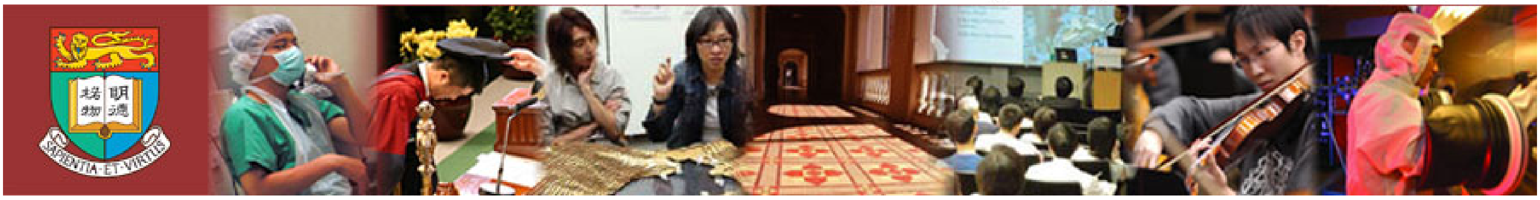

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Suprasegmental Speech Perception, Working Memory and Reading Comprehension in Cantonese-English Bilingual Children

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Abstract

This study set out to examine (a) lexical tone and stress perception by bilingual and monolingual children, (b) interrelationships between lexical pitches perception, general acoustic mechanism and working memory, and (c) the association between lexical tone awareness and Chinese text reading comprehension. Experiment 1 tested and compared the perception of Cantonese lexical tones, English lexical stress and nonlinguistic pitch between Cantonese-English bilingual and English monolingual children. The relationships between linguistic pitch perception, non-linguistic pitch perception and working memory were also examined among Cantonese-English bilingual children. Experiment 2 explored the relationship between Cantonese tone awareness and Chinese text reading comprehension skills. Results of this study illustrate differential performances in tone perception but similar performances in stress perception between bilinguals and monolinguals. In addition, inter-correlations were found between linguistic pitches perception, general acoustic mechanism, working memory and reading comprehension. These findings provide new insight to native and non-native perception of lexical pitches, and demonstrate an important link that exists between lexical tone awareness and reading comprehension.

Keywords: Bilingualism, suprasegmental speech perception, lexical tone, lexical stress, nonlinguistic pitch, working memory, reading comprehension, prosody

Suprasegmental Speech Perception, Working Memory and Reading Comprehension in Cantonese-English Bilingual Children

Models of bilingual speech perceptions have been largely focused on describing the structures and processes involved in perceiving segmental sounds (i.e. vowels and consonants which speech is composed of). Some examples of the models are Speech Learning Model (SLM) (Flege, 1986), Native Language Magnet Model (NLM) (Kuhl, 1991) and Perceptual Assimilation Model (PAM) (Best, 1994). These models share the same presumption that perception of non-native segmental contrasts is strongly influenced by native speech system (Best et al., 2001). However, substantial differences exist between these models, especially with their presumptions of different native perceptual frameworks. On one hand, NLM and PAM posit that speech perception shares the same general-purpose auditory processes with non-speech sound perception (Best et al., 2001). On the other hand, SLM remains neutral on whether the perceptual mechanism is general (use of general-purpose-acoustic mechanism for processing) or specialized (linguistic processing specialized in phonemes) (Flege, 1986). Another substantial difference between the models is the type of information which operates the perceptual mechanism. NLM assumes perceptual mechanism is driven by acoustic information (Kuhl, 1991), whereas PAM posits the role of articulatory information in operating perceptual mechanism (Best, 1995; Best et al., 2001).

While growing number of studies evaluating these models about bilingual segmental speech perception has been evident in the past decades (Best et al., 2001; Bosch & Sebastian, 1997; Browman & Goldstein, 1986; Flege, 1986; Kuhl & Grieser, 1989; Lively, 1993; Werker et al., 1981), little attention has been paid to suprasegmental speech perception, especially in bilinguals (Dupoux, Peperkamp, & Nuria, 2010; Dupoux, Peperkamp, & Sebastian-Galles, 1999; Yu & Andruski, 2010). Lexical tone and lexical stress are linguistic pitch patterns used in Cantonese and English respectively to distinguish meanings between words having the same segmental features (phonemes). Studying Cantonese-English bilinguals is of paramount importance as it would enable us to compare the two related but distinct linguistic pitches (lexical tone and lexical stress). Therefore, the current study first aims at examining the perception of lexical tones and lexical stress by Cantonese-English bilingual children and English monolingual children.

Lexical Stress Perception

There have been a great number of studies examining monolinguals' native and non-native lexical stress perception (Bosch et al., 2009; Jusczyk, Cutler, & Redanz, 1993; Jusczyk & Thompson, 1978; Pons & Bosch, 2007; Sansavini, Bertoncini, & Giovanelli, 1997). For example, Bosch et al. (2009) explored lexical stress perception skills of Spanish (language with lexical stress) and French (language without lexical stress) monolingual infants. They found that by 9 months old, Spanish infants, whose lexical stress perception was fully adapted to the native language at abstract phonological level, spontaneously encoded lexical stress at a phonological level when listening to speech. However, French infants' lexical stress perception was only at the acoustic level, in which they did not encode lexical stress when listening to speech (Spanish), but retained the capacity to detect lexical stress contrasts acoustically.

In related work, Dupoux, Peperkamp, and Sebastian-Galles (2010) examined whether French-Spanish bilinguals would demonstrate lexical stress perceptual ability at a similar level to Spanish monolinguals, French monolinguals, or intermediate between them. They showed a bimodal distribution of performances, in which the simultaneous bilinguals either showed French-like (French later learners of Spanish) or Spanish-like (native) performance. Performance of Spanish-dominant bilinguals was the same as Spanish monolinguals, while performance of French-dominant bilinguals resembled French late learners of Spanish. These results were compatible with a previous study on adult French-Spanish bilinguals' lexical stress perception (Peperkamp, Dupoux, & Sebastian-Galles, 1999). This supports an early claim by Cutler et al. (1989) that simultaneous bilinguals could only process one language in native-like fashion, at least in the area of phonological perception.

