese segmental phonological awareness. A Cantonese syllable and phoneme-onset deletion task was used to assess the Cantonese segmental phonological awareness. Both syllable deletion and phoneme-onset deletion task have been used successfully to assess Chinese-English bilingual children of the same age in

a previous study (Tong & McBride-Chang, 2010).

In the syllable deletion part, children were presented aurally with a tri-syllabic word (e.g. /daai6 mun4 hau2/) or pseudoword (e.g. /wit6 sem2 kwan1/). Children were then asked to orally produce the word with one syllable deleted (e.g. say /daai6 mun4 hau2/ without /mun4/, the correct answer was /daai6 hau2/). The syllable deletion occurred in various word positions, i.e., first, second or third syllable.

In the phoneme deletion part, children were presented with monosyllabic words (e.g. /goi1/) or pseudowords (e.g. /pe4/) and asked to produce the word or pseudoword with the onset phoneme deleted (e.g., say /goi1/ without the initial sound. The correct answer was /oi1/). Each part of the task started with four practice trials. There were 29 syllable deletion test items and 22 onset phoneme deletion test items. One point was awarded for each item, with a maximum possible score of 51. The Cronbach's alpha reliability was good ($=.94$).

English word reading. The English Word Reading Test and the Word Identification Subtest adopted from the Woodcock Reading Mastery Test-Revised (WRMT-R; Woodcock, 1998) were used to evaluate children's ability to read aloud printed single words. The tasks were administered in accordance with the test manual. The English Word Reading Test consisted of 60 words, with difficulties ranging from kindergarten third grade (e.g. classroom) to primary fifth grade (e.g. equipment).

Cronbach's alpha was high ($=.93$). The Word Identification Subtest consisted of 46 words, with difficulties ranging from first (e.g. house) to tenth grade or above (e.g. embassy). In both tasks, items were presented with one word at a time. Cronbach's alpha was high ($=.98$). One point was awarded for each correctly pronounced word, giving maximum possible scores of 60 and 46 respectively for the English Word Reading Test and Word Identification Subtest.

English reading comprehension. The *Gates-MacGinitie Reading*

Comprehension Test – Fourth Edition (MacGinitie, MacGinitie, Maria, & Dreyer, 2002)

was used to evaluate English reading comprehension. Children were given short passages to read silently. Each passage was followed by three to six multiple-choice questions about the passage content with the passage present. The test consisted of 85 question items, arranged in increasing level of difficulty. The items tested reading skills such as word decoding, word knowledge, sentence comprehension and passage comprehension. The test has been used extensively in studies of reading comprehension among children (e.g., Cutting & Scarborough, 2006; Kruk, Sumbler, & Willows, 2008). One score was given for each correct item, with a maximum possible score of 85. Cronbach's alpha was high ($=.98$).

Procedure

Parental and school consents were obtained prior to testing. There were two

phases of testing, roughly one year apart. At Time 1, Cantonese lexical tone sensitivity, English lexical stress sensitivity, general auditory sensitivity, Cantonese segmental phonological awareness and English word reading were assessed. At Time 2, English reading comprehension was measured for the same participants. Each task (except reading comprehension) was administered to children individually in a quiet room by trained experimenters and practice trials were given in each task to ensure complete understanding of the task instructions.

Results

Skewness and kurtosis statistics revealed that all variables had a normal univariate distribution (George & Mallery, 2010). Thus, raw scores were used for all variables in the data analyses reported below. The means, standard deviations, and correlations of all constructs are summarized in Table 1.

Preliminary Analyses

Cantonese lexical tone sensitivity was significantly correlated with English lexical stress sensitivity ($r = .47, p < .001$), English word reading ($r = .55, p < .001$) and English reading comprehension ($r = .47, p < .001$). Moreover, English lexical stress sensitivity was significantly and highly correlated with English word reading ($r = .82, p < .001$) and English reading comprehension ($r = .87, p < .001$). These significant correlations suggest that these measures share common variance for the

structural equation modeling analyses.