Although lexical stress perception and its mechanism have been explored both in monolinguals (e.g., Bosch et al., 2009; Pons & Bosch, 2007), and in bilinguals (e.g., Dupoux et al., 1999; Dupoux et al., 2010; Yu & Andruski, 2010), most of the studies investigating lexical stress perception among stress-non-stress bilinguals used French (monolingual or bilingual) speakers as subjects, whilst very few studies have examined lexical stress perceptual abilities by bilingual speakers whose native languages (L1) are tone languages. Yu and Andruski (2010) took an important step in examining the perception of English lexical stress in English-Mandarin bilingual speakers. They found that English monolinguals and English-Mandarin bilinguals depended on different acoustic cues, benefited differently by lexical and segmental information, and had different stress (trochaic stress and iambic stress) preferences. They concluded that language background affected lexical stress perception. Yu and Andruski (2010)'s study provides a starting point for our investigation of Cantonese-English bilingual children's perception of English stress. Although Cantonese and Mandarin exhibit some similarities especially in the use of lexical tone to distinguish among different lexical items, there are substantial differences in their lexical tone systems. Mandarin consists of four lexical tones, while Cantonese consists of nine tones (six contour tones and three entering tones). In addition, most Cantonese children begin learning English at the age of three, which is very different from Mandarin children, who learn English at a later age. It is possible that, due to different lexical tone systems, and the age to start acquiring English, Mandarin-English bilinguals and Cantonese-English bilinguals employ different mechanisms for perceiving English lexical stress. Studies of Cantonese-English bilingual children's perception of lexical stress are needed to explore this possibility.

Lexical Tone Perception

A majority of the early studies of lexical tone perception focused on monolinguals (e.g., Klein, Zatorre, Milner, & Zhao, 2001; Lee, Douglas, & Lee, 1996; Mattock & Burnham, 2006; Wang, Jongman, & Sereno, 2001) from tonal and non-tonal language backgrounds. Mattock and Burnham (2006) investigated non-native perception of Thai tone contrasts by Chinese (tone language) and English (non-tone language) infants, and showed maintenance of perceptual discrimination of lexical and non-lexical tone contrasts across age in Chinese infants. On the contrary, despite low statistical power due to a small sample size in longitudinal study, English infants' lexical tone discrimination declined while that of non-lexical tone did not change across age. Mattock and Burnham (2006) attributed these results to perceptual reorganization in English infants for lexical tones at phonological level but not general acoustic level. In other words, perceptual reorganization attenuated English infants' ability to discriminate lexical tones due to lexical tones' linguistic irrelevance in English. The level of perceptual reorganization was at phonological level but not acoustic level, revealed by English infants' maintenance of non-lexical tone performance across age.

Lee, Douglas, and Lee (1996) examined how experience of one tone language (Cantonese/Mandarin) influenced perception of another tone language (Mandarin/Cantonese respectively). They revealed better discrimination of Mandarin lexical tone by Cantonese speakers than English speakers. The authors attributed the outperformance of Cantonese speakers to English speakers in Mandarin tone perception to the acquisition of general abilities of tone discrimination as influenced by their Cantonese language experience. However, such a claim might be confounding as the authors did not exclude the possibility of Mandarin exposure to, or even Mandarin learning by their Cantonese subjects, which was not uncommon among local Cantonese university students (participants in their study were all students from the Chinese University of Hong Kong). An even more interesting result which the authors failed to provide a viable explanation for was that Mandarin and English speakers performed similarly in Cantonese tone perception. A question naturally arises: Do Mandarin and English speakers share similar processes, or depend on similar acoustic cues for their perception of Cantonese tone? Before examining such question contrasting non-native tone perception (Cantonese) between tone speakers (Mandarin) and non-tone speakers (English), we would first like to address the fundamental differences between native tone perception (Cantonese) by Cantonese-English bilingual speakers and non-native tone perception (Cantonese) by English speakers.

Only few studies of lexical tone perception involved bilinguals who were exposed to both tone and non-tone languages. Wang et al. (2004) discovered left-hemisphere advantage for Mandarin listeners during lexical tone perception, supporting the functional hypothesis (Gandour et al., 2003; Wong, 2002), in which lateralization of processing is functionally determined. If the pitch (lexical tone) carries linguistic information (which is true for Mandarin listeners), left-hemisphere specialization of lexical tone perception will take place. The study of Wang et al. (2004) also rejected the opposing view, namely the acoustic hypothesis (Robin, Tranel, & Damasio, 1990), in which lexical tone is processed by all humans using general pitch processing mechanism lateralized in right hemisphere. Wang et al. (2004) also revealed that bilingual English-Mandarin speakers who acquired Mandarin as second language (L2) showed the same left-hemispheric lexical tone processing as Mandarin listeners, and that no hemispheric predominance was found in English listeners. Putting aside the unexplored domain of neurological activation of lexical tone perception by Cantonese-English bilinguals, no research to date has been done to compare lexical tone perception abilities between Cantonese-English bilinguals and English monolinguals. The importance in exploring the perception of lexical tone and lexical stress in Cantonese-English bilingual children, however, should not be underestimated. Such an investigation may provide insight into the perceptual processing of lexical tone and lexical stress, specifically on whether they share the same perceptual cues or cognitive processes.

Linguistic Pitch v.s. Non-linguistic Pitch

Lexical tone and lexical stress are linguistic pitch variations used in Cantonese and English respectively to distinguish lexicons sharing the same array of phonemes. Lexical tone is distinguished by variations in level or contour of fundamental frequency (pitch) of syllables (Gandour & Harshman, 1978). Lexical stress primarily consists of pitch variations used in syllable-level (Mok & Qin, 2012), although speakers of different languages rely on different acoustic dimensions (pitch contour, vowel duration, vowel quality, to name but a few) to process lexical stress in different contexts (Yu & Andruski, 2010). In this study, non-linguistic pitch refers specially to pitch variations in non-speech context, such as musical tone.