We note that the Cronbach's alpha reliabilities of the Cantonese lexical tone discrimination test ($\alpha = .51$) and the beat perception in music task ($\alpha = .46$) were relatively low. The low reliability of the Cantonese lexical tone discrimination test may be due to the nature of the oddity task. In the field of tone perception, the oddity task is generally considered difficult for young children because it not only requires children to have tacit knowledge of tones, but also demands that the aurally presented tonal syllable be stored and processed (e.g., Burnham, Sekiyama, Bailly, Perrier, & Vatikiotis-Bateson, 2011). Considering the evidence that 10-year-old Cantonese children can reach adult levels of accuracy in tone identification task (Ciocca & Lui, 2003), the Cantonese lexical tone discrimination test was used to avoid a ceiling effect, and it was also complementary to Cantonese lexical tone identification test. Despite the low reliability, we found that Cantonese lexical tone discrimination test correlated significantly with the Cantonese lexical tone identification test, $r = .42$, $p < .001$, even after controlling for general auditory sensitivity, $r = .40$, $p < .001$, suggesting that tone discrimination is a valid measure of tone sensitivity. In addition, this task has been successfully used in a previous psychoacoustic study that tested Cantonese children in Hong Kong (Tong et al., 2014).

As for the beat perception in music task, the low reliability could be due to

measurement error. However, this task has been used successfully in measuring children's general auditory sensitivity (Goswami et al., 2012). Consistent with Goswami et al., we found an association between general auditory sensitivity and English reading comprehension, $r = .27, p < .01$. Schmitt (1996) pointed out that "when a measure has other desirable properties, such as meaningful content coverage of some domain and reasonable unidimensionality, this low reliability may not be a major impediment to its use" (p. 352). Thus, we believe that the Cantonese lexical tone discrimination test and the beat perception in music task are suitable and appropriate measures of Cantonese lexical tone sensitivity and general auditory sensitivity respectively. Also, any measurement error was taken into account by our use of structural equation modeling.

Testing Prosody Transfer: Structural Equation Modeling

Structural equation modeling was used to evaluate (a) whether Cantonese lexical tone sensitivity predicts English reading comprehension and (b) the possible pathways underlying the relation between Cantonese lexical tone sensitivity and English reading comprehension. For this, an integrated model consisting of all possible pathways, as shown in Figure 1, was evaluated.

The latent variable structural equation modeling of the covariances matrix was conducted with LISREL 8.80 (Joreskog & Sorbom, 2007). With regard to the latent

factors, Cantonese lexical tone sensitivity was modeled with two indicators, namely Cantonese lexical tone identification and Cantonese lexical tone discrimination.

General auditory sensitivity was modeled with beat perception in music. English lexical stress sensitivity was modeled with revised stress mispronunciation. English word reading was modeled with the composite score of English word identification and English word reading test, because these tasks were highly correlated, $r = .93$, $p < .001$, suggesting that these two tasks assess the same component of word reading ability. Cantonese segmental phonological awareness was modeled with the composite score of Cantonese syllable and phoneme deletion tasks. English reading comprehension was modeled with the English reading comprehension task.

The goodness of fit of the data to the model was examined by five goodness-of-fit indices: Chi-square, comparative fit index (CFI), normed fit index (NFI), non-normed fit index (NNFI), and root mean square error of approximation (RMSEA). According to Hu and Bentler (1999), a value of .95 or above for CFI, NFI and NNFI, and .06 or below for RMSEA denotes a good fit model. The model fitted the data well, as reflected by the five goodness of fit indices, $\chi^2(10, N = 133) = 5.67$, CFI = 1.00, NFI = .99, NNFI = 1.01, RMSEA < .001. This model predicted 79% of variance in English reading comprehension. The standardized estimates of path weights are summarized in Figure 2. The significance of each of the four proposed

pathways is reported below.

Evaluating the Four Proposed Pathways: Direct and Indirect Prosodic Transfer

Pathways

To test the direct and indirect pathways, mediation analysis was conducted by fitting the model to the data using LISREL. We computed 95% bias-corrected bootstrap confidence interval (BCI) with 1000 bootstrap samples for each mediation effect following the method proposed by Lau and Cheung (2010). According to Lau and Cheung, the bias in the bootstrapped sampling distribution can be corrected by using bias-corrected bootstrap confidence intervals. Specifically, they noted that “Adjustment of the bootstrapped sampling distribution ensures the accuracy of inferences made about the true population value of the mediation effect. The bias-corrected bootstrap method thus provides more accurate confidence intervals than those methods without such bias correction, such as the percentile method.” (p. 13).