The relationship between perception of linguistic and non-linguistic pitches has been extensively investigated by brain-imaging studies (e.g., Abrams et al., 2011; Gu et al., 2013; Koelsch et al., 2002; Rauschecker & Scott, 2009; Rogalsky et al., 2011; Schon et al., 2010;

Tillmann et al., 2003). Gandour et al. (1998) revealed that linguistic and non-linguistic pitches were processed differently by native tone language speakers: Linguistic pitch was processed phonologically in left hemisphere language regions while non-linguistic pitch was processed in a more general acoustic mechanism with less left-hemispheric activation. Nevertheless, it does not mean linguistic and non-linguistic pitches are processed by completely separated mechanisms. In fact, numerous functional resonance imaging studies (e.g., Abrams et al., 2011; Koelsch et al., 2002; Rauschecker & Scott, 2009; Rogalsky et al., 2011; Schon et al., 2010; Tillmann et al., 2003) provided converging evidence that perception of speech and music shared at least small parts of overlapping neural regions. The regions include anterior, posterior and superior temporal areas, temporoparietal areas, and inferior frontal areas, even Wernicke's and Broca's areas in the left hemisphere which were considered specific to language. Contradiction existed among different types of studies yielding dissociation (brain damage studies) and association (normal brain imaging studies) of speech-music perception (Hausen et al., 2013), and of the tone language used and population to be tested. Patel (2012) took one step further in proposing the Resource Sharing Framework to explain this contradictory phenomenon. In this framework, brain mechanisms are shared by musical and linguistic processing, while in the long term memory, representations of music and speech are separate. Damage to one of these separated representations in long term memory will lead to specific deficit either in musical or linguistic processing (dissociation). In normal brain, music and language share brain mechanisms in similar cognitive operations (association). Such theory of resource sharing framework was consistent with the study by Hausen et al. (2013) showing the association between music and speech prosody perception.

The association between linguistic (lexical) and nonlinguistic (acoustic) pitch processing may be even stronger in the Cantonese population. A recent mismatch negativity (MMN) study by Gu, Zhang, Hu, and Zhao (2013) revealed left hemispheric lateralization in both lexical pitch processing and acoustic pitch processing. Their results were in contrary to other studies indicating right hemispheric lateralization in acoustic pitch processing in non-tonal speakers (Gandour et al., 1998) and tonal speakers (Gandour et al., 1998; Ren et al., 2009; Xi et al., 2010). To explain this phenomenon, Gu et al. (2013) proposed the lateralization-carryover hypothesis, in which acoustic pitch processing was modulated to left hemispheric lateralization due to frequent usage of pitch information in speech. However, two previous MMN studies (Ren et al., 2009; Xi et al., 2010) on acoustic pitch processing in Mandarin speakers did not indicate significant left hemispheric lateralization. This could be explained by the nature of tone system of the tone language being tested. Specifically, the tone system of Mandarin was simpler than Cantonese. Due to a more complex tone system, Cantonese speakers are required to perceive finer differences in fundamental frequencies for identification of tone category. As a result, Cantonese speakers experience a stronger lateralization-carryover effect from lexical pitch processing to acoustic pitch processing when compared with Mandarin speakers (Gu et al., 2013).

To further explore the perceptual processes for linguistic and non-linguistic pitches, non-linguistic pitch perception is also tested and compared with linguistic pitch perception in the present study. Also, we will control for possible individual differences in non-linguistic pitch perception so as to attribute, if any, the differences of linguistic pitch perception abilities between Cantonese-English bilingual children and monolingual English children to specific linguistic experience rather than general acoustic or music perception. In other words, differential performances between bilinguals and monolinguals should be due to differences at linguistic/phonological level, rather than general acoustic or musical perception mechanisms. In addition, the relationship between linguistic and non-linguistic pitch perception among Cantonese-English bilingual children can be explored.

Working Memory and Linguistic Pitch Perception

There are empirical studies investigating the relationship between working memory and frequency perception (e.g., Mauney, 2006; Payne, 2003). Payne (2003) discovered a relationship between working memory and the ability to perceive pitch differences. Although Mauney (2006) also predicted a relationship between working memory capacity and frequency discrimination, no significant relationship was found. The failure for such a relationship to emerge itself in Mauney's study might be explained by flaws in subject recruitment. As pointed out by Mauney herself, the overall sample consisted of more subjects with high working memory span than mid and low spans, causing range restriction problems with span scores (Mauney, 2006). Another possible explanation was difference in methodology. Payne (2003) applied the method of limits (judging whether two sounds differ), while Mauney (2006) applied the method of constant stimuli (comparing frequency level of stimuli). Different response types (yes/no, and high/low) may exhibit different relationships with working memory capacity (Mauney, 2006), accounting for the deviant results between two studies.

In light of the frequency nature (contour, onset, offset, height) of lexical tones, perception of lexical tones is thought to be related to working memory (Li, 2000; Li et al., 2010; Mattock & Burnham, 2006). Mattock and Burnham (2006) suggested high cognitive load for processing lexical tone. In their view, attention resource for vowels and consonants was shared with lexical tone in online speech stream processing. In addition to acoustic features of vowels (such as first, second and third formant frequencies corresponding to articulation and phonemic quality), lexical tones consist of extra features such as frequency duration and contour, to name but two. Based on this, Mattock and Burnham (2006) deduced the involvement of cognitive processing (requiring working memory) in lexical tone perception. The involvement of working memory in lexical tone perception has also been supported by brain-imaging studies (Li, 2000; Li et al., 2010). Also, a study by Li (2000) on Mandarin speakers revealed neural activity specific to encoding of lexical tone and its memory processes, although specific processes under working memory (such as phonological loop, and different central executive functions) could not be identified due to technological limitations. Li et al. (2010) identified an interaction between working memory and prelexical phonological processing of lexical tones, with consistent left inferior frontal regional activation during tone and pitch tasks for Mandarin speakers.

It has been suggested that perceptual ability on lexical stress was associated with working memory (Mattys & Samuel, 2000). Mattys and Samuel (2000) identified the role of working memory in lexical stress processing. In particular, extra memory storage was evident for non-initial-stress words than initial stress words due to a cognitive strategy adopted by English speakers whose lexicons were predominantly initial-stressed. One possible source of extra processing was retroactive processing (Mattys & Samuel, 2000). Not only did the listeners perform proactive (left to right) processing initiated by the stressed syllable, but also retroactive processing. It was because failure to access the lexicon by the non-initial stressed syllable would require further retroactive (right to left) processing (i.e. “second search” based on the preceding unstressed syllable). Another possible source was based on network/activation models (McClelland & Elman, 1986; Norris, McQueen & Cutler, 1995), in which several lexicons were activated and competed with each other. Initial-stress selection bias caused initial-stress lexical candidate to be more strongly activated than non-initial-stress candidate, and extra processing was required to select the correct candidate. On top of the “standard” cognitive processing for lexical stress of initial-stress words, in either hypothesis, extra storage and processing were needed for non-initial-stress words (Mattys & Samuel, 2000).

Individual difference in non-native speech perception, ranging from individual speech contrasts to whole words containing difficult contrasts was reported to arise from pre-existing cognitive ability, especially in various aspects of working memory (Ingvalson et al., 2012). A body of empirical studies (Carlson & Meltzoff, 2008; Morales, Calvo, & Bialystok, 2013) revealed better executive functioning in bilingual children than monolingual children. Carlson and Meltzoff (2008) posited bilingual children had better “executive control skills” due to intensive training from their frequent need to suppress activation of the undesired language, while bearing in mind the two activated languages. More specifically, Morales, Calvo and Bialystok (2013) found better performance by bilingual children in working memory tasks when compared with monolingual children

To date, there is a paucity of research on the direct relationship between suprasegmental speech perceptions (lexical tone and lexical stress) and working memory in bilingual children. This type of research is of high theoretical significance as it will contribute to a better understanding of the underlying processes of linguistic pitch perceptions in bilingual children speaking both lexical tone language and lexical stress language. In addition, the current study examines whether the differences (if any) of lexical pitch perceptions between Cantonese-English bilingual children and English monolingual children can be explained by working memory. Also, the possible involvement of working memory in linguistic pitches perception among Cantonese-English bilingual children is further explored.

Lexical Tone Perception and Reading Comprehension

The relationship between prosody and literacy has been extensively investigated in the past decades (e.g., Goswami et al., 2002, 2013; Kitzen, 2001; Kuhn & Stahl, 2003; Richardson et al., 2004; Schwanenflugel et al., 2004). Prosody refers to "phonetic distinction related to pitch (i.e., fundamental frequency (f0), duration and /or amplitude)" (Yeung, Chen, & Werker, 2013, p. 124). Chinese lexical tone and English lexical stress represent different manifestations of prosody in Chinese and English, respectively. Apart from the distinction of phonetic segments, such as (pin vs. bin; 牌 /paai/ vs. 擺 /baai/), the modulation of pitch, also results in change of meaning, such as PREsent vs. preSENT, and 沙/saa1/ vs. 耍/saa2/, in both languages.

LaBerge and Samuels (1974) proposed the automaticity theory suggesting facilitation of word retrieval would eventually automate word recognition, allocating cognitive resources from low level word decoding to higher level non-automatic processes (e.g., inferencing and retrieval of world knowledge, to name but a few) required for reading comprehension. In relation to such theory, a number of studies (e.g., Palma et al., 2009; Wade-Wolley et al., 2004) have set out to demonstrate the relationship between stress sensitivity and word reading. Their results could be explained by the automaticity theory. Nevertheless, their studies only focused on reading aloud pseudowords and words. Only a handful of studies focused on reading comprehension at passage level (Holliman et al., 2013; Whalley & Hansen, 2006).

Whalley and Hansen (2006) proved that lexical stress sensitivity could predict unique variance in reading comprehension at passage level. However, they remained unsure about the exact nature of relationship between lexical stress sensitivity and reading comprehension. In particular, no conclusive evidence was shown to confirm whether the lexical stress sensitivity contributes beyond word retrieval, such as discerning syntactic structure and identification of salient information, in aiding reading comprehension (Cutler et al., 1997). In later years, Holliman et al. (2013) discovered a link between prosodic sensitivity and passage comprehension. However, in their study, prosody was represented by a multi-component measure. Thus, lexical stress was only investigated as a sub-component of prosodic sensitivity. The exact nature of the relationship between lexical stress and reading comprehension is still a controversy.

With the differences in orthographic nature between European languages (alphabetical) and Chinese (logographic), it is reasonable to question whether the results obtained from studies of European languages (e.g., Goswami et al, 2002; Holliman et al., 2013; Kitzen, 2001; Kuhn & Stahl, 2003; LaBerge & Samuels, 1974; Palma et al., 2009; Perfetti, 1985; Richardson et al., 2004; Schwanenflugel et al., 2004; Whalley & Hansen, 2006) can be extended to Chinese reading acquisition. Nevertheless, there is growing number of studies examining the role of Chinese tone awareness in word reading (McBride-Chang et al., 2008; Zhang & McBride-Chang, 2013). These studies have focused on word reading, and there is no study to date examining the connection between Cantonese tone perception and Chinese text reading comprehension. To address this issue, Experiment 2 is going to test the association between Cantonese tone awareness and Chinese text reading comprehension by conducting Pearson’s correlation analysis.

The Present study

To summarize, our study serves three main purposes. In experiment 1, we first investigate lexical tone and stress perceptions by bilingual and monolingual children. Second, we examine the interrelationships between lexical pitches perception, general acoustic mechanism and working memory. In experiment 2, we explore whether there is an association between lexical tone awareness and Chinese text reading comprehension among bilinguals.

Experiment 1

Method

Participants. A group of 673 children were recruited. Among them, there were 646 Cantonese-English bilinguals and 27 English monolinguals. The mean age of the sample was 7 years and 11 months (*SD*=10.80 months). The bilinguals and monolinguals were recruited from five local and international schools in Kowloon and New Territories, Hong Kong. Information about English language proficiency, language background and exposure were obtained from teachers and students' self reports. Inclusive criteria include normal intelligence, and absence of speech-language delay, neurobehavioral, and sensorial problems. Another inclusive criterion for the bilinguals was that their first language was Cantonese and they had received English language education for at least 2 years. The inclusive criterion for the monolinguals was that they had never received education in Cantonese/Mandarin/any tone language, and have been reported by teachers and themselves to have limited exposure to Cantonese/Mandarin in their daily lives. Parents or caregivers of the participants all gave consent via a consent forms. The monolingual children were reported to fit the inclusive criterion for monolinguals described above.