We first bootstrapped the covariance matrices with 1000 bootstrap samples and 100 sample fractions. We then generated parameter estimates using the 1000 covariance matrices and tested 1000 replications of the model. In the next step, we calculated the product terms of the mediation pathways in the 1000 samples. Then, the number of bootstrap mediation effects which were less than or equal to the original

sample mediation effects were counted. Based on this number, we obtained the biasing constant and then the bias-corrected bootstrap confidence interval at upper and lower endpoints. In total, we obtained the 95% bias-corrected bootstrap confidence interval with 1000 bootstrap samples for each mediation effect. The unstandardized estimates (b) and estimated standard error (SE) for the path coefficient were obtained from the sample. A ratio of the unstandardized estimates b to the SE larger than 1.96, indicates that the path is statistically significant (Bentler, 2006).

As shown in Figure 2, the direct prosodic transfer pathway was significant (Cantonese lexical tone sensitivity \rightarrow English lexical stress sensitivity \rightarrow English reading comprehension), $b = 9.58$, $SE = .26$, $p < .001$, 95% $BCI = (6.47, 13.20)$. Additionally, the first indirect prosodic transfer pathway was also significant (Cantonese lexical tone sensitivity \rightarrow English lexical stress sensitivity \rightarrow English word reading \rightarrow English reading comprehension) with $b = 3.43$, $SE = .01$, $p < .001$, 95% $BCI = (1.71, 7.32)$. Related to these two pathways, the route from general auditory sensitivity to English lexical stress sensitivity was significant, $b = 2.18$, $SE = .08$, $p < .001$. In contrast, the second indirect prosodic transfer pathway from Cantonese segmental phonological awareness to English reading comprehension was not significant with $b = -0.20$, $SE = .13$, $p = .124$, 95% $BCI = (-5.73, 2.02)$. However, there was a significant fit for the third indirect prosodic transfer pathway (Cantonese

lexical tone sensitivity → English word reading → English reading comprehension)

with $b = 4.01$, $SE = .37$, $p < .001$, 95% $BCI = (0.74, 10.93)$.

Relative Strength of the Direct Prosodic Transfer Pathway and the First Indirect

Prosodic Transfer Pathway

To evaluate the relative contributions of the direct prosodic transfer pathway (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English reading comprehension) and the first indirect prosodic transfer pathway (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English word reading → English reading comprehension) to English reading comprehension, we conducted a mediation analysis on the first indirect prosodic transfer and the direct prosodic transfer pathways, which differed only in English word reading as shown in Figure 3.

The mediating effect was estimated by the difference in the product of coefficients of the two pathways (MacKinnon, Fairchild, & Fritz, 2007). In Figure 3, the coefficient between Cantonese lexical tone sensitivity and English lexical stress sensitivity is labeled as a ($a = 2.42$), and that between English lexical stress sensitivity and English word reading as b ($b = 1.77$), and the route between English word reading and English reading comprehension as c ($c = 0.8$). The coefficient of the route between English stress sensitivity and English reading comprehension is labeled as d ($d = 3.96$). The coefficients were obtained from the same model (Figure 2) we tested.

For the mediation analysis, we did not include the variables outside the direct pathway and the first indirect pathway, for example Cantonese segmental phonological awareness. One reason was that the coefficients of the routes in the direct and the first indirect pathways, that is a , b , c and d , had already taken into account the influence of other latent variables (e.g., Cantonese segmental phonological awareness).

To determine whether English lexical stress sensitivity has a larger direct than indirect contribution to English reading comprehension, we evaluated the relative contributions of the direct pathway and the first indirect pathway by the difference in their product coefficients, that is $abc-ad$. In this case, the difference in the coefficients of the two pathways, that is $abc-ad$, is $(2.42 \times 1.77 \times 0.8) - (2.42 \times 3.96) = -6.15$.

According to MacKinnon et al., our negative value of -6.15 for the difference between the coefficients means that the direct prosodic transfer pathway has a larger contribution than the first indirect prosodic transfer pathway to English reading comprehension.

Our results suggest that the relation between Cantonese lexical tone sensitivity and English reading comprehension is partly mediated by English lexical stress sensitivity, through both direct and indirect prosodic transfer pathways. The direct prosodic transfer pathway (Cantonese lexical tone sensitivity \rightarrow English lexical stress sensitivity \rightarrow English word reading) had a larger relative contribution than the indirect

prosodic transfer pathway (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English word reading → English reading comprehension) to English reading comprehension. In addition, the prosodic transfer between tone and stress was partly mediated by general auditory sensitivity.