Materials. ***Lexical stress perception task / DEEdee Task.*** The audio stimuli consisted of recordings of single English words and non-linguistic vocalization "DEEdee" recorded by a native English female speaker. On each trial, an English word (e.g. Aladin) was presented via microphones, followed by two non-linguistic vocalizations of "DeeDeeDee" (one stimulus resembled stress pattern of the English word) with a 1 second pause in between. The subjects were required to identify which of the two vocalizations "DeeDeeDee" resembled the stress pattern of the English word. Two practice trials with corrective feedback were done to ensure full understanding of the task requirements. The order of target and non-target items was counterbalanced across trials.

Cantonese lexical tone discrimination task. Audio stimuli were used in this experiment. The audio stimuli consisted of audio recordings of single Cantonese words recorded by a native Cantonese female speaker. On each trial, 3 single Chinese characters (e.g. /sing1/, /saa1/, /sau2/) were presented audibly via microphones. Trials with different phonemic conditions of the items (same onsets & different rimes, different onsets & different rimes, different onsets & different rimes) were randomly distributed during the test. The subject was required to select the Cantonese word he/she identified as carrying a different lexical tone from the other two words. Three practice trials with corrective feedback were done to ensure full understanding of the task requirements.

Non-linguistic pitch perception task / Metric task. The audio stimuli consisted of non-linguistic pitches with varying duration, height, and contour. This task adopted a forced choice paradigm. On each trial, two auditory stimuli were presented via microphones. The subjects were required to indicate whether the two stimuli presented were same or different. Two practice trials with corrective feedback were done to ensure full understanding of the task requirements.

Digital Span Task. A Microsoft PowerPoint with sets of digits on each slide was presented. The participants were required to read aloud the digits (e.g. 182 563 217). After they had read aloud the digits, the experimenter immediately blanked out the slide. The participants were asked to write the last digit of each set of digits (e.g. 237) on the answer booklet. Two practice trials with corrective feedback were done to ensure full understanding of the task requirements.

Animal race task. A serial-order reconstruction task adapted from Majerus et al. (2006) was used. Short-term retention demands for order information were maximized while item information processing demands were minimized. The task was presented as a game, in which the children heard sequences of animal names (lion, cat, dog, cock, bear, wolf, and monkey) with increasing length from 3 to 7 names. For Cantonese participants, to minimize lexical effect, Cantonese names of the corresponding animals were presented. The participants were asked to reconstruct the order of presentation of the animals by putting a digit (1-7) in the boxes under the animals' pictures.

Procedure. Group testing (20 to 180 participants simultaneously) was carried out in classrooms/hall of the primary schools. The participants received an answer booklet consisting of all tasks. Prior to each task, instruction was given from the experimenter to ensure their understanding of the tasks' requirements. An average of 2 to 3 practice items were done for each task. All audio stimuli were presented via microphone system in the classroom/hall with adequate loudness.

Results

Do bilinguals and monolinguals perceive linguistic pitches differently?

To examine the differences between Cantonese-English bilingual children and English monolingual children in perceiving linguistic pitch and non-linguistic pitch, we conducted MANOVA analysis with accuracies of Cantonese Lexical Tone Discrimination Task, Animal Task, Metric Task and DEEdee Task as dependent variables and group (Cantonese-English bilingual vs. English monolingual) as the independent variable. The means and standard deviation of correct response rates for bilingual and monolingual children are shown in Table 1. There was a statistically significant difference in Tone Task between bilingual and monolingual groups, $F(1, 52) = 73.92$, $p < .001$, $\eta_p^2 = .520$, in which the bilingual group performed significantly better than the monolingual group. No statistically significant differences were obtained in DEEdee Task, $F(1,52) = 2.48$, $p = .12$, Metric Task $F(1,52) = .087$, p = .77 and Animal Task, $F(1,52) = 1.43$, p = .24 between the two groups.

Table 1

Means and Standard Deviations of all Variables for Between Group Comparison (N=54)

	Bilinguals	Monolinguals	
	M (SD)	*M (SD)*	*F (1, 52)*
Tone Perception	38.67 (6.32)	21.44 (8.27)	73.92***
DEEdee	12.63 (2.91)	11.78 (2.29)	2.48
Metric Perception	16.19 (3.81)	15.89 (3.54)	.087
Animal Task	7.30 (1.03)	6.70 (1.66)	1.43

***$p < .001$

Inter-correlations between linguistic pitches, non-linguistic pitch and working memory. To examine the relationships among linguistic pitches (i.e., Chinese lexical tone, English lexical stress), non-linguistic pitch and working memory, correlations and regression analyses were conducted, separately for bilingual and monolingual groups. Means, standard deviations and correlations among all variables for 646 Cantonese-English bilingual children were reported (*N*=646) in Table 2. Pearson's product-moment correlation was run to assess the intercorrelations among Tone Task, DEEdee Task, Metric Task, Animal Task, and Digital Span Task within bilingual group and monolingual group. Within bilingual group, there was a moderate positive correlation between Tone Task and DEEdee task, $r = .33$, $p < .001$, with Tone Task explaining 2.5% of variation in DEEdee task after controlling for working memory. Small but statistically significant positive correlations were found between Tone Task and Metric Task, $r = .28$, $p < .001$, and Animal Task, r = .20, $p < .001$. Small positive correlations were found between DEEdee Task and Metric Task, $r = .22$, $p < .001$, and Animal Task, r = .14, $p < .005$. Interestingly, a strong positive correlation, $r = .65$, $p < .001$, was found between DEEdee Task and Animal Task within monolingual group, with Animal Task accounting for 42.1% of variation in DEEdee Task as revealed by regression analysis.

Table 2

Means, Standard Deviations and Correlations of all Variables within Bilingual Group (N=646)

Variables	1	2	3	4	5
1. Tone Task	-				
2. DEEdee Task	.33	-			
3. Metric Task	.28	.22	-		
4. Animal Task	.20	.14	.18	-	
5. Digital Span Task	ns	ns	ns	.14	-
M	38.67	12.63	16.19	7.30	9.13
SD	6.32	2.91	3.81	1.03	2.72

ns= nonsignificant

Note. All correlations are significant, all $p < .01$.

Experiment 2

The primary goal of experiment 2 is to explore whether tone task is correlated with Chinese reading comprehension task, and to what extent tone task predicts Chinese reading comprehension task after controlling for working memory.

Method

Participants. Among the 673 children recruited, 126 children were invited to take part in experiment two to conduct a Chinese reading comprehension task. Among them, all were Cantonese-English bilinguals. The mean age is 8 years 0 month (SD=8.16 months).

Materials. ***Reading Comprehension Task.*** The task consisted of 3 long passages with a total number of 18 questions. The questions included direct questions (answer could be obtained directly from the information provided in the passage) and indirect questions requiring inference. The difficulty of the passages had been selected to suit the participants' literacy ability in order to prevent floor/ceiling effect.

Procedure. Group testing (approximately 20 to 33 participants simultaneously) was carried out in classrooms of a primary school. The same answer booklet as experiment 1 was used except that 3 long passages were attached to the booklet. The participants were given sufficient time to finish the Reading Comprehension Task.

Results

Relationship between Tone Task and Reading Comprehension Task. To examine the relationship among Chinese lexical tone and reading comprehension, correlations and regression analyses were conducted. Pearson's product-moment correlation analysis was run to assess the intercorrelations among Tone Task, Reading Comprehension Task, and Animal Task. Means, standard deviations and correlations among all variables for 126 Cantonese-English bilingual children were reported (N=126) in Table 3. Only correlations with significance at the $p < .05$ level were shown. There was a small positive correlation between Reading Comprehension Task and Tone Task, $r = .22$, $p < .05$, with Tone Task explaining 3.2% of variation in Reading Comprehension Task after controlling for working memory. Small but statistically significant correlation was also found between Reading

Comprehension Task and Animal Task, $r = .23$, $p < .01$.

Table 3

Means, Standard Deviations and Correlations of all Variables within Bilingual Group (N=126)

Variables	1	2	3
1. Tone Task	-		
2. Animal Task	na	-	
3. Reading Comprehension	.22	.23	-
M	26.93	6.50	11.28
SD	9.65	1.43	3.18

na= not analyzed.

Note. All correlations are significant, all $p < .01$.

General Discussion

This study set out to examine (a) lexical tone and stress perception by bilingual and monolingual children, (b) interrelationships between lexical pitches perception, general acoustic mechanism and working memory, and (c) the association between lexical tone awareness and Chinese text reading comprehension. We have found that Cantonese-English bilingual children performed better than English monolingual children in lexical tone perception but not lexical stress perception, non-linguistic pitch processing and working memory. There was a significant relationship between Chinese tone awareness and Chinese text reading comprehension. The findings will be discussed below.

Perception of Linguistic and Non-linguistic Pitches: Bilinguals vs. Monolinguals

Lexical tone. As expected, significant difference was found between monolingual and bilingual groups in lexical tone perception, in which monolingual children performed significantly poorer than bilingual children. The results from this study cohere to our prediction of outperformance of bilinguals in tone task when compared with monolinguals.

The expected difference in tone discrimination ability between monolingual and bilingual children is best accounted for by language experience. Indeed, working memory advantage has been extensively evident among bilingual children (e.g., Bialystok, 2001;

Carlson & Meltzoff, 2008; Emmorey et al., 2008; Mezzacappa, 2004; Morales, Calvo, & Bialystok, 2013), and one may attribute the underperformance of monolingual children in tone perception to poorer working memory, or even less sensitive general acoustic mechanism when compared with bilingual children. However, no significant difference was shown between the two groups in Animal Task and Metric Task, which tapped working memory and general acoustic mechanism respectively. Therefore, it is reasonable to believe that the poorer performance of monolingual children in tone perception was not due to differences in working memory or general acoustic mechanism, but best explained by differences in language experience. Such interpretation of language experience affecting suprasegmental speech perceptual system was in line with another study examining lexical stress deafness among French speakers (Bosch et al., 2009). We believe that the monolingual children's ability to discriminate lexical tones was attenuated, perhaps at an age as early as 9 months old with reference to Mattock and Burnham (2006), due to linguistic irrelevance of lexical tones in English. In contrast, the ability to discriminate lexical tones was not only retained, but had been developing since childhood among bilingual children due to the significance of lexical tone in discriminating Cantonese words. We are among the first studies to provide empirical findings demonstrating attenuation of Cantonese lexical tone perceptual ability among English monolingual children due to the influence of language background.

Lexical stress. Surprisingly, near equal performance between monolinguals and bilinguals in lexical stress perception was obtained. This sheds light on the possibility of perceptual assimilation of English stress to native prosodic categories (Cantonese lexical tone), or prosodic transfer across Cantonese and English. As stated previously, lexical stress and tone are linguistic pitch variations sharing certain similarities such as pitch contour, duration, and height. It is plausible that tonalization of English lexical stress occurred, and Cantonese bilinguals processed English stress in a very similar way to how Cantonese tones were processed. Similarly, a previous study illustrated the use of different acoustic cues by English monolinguals and (Mandarin-English) bilinguals to perceive lexical stress (Yu & Andruski, 2010). As opposed to English speakers' reliance on a complex pattern of acoustic cues (pitch, duration, intensity and vowel quality), Mandarin speakers mainly rely on pitch to process English stress, the same acoustic cue they rely on for the perception of Mandarin tone. Specifically, our study discovered a moderate association between tone and stress tasks within bilingual group, and that lexical stress task was significantly predicted by tone task. It is therefore reasonable to speculate that Cantonese bilinguals used highly similar or the same mechanism to perceive both linguistic pitches (tone and stress). A further interpretation of the postulation is that the near equal accuracy of lexical stress perception among monolinguals and bilinguals reflects the bilinguals' mature use of such mechanism to assimilate and perceive lexical stress, given that the bilinguals recruited are highly proficient in English with native standards. Future neuroimaging studies are warranted to confirm our postulation. As a pioneer for future extensive investigations of stress perception among Cantonese-English bilinguals, our study discovered that proficient Cantonese-English bilingual children performed similarly in lexical stress perception when compared with English monolinguals.