Discussion

The current study sought to examine the role of Cantonese lexical tone sensitivity in predicting English reading comprehension. In addressing this issue, we tested an integrated model incorporating direct prosodic transfer pathway (i.e., stress mediated pathway only) and indirect prosodic transfer pathways (i.e., word reading-mediated pathways). The structural modeling analysis revealed that this model fitted the data well and predicted 79% of variance in English reading comprehension.

Furthermore, Cantonese lexical tone sensitivity significantly predicted English reading comprehension and this prediction was mediated by either English lexical stress sensitivity or English word reading, or both. In addition, English lexical stress sensitivity made a larger direct than indirect (English word reading mediated) contribution to English reading comprehension. These results are discussed in terms of prosodic transfer and theoretical accounts of English reading comprehension.

English Lexical Stress Links Cantonese Lexical Tone with English Reading

Comprehension: Prosodic Transfer

These results suggest an association between English lexical stress sensitivity and Cantonese lexical tone sensitivity, and also a mediating role of English lexical stress sensitivity in the relation between Cantonese lexical tone sensitivity and English reading comprehension. Concerning the nature underlying the prosodic transfer between Cantonese lexical tone and English lexical stress, our structural equation model analysis revealed two routes: the direct route and also an indirect route by general auditory sensitivity. These results support our hypothesis that the prosodic transfer between Cantonese lexical tone and English lexical stress is partly driven by their acoustic features, and is also partly driven by the underlying phonological processing component of these two aspects of lexical prosody. In other words, our findings suggest that prosodic transfer is both acoustically and phonologically driven.

The prosodic transfer from Chinese lexical tone sensitivity to English lexical stress sensitivity is an essential constituent of the Cantonese lexical tone sensitivity-English reading comprehension relation, by virtue of the association between English lexical stress sensitivity and Cantonese lexical tone sensitivity, and the direct (English lexical stress sensitivity → English reading comprehension) and indirect (English lexical stress sensitivity → English word reading → English reading comprehension) contributions of English lexical stress sensitivity to English reading comprehension.

English Lexical Stress as a Direct Mediator of Cantonese Lexical Tone Transfer to English Reading Comprehension

Our analysis revealed a significant direct prosodic transfer pathway in which Cantonese lexical tone sensitivity was directly associated with English lexical stress sensitivity, which in turn predicted English reading comprehension. Such a significant direct prosodic transfer pathway provides further evidence of the role of prosody, in particular lexical stress, in English reading comprehension (Kuhn et al., 2010). As noted in the introduction, prosody may contribute to reading comprehension through facilitating speech and syntactic parsing (Ramus, Hauser, Miller, Morris, & Mehler, 2000; Wheeldon & Lahiri, 1997). It may also support the storage of information in auditory memory and provide cues to guide the analysis of discourse information (Smith, 2004; Swets, Desmet, Hambrick, & Ferreira, 2007). Specifically, lexical stress may have a unique role in the identification of word boundaries and segmentation of incoming lexical units. For example, there is compelling evidence showing that strong-weak syllable stress pattern can be used as an effective cue in locating word beginnings and guide segmentation (e.g., Cutler & Norris, 1988; Vroomen, Tuomainen, & Gelder, 1998).

Placing this into the current context, the direct prosodic transfer pathway may arise from the prosodic contribution of lexical stress sensitivity to reading

comprehension, especially in sparing cognitive resources from low level processes such as segmentation. The discovery of a direct prosodic pathway that is independent of word reading may partly account for previous findings in which poor comprehenders have difficulties in reading comprehension but not in word reading (e.g., Cain & Oakhill, 2006; Tong, Deacon, Kirby, Cain, & Parrila, 2011). In other words, the poor comprehenders may have problems on suprasegmental processing rather than word retrieval.