Bilingual Working Memory Advantage Revisited

Contrary to traditional studies (e.g., Bialystok, 2001; Carlson & Meltzoff, 2008; Emmorey et al., 2008; Mezzacappa, 2004; Morales, Calvo, & Bialystok, 2013), no working memory advantage is found in this study. The lack of statistical difference of verbal working memory (Animal Task) between monolingual and bilingual groups may be explained by three possibilities. One possible explanation concerns the measure of working memory among different studies. In this study, Animal Task was used to tap verbal working memory for serial order construction among children. It is possible that "working memory advantage" covered only other aspects of working memory, such as inhibitory control and different components of executive control (e.g., Bialystok, 2001; Carlson & Meltzoff, 2008; Emmorey et al., 2008; Mezzacappa, 2004; Morales, Calvo, & Bialystok, 2013). The second possible explanation was the failure of working memory advantage to emerge due to small sample size of 27 participants in monolingual group in this study. Despite the statistical insignificance, the bilingual group scored a higher mean (7.30) than the monolingual group (6.70) in verbal working memory task. The third possible explanation was the absence of working memory advantage among Cantonese-English bilingual children, or that such "advantage" was too subtle to be detected.

Linguistic Pitch and Musical Pitch

Small but significant association was found between lexical and musical pitches perceptions among bilingual children. Taking into account the close resemblance of acoustic features (i.e. pitch contour, pitch onset, duration, accent on notes, etc.) between lexical tone, stress, and musical pitch, we postulate general acoustic mechanism as being a basic essential part representing acoustic pitch processing at an early level of acoustic analysis required for linguistic pitches perception. In this hypothesis, part of the perceptual mechanisms is shared by linguistic and musical pitch, and may account for the association between perception of linguistic and musical pitches. The association found in this study may be viewed as a preliminary evidence to extend the Resource Sharing Framework (Patel, 2012) to Cantonese bilingual children, in which part of brain mechanisms are shared by musical and linguistic pitches processing. Also, the association was consistent with lateralization-carryover hypothesis (Gu et al., 2013) which specified left-hemispheric modulation of lexical pitch and acoustic pitch processing due to frequent usage of pitch information in speech. Furthermore, our findings do not reject the view of Wong and Perrachione (2007), in which experience of musical perception might influence or even facilitate the perception of speech.

However, caution must be paid as we remain uncertain whether the association between lexical and musical pitches is confounded by working memory, specifically, serial order construction. In our study, bilingual children's lexical tone and musical pitch perceptions were associated with working memory task (Animal Task), which is consistent with previous studies identifying better verbal working memory among musicians when compared with non-musicians (Brandler & Rammsayer, 2003; Chan, Ho, & Cheung, 1998). We cannot deny the possibility that the relationship we found between lexical and musical pitches perception is indirect: general acoustic mechanism associates with working memory, and working memory interacts with linguistic pitches perception. Nevertheless, the stronger association between musical pitch and linguistic pitches perceptions ($r = .28$, $p < .001$ and

$r = .22$, $p < .001$ for tone and stress respectively) as compared to that of working memory and linguistic pitches perception (r = .20, $p < .001$ and $r = .14$, $p < .001$ for tone and stress respectively) may be somewhat suggestive of a more direct relationship between linguistic and musical pitches perception than linguistic pitches perception and working memory.

Attention must be paid to on the directionality of the association between linguistic and musical pitches perception. Pearson correlation analysis used in this study fails to demonstrate the direction of association. Indeed, musical experience has been shown to aid speech perception (Wong & Perrachione, 2007). However, we are cautious that experience in perceiving tone languages might also affect the perception of musical pitch patterns (Bent, Bradlow, & Wright, 2006). Before a conclusion can be drawn, a future study is warranted to examine whether musical pitch perception facilitated perception of linguistic pitches, or vice-versa. Nonetheless, we have identified a complex relationship between linguistic pitches perception and general acoustic mechanism.

Linguistic Pitches Perception and Working Memory

A new finding emerges in which tone and stress perceptions in Cantonese-English bilingual are associated with verbal working memory (serial-order construction). This new finding is largely consistent with previous studies on perception of Mandarin tones by Mandarin speakers (Li, 2000; Li et al., 2010) and stress perception by native English speakers (Mattys & Samuel, 2000). The current study identifies working memory involvement in tone and stress perceptions among Cantonese-English bilinguals. We hope to provide a new direction for a future neuroimaging study investigating working memory's involvement in tone and stress perception among Cantonese-English bilingual children. Neuroimaging will help explain the mechanism regarding how specific components of working memory are involved in tone and stress perception by Cantonese-English bilingual children. Specifically, we remain unsure about the exact role of verbal working memory (serial-order construction) in lexical tone and stress processing, or vice-versa, among Cantonese-English bilingual children. In addition, the much stronger positive correlation, $r = .65$, $p < .001$, between lexical stress perception and verbal working memory among monolinguals relative to bilinguals, $r = .20$, $p < .001$, warrants a future study to explain this phenomenon.

Lexical Tone Perception and Reading Comprehension

An encouraging result is obtained, in which lexical tone perception was correlated with reading comprehension. Provided that lexical tone was prosody at the syllable-word level, it is reasonable to conceive the effect of lexical tone as being largely laid at syllable-word level, but not beyond it to sentence and passage level. In fact, the revelation of association between tone detection awareness and Chinese word recognition (McBride-Chang et al., 2008; So & Siegel, 1997) has further consolidated our belief. Based on the above, it is not unreasonable to believe the extension of automaticity theory (LaBerge & Sammuels, 1974) to Cantonese tone and literacy. Despite the lack of directionality in the Pearson correlation, we hypothesize that word recognition is facilitated by the use of tonal information which speeds up retrieval of word from mental lexicon. Specifically, perception of a word (沙 /sa1/) will activate different competitors with same segments but different tones (耍 /sa2/, 嗄 /sa3/), same tone but different segments (家 /ga1/, 梳 /so1/, 高 /go1/, 街 /gai1/), and without phonological similarity with the target word (早 /tso2/, 敬/ging3/). With reference to the TTRACE model proposed by Tong et al. (in press), the activation strength of competitors varies according to phonological similarity between competitors and target word. We postulate that enhanced tonal awareness facilitates lexical retrieval of target word at least among homophones with different tones (e.g. 沙 /sa1/, 耍 /sa2/, 嗄 /sa3/). With regard to automaticity theory (LaBerge & Samuels, 1974), we hypothesize that facilitation of word retrieval will eventually automate word recognition, thus allocating cognitive resources from low level word decoding to higher level non-automatic processes (e.g. inferencing, and retrieval of world knowledge, to name but a few) required for reading comprehension. However, the relationship between reading comprehension, word recognition and lexical tone awareness is not as simple as we think. A growing number of literature provides evidence suggesting that perceptual mechanism is neither bottom-up nor top-down, but a combination of bottom-up and top-down processes (McClelland, Mirman, & Holt, 2006; McMurray & Jongman, 2011; Samuel, 2001). As the role of lexical knowledge in lexical tone distinction has not been explored, we cannot deny any influence on tonal distinction exerted by lexical knowledge (top-down process). Therefore, caution must be paid before probing in depth the relationship between lexical tone perception and reading comprehension.