English Lexical Stress as an Indirect Mediator of Cantonese Lexical Tone

Transfer to English Reading Comprehension

One plausible way in which English lexical stress sensitivity contributes to English reading comprehension among Cantonese-English bilinguals is by facilitating word retrieval. Consistent with Holliman et al. (2010), the current study found that English lexical stress sensitivity predicted English word reading among the Cantonese-English bilingual children. The current study extends that finding by showing English lexical stress sensitivity plays a role not only for L1 stress-timed language speakers, but also for bilingual speakers whose L1 involves the lexical encoding of another type of prosodic information, that is tones. Critically, we have extended the findings of Holliman et al. (2010) to show that lexical stress influences not just simple word decoding, but also higher-level text reading comprehension.

These findings suggest a place for suprasegmental information in the lexical quality hypothesis. For example, Cantonese-English bilinguals might have well-formed suprasegmental phonological representations of English words as a result of their sensitivity to English lexical stress. This will help the ease of retrieval of lexical information. Consistent with the assumption of the automaticity theory, this would mean that Cantonese-English bilingual children would devote fewer cognitive resources to low level word decoding and greater resources would become available for high-level comprehension processes. Collectively, the current findings provide empirical support for prosodic transfer, and suggest that English lexical stress sensitivity plays a mediating role between Cantonese lexical tone sensitivity and English reading comprehension by facilitating English word decoding.

Relative Contributions of Stress to English Reading Comprehension: Direct

Route vs. Word Mediation

Comparing the direct and indirect prosodic transfer pathways, the current results indicate that the direct pathway (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English reading comprehension) has a larger relative contribution than the first indirect pathway (Cantonese lexical tone sensitivity → English lexical stress sensitivity → English word reading → English reading comprehension) to English reading comprehension. This may be due to the low status

of lexical stress in English: Examination of English corpora reveals only a very few English words that are contrastive in stress (Cutler, 2012). In other words, lexical stress has a smaller linguistic function in word distinction than do vowels and consonants.

To place this finding within a lexical quality account, it would suggest that, although the phonological representational qualities of English words are defined by both segmental and stress information, the former might have a more prominent role than the latter. Thus, it is not unreasonable that sensitivity to lexical stress contributes little to English reading comprehension via lexical retrieval, and instead contributes to reading comprehension largely on the prosodic dimension, which has been identified as an important aspect of reading fluency closely related to reading comprehension (Kuhn et al., 2010). In addition to this, given that a majority of English words are initial stressed, lexical stress may be an effective cue in aiding segmentation, contributing to English reading comprehension in this way.

Consistent with a previous study (Wang et al., 2009), we found a direct route from Cantonese lexical tone sensitivity to English word reading. This is somewhat surprising, as we originally conceived that the direct route found in Wang and colleagues' study was in fact mediated by English lexical stress sensitivity. Auditory sensitivity might offer a possible account for this finding (Wang et al., 2005; 2009).

Specifically, Reed (1989) suggested a link between auditory sensitivity and English reading, by virtue of the fact that reading disabled children showed impaired auditory sensitivity when compared with normal reading children. Wang et al. proposed that auditory sensitivity might mediate the relation between Mandarin Chinese lexical tone sensitivity and English word reading. Our results support this hypothesis by showing that the association between Cantonese lexical tone sensitivity and English reading comprehension is partially mediated by general auditory sensitivity, and that both Cantonese lexical tone sensitivity and English lexical stress contributed to English word reading.

Alternatively, phonological encoding might account for this pathway. Unlike the pure tones used in the auditory sensitivity tasks, Cantonese lexical tones are phonologically encoded as a part of lexical representation in Chinese (Tong et al., 2015). The Cantonese lexical tone and English word reading tasks may have probed common skills involved in the encoding of phonological constituents in English and Cantonese.

Theoretical and Clinical Implications

The current study is of substantial theoretical importance as it extends the notion of lexical quality hypothesis and also how automaticity influences reading from the segmental to the suprasegmental domains. Specifically, the phonological

specificity in the lexical quality hypothesis has to date been restricted to segmental information. Here, we demonstrate that a new suprasegmental dimension - lexical tone and stress – should be included as part of the phonological representation of a word.

We found that the transfer of Cantonese lexical tone sensitivity to English reading comprehension can be through both English lexical stress sensitivity and English word reading. This finding suggests that the lexical quality hypothesis be expanded to accommodate the suprasegmental dimensions in both L1 and L2, at least for Cantonese-English bilingual readers. Specifically, for bilingual readers, the phonological systems involved in encoding and specifying L1 Cantonese and L2 English phonological representations may be partially overlapping, at least for the suprasegmental dimension, as suggested by the current findings, as well as a previous perceptual study (Tong et al., 2015).

We have also provided empirical evidence that English lexical stress sensitivity mediates the relation between Cantonese lexical tone sensitivity and English reading comprehension. This confirms the transfer of lexical prosodies across languages. Further, our findings showing the prediction of English reading comprehension by English word reading among Cantonese-English bilinguals suggest that the lexical quality hypothesis and automaticity theory could be extended to

Chinese-English bilingual readers. Specifically, English L2 reading comprehension may depend on the well formed suprasegmental phonological representation in both L1 and L2, and this may give rise to higher lexical quality, making word retrieval more efficient (or even automatized) to support L2 reading comprehension.

In addition to its theoretical significance, the current study suggests the potential of lexical tone sensitivity as an early indicator of English reading difficulties among bilingual children. For clinical assessment, this would be an alternative or additional measure to segmental phonological awareness and word reading. Also, these findings imply that the basis of L2 reading difficulties may be grounded in prosody instead of word retrieval. This may encourage teachers or clinicians to consider the incorporation of suprasegmental speech or prosodic training into traditional teaching methodologies for English reading comprehension. The efficacy of this approach should be explored in future work.

Limitation and Future Direction

The present study is the first to demonstrate the role of lexical prosody in bilingual children's English reading comprehension. It should be noted that only lexical prosody, that is Cantonese lexical tone and English lexical stress, were assessed. There are other aspects of prosody, such as affective prosody and pragmatic prosody. A promising extension of the current study would be to evaluate further the

role of prosody in reading comprehension by including different aspects of prosody.

Also, we included only one measure of general auditory sensitivity and English lexical stress sensitivity, that is the beat perception in music task and the revised stress mispronunciation task, respectively. In particular, the general auditory sensitivity measure here was largely sensitivity to music pitch. Future studies should include multiple measures of general auditory sensitivity and English lexical stress sensitivity. For instance, the general auditory sensitivity measures should extend beyond fundamental frequency and include other acoustic parameters. Similarly, the productive form of the stress task should be included to holistically represent English stress sensitivity. Also, future studies may evaluate whether general auditory sensitivity and English lexical stress sensitivity correlate with other prosodic features such as intonation, thereby mediating their possible relation with reading comprehension.

A final limitation was that we tested English reading comprehension only when our participants were in Grade 2. This decision was based on our pilot testing of first-graders suggesting that even the lowest level of *Gates-MacGinitie Reading* comprehension task was too difficult for Cantonese-English bilingual first graders. Thus, there is a need for future research to consider designing an English reading comprehension task that is suitable to test younger bilingual readers. In addition, it

should be noted that all suprasegmental and segmental measures (i.e., Cantonese lexical tone sensitivity and English lexical stress sensitivity and segmental phonological awareness) were tested in Grade 1 only. Future research should consider assessing both segmental and suprasegmental performance, as well as reading comprehension, across different times, to identify developmental change and the possible causal relationship between suprasegmental sensitivity and reading comprehension.

In conclusion, the current study has demonstrated the role of Cantonese lexical tone sensitivity in predicting English reading comprehension. In relation to this, we found that Cantonese lexical tone sensitivity predicted English word reading, and then English reading comprehension, even taking into account segmental phonological awareness and stress sensitivity. Additionally, we have also identified a mediator, English lexical stress sensitivity, which links with Cantonese lexical tone sensitivity and contributes to English reading comprehension both directly and indirectly through English word reading. These results suggest that lexical prosody, such as Cantonese lexical tone and English lexical stress, plays a key role in Cantonese-English bilingual reader's English reading comprehension, and should be incorporated in theoretical models of reading comprehension development.

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Table 1

Means, Standard Deviations and Correlations of all Variables

Variables (maximum possible score)	1	2	3	4	5	6
1. Cantonese tone sensitivity (72)	-					
2. Auditory sensitivity (24)	.17 [†]	-				
3. English stress sensitivity (18)	.47 ^{***}	.33 ^{***}	-			
4. Cantonese segmental phonological awareness (51)	.59 ^{***}	.15	.56 ^{***}	-		
5. English word reading (106)	.55 ^{***}	.29 ^{**}	.82 ^{***}	.62 ^{***}	-	
6. English reading comprehension (85)	.47 ^{***}	.27 ^{**}	.87 ^{***}	.58 ^{***}	.83 ^{***}	-
<i>Mean</i>	46.93	13.17	9.78	31.52	15.66	49.57
<i>SD</i>	6.41	3.26	3.86	10.35	12.27	26.92

Note. N = 133. [†] $p = .053$. ^{**} $p < .01$. ^{***} $p < .001$.