As to whether the role of tone awareness can be further extended to sentence and passage levels, some researchers (Kuhn & Stahl, 2003) hold the theory that prosodic reading may facilitate reading comprehension. This is based on their claim that prosodic reading is an indication of children's segmentation of passage according to their syntactic and semantic elements, which are essential processes for reading comprehension. Schwanenflugel et al. (2004) opposed this view and proved that the effect of reading prosody did not contribute beyond efficiency of word recognition to predict reading comprehension. They concluded that the sole use of automaticity theory was sufficient to explain the interaction between prosody and reading comprehension. At this stage, we do not attempt to evaluate the above claims as the current study only investigated prosody at the syllable-word level (lexical tone), while those evaluated by the above researchers were of higher levels (phrase, sentence, and passage levels). Nevertheless, we are the first to discover the relationship between tone and reading comprehension in Cantonese children, which nature is to be disentangled in future.

Theoretical Significance

Suprasegmental speech perception. This study is of substantial theoretical significance as it has provided empirical evidence demonstrating poor lexical tone perception by monolingual English children and native-level lexical stress perception by Cantonese-English bilingual children. We are among the first to shed light on the plausibility of perceptual tonalization of lexical stress by Cantonese-English bilingual children. In addition, we have proved the involvement of working memory in tone and stress perceptions among Cantonese-English bilinguals. Our study has laid a foundation for future research to investigate the processes involved in suprasegmental speech perception among Cantonese-English bilingual children.

Cognitive advantage. A growing number of studies have focused on cognitive advantage of bilinguals (Bialystok et al., 2013; Carlson & Meltzoff, 2008; Luk et al., 2008;

Mezzacappa, 2004). Despite the disparity of specific components (inhibitory control skills, shifting, executive function and working memory) of cognitive control addressed, there is general consensus that bilinguals had enhanced cognitive control when compared with monolinguals (Bialystok et al., 2013; Carlson & Meltzoff, 2008; Emmorey et al., 2008; Luk et al., 2008). We have revisited this issue by comparing verbal working memory capacity (one component relating to cognitive control) between Cantonese-English bilinguals and English monolinguals. The current study yields a somewhat different result, and provides a new insight in examining whether bilingual cognitive advantages found by previous studies (Bialystok et al., 2013; Carlson & Meltzoff, 2008; Luk et al., 2008) can be extended to Cantonese-English, beyond the languages they studied (English-Spanish, Vietnamese, etc).

Lexical tone and reading comprehension. Our study is the first to discover the complex relationship between lexical tone awareness and reading comprehension ability. We believe the encouraging results yielded in this study will inspire future researchers to disentangle such complex relationship and provide a framework for an effective screening and treatment methodology for reading comprehension ability among normal bilingual readers, and even dyslexic children.

In summary, the implications of this study may even extend to the clinical and educational field. The study will provide theoretical insight to clinicians and teaching staff for adjusting their directions or teaching methodology for suprasegmental perception/production, as well as reading comprehension among Cantonese-English bilingual children.

Limitation and further research

Despite the theoretical significance of the current study, there are also several limitations. First, the measure of working memory is limited. Putting aside the Digital Span Task which showed ceiling effect, Animal Task could only tap into serial order construction aspect of verbal working memory. In fact, executive function was an integrated set of skills with various aspects (Carlson & Meltzoff, 2008; Miyake et al., 2000; Zelazo et al., 1997), but the tasks used in this study only covered few measures of executive function. Second, the type of bilingual participants targeted in this study was limited. All Cantonese-English bilinguals were sequential bilinguals. The results and implications of this study might not be generalizable to another bilingual population, i.e. simultaneous Cantonese-English bilinguals. Third, the current study was a cross-sectional study. The experimental design did not allow researchers to observe changes/development of suprasegmental perception skills in bilingual children over time. Forth, vocabulary size and general intelligence of the participants, which might be largely related to reading comprehension, were not controlled in Reading Comprehension Task.

My follow-up future research will be designed to fill the gaps identified from the limitations of the current study. Future research should adopt a longitudinal design to monitor development of suprasegmental perception skills in Cantonese-English bilingual children. To have a better understanding on neural mechanisms of suprasegmental perception skills in Cantonese-English bilingual children, neural studies can be done to compare the neuro-activation patterns between Cantonese-English bilinguals, Cantonese monolinguals, and English monolinguals. In addition, examining the tone perception performance of bilinguals and monolinguals across different phonetic contexts (same-onset-different-rime, different-onset-same-rime, different-onset-different-rime) may enhance our understanding on their underlying tone perceptual processes. For any further research involving working memory, the multifaceted nature of cognitive control (Carlson & Meltzoff, 2008; Miyake et al., 2000; Zelazo et al., 1997) should be addressed. Also, simultaneous bilinguals should be included in the design to obtain a full image of Cantonese-English bilingualism. Furthermore, a large scale research involving other types of bilingual children (Tagalog-English, Thai-English, and Korean-English, etc.) will enhance the understanding of the nature of bilingual children's speech perception. Lastly, vocabulary size and general intelligence of the participants will be controlled in Reading Comprehension Task to minimize confounding.

Conclusion

To conclude our study, we have provided empirical evidence to demonstrate the discrepancy in tone perception, and similarity in stress perception between Cantonese-English bilinguals and English monolinguals. Our findings also revealed working memory's involvement in linguistic pitches perception, and a complex relationship between linguistic and non-linguistic pitches perception.

Lastly, we are the first to discover a complex interaction between lexical tone awareness and Chinese reading comprehension, and have offered explanations to account for such a phenomenon.

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