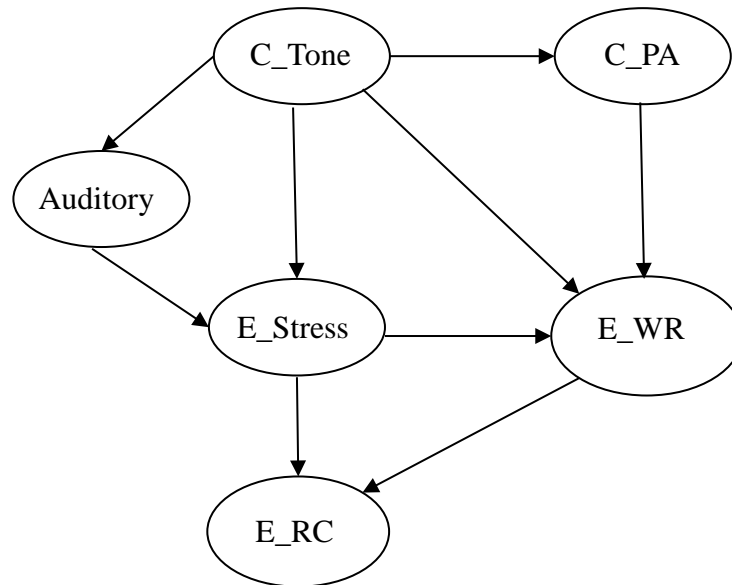


Figure 1. An integrated model for the relation between Cantonese lexical tone sensitivity and English reading comprehension. C_Tone = Cantonese lexical tone sensitivity; E_Stress = English lexical stress sensitivity; Auditory = general auditory sensitivity; CPA = Cantonese segmental phonological awareness; E_WR = English word reading; E_RC = English reading comprehension.

The first indirect prosodic transfer pathway is Cantonese lexical tone sensitivity → English lexical stress sensitivity → English word reading → English reading comprehension. The second indirect prosodic transfer pathway is Cantonese lexical tone sensitivity → Cantonese segmental phonological awareness → English word reading → English reading comprehension. The third indirect prosodic transfer pathway is Cantonese lexical tone sensitivity → English word reading → English reading comprehension. The direct prosodic transfer pathway is Cantonese lexical tone sensitivity → English lexical stress sensitivity → English reading comprehension.

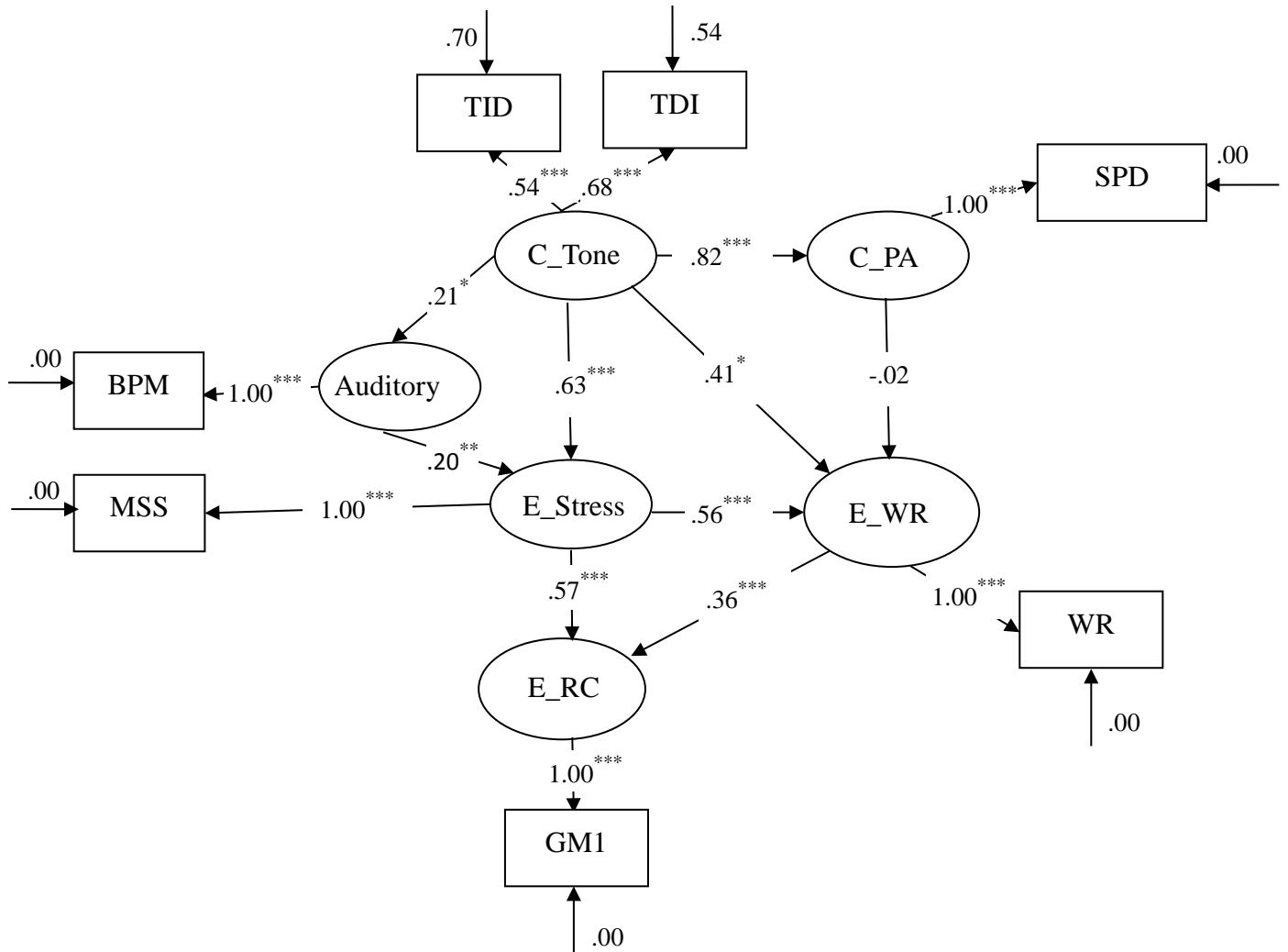


Figure 2. Integrated Model for the relation between Cantonese lexical tone sensitivity and English reading comprehension. The numerical values represent the standardized factor loadings. The observed variables, namely Cantonese lexical tone identification test (TID), Cantonese lexical tone discrimination test (TDI), revised stress mispronunciation task (MSS), Cantonese syllable/phoneme deletion task (SPD), English word reading test (WR), beat perception in music task (BPM) and Level One of the *Gates-MacGinitie Reading Comprehension Test–Fourth Edition* (GM1) are represented by the rectangular boxes. * $p < .05$. ** $p < .01$. *** $p < .001$.

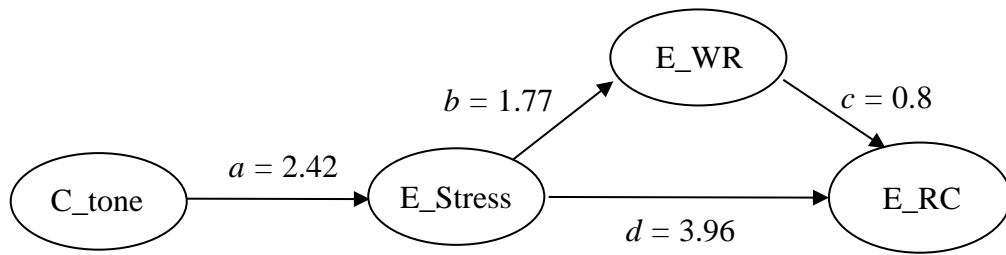


Figure 3. The first indirect (abc) and direct (ad) pathways by which Cantonese lexical tone sensitivity contributed to English reading comprehension. “ a ”, “ b ”, “ c ” and “ d ” represent the coefficients of their designated routes.

C_tone = Cantonese lexical tone sensitivity. E_Stress = English lexical stress sensitivity. E_WR = English word reading. E_RC = English reading comprehension.