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Toward a hierarchical representation model of Lexical tones: Effects of acoustic, segmental and semantic characteristics on tone perception in Cantonese-speaking children

Xiuli Tong

MARCS Auditory Laboratories, University of Western Sydney, Australia

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ABSTRACT

Lexical tones are pitch patterns that distinguish between meanings of syllables with an identical segmental structure in languages such as Cantonese. Cantonese has 6 lexical tones that are distinctive in terms of their acoustic, segmental and semantic characteristics. A model of lexical tone representation presented that posits a hierarchy of lexical tone representation, in which acoustic, segmental and semantic characteristics each contribute to tone perception. Two experiments were designed to test this model with Cantonese-speaking kindergarteners, and second- and fifth graders. In Experiment 1 kindergarteners were best at identifying the target tone in high level (55) vs. high rising (25) (same offset of the height, different contours) contrasts than other pairs of tone contrasts, with the worst performance on the mid level (33)-low level (22) (same contour, small height difference) contrasts. In Experiment 2, second- and fifth-graders were tested for tone discrimination in three different segmental contexts and it was found that for both groups tone discrimination was most difficult in different onset/same rime (DO/SR) then same onset/different rime (SO/DR), then different onset/different rime (DO/DR) contexts; DO/SR > SO/DR >DO/DR. In regression analyses in each experiment, it was found that tone perception ability uniquely contributed to early Chinese word reading for young kindergarteners but not for second- or fifth-graders, even after controlling for segmental levels of phonological awareness.There is also a strong association between tone perception and Chinese vocabulary across ages. Interesting, tone perception is also uniquely associated with English word reading for grade 2 children but not for grade 5. Our results support a hierarchical representation model of lexical tones in which the distinctiveness of acoustic cues (pitch height and contour), segmental contexts (vowels and consonants) and semantic levels affect tone perception even up to grade 5, but that while tone perception predicts vocabulary across ages, it only predicts reading ability (in both Chinese and English) for young children. This may be due to the development of better tone perception across acoustic and contextual variation at older ages.

INTRODUCTION

Understanding the influence of the variation of voice pitch on the change of word meaning is essential in order to understand the process involved in learning tonal languages, such as Cantonese. In turn, the acquisition of lexical tone perception depends on the way in which lexical tones are perceptually organized in the human psycholinguistic system. The goal of this study is to establish and test a hierarchical model of lexical tone representation in young (kindergartners) and older (second grade and fifth grade) Cantonese-speaking children. The hierarchical model of lexical tone representation (see Figure 1) involves a hierarchy of segmental, acoustic and semantic processing units of lexical tone, and posits that a well-refined linguistic representation of tones depends on learned connections between acoustic, segmental and semantic processing units.The relative salience or prominence of these units is affected by strength of the connections between them, which in turn are reinforced and modulated by long-term learning and language exposure.

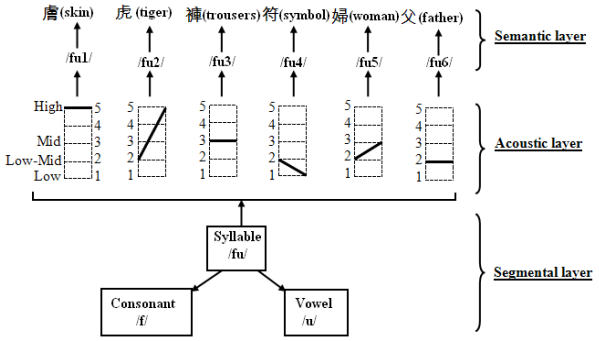

Figure 1. A hiearchical representation model of lexical tones in Cantonese

The hierarchical representation model of lexical tones is illustrated in Figure 1 with Cantonese tones. There are six lexical ones in Cantonese: high level (55), high rising (25), mid level (33), low falling (21), low rising (23), low level (22) (Fromin, 2000; Matthews & Yip, 1994). At the acoustic level, lexical tones are perceptually distinctive pitch patterns characterized by fundamental frequency in terms of the level (high, mid, low-mid or low) and contour (level, rising, or falling) of the pitch (Chao, 1947; Gandour, 1981). At the segmental level, lexical tones function phonemically in Cantonese. Lexical tone is attached to the vowel of a spoken syllable represented by a single Chinese character or morpheme, but there is no written representation of the tone. Change of the tones for a segmentally-identical syllable may change its meaning. For example, in Cantonese the syllable /fu/ spoken with different tones means "skin/fu55/, "tiger"/fu25/, "trousers" /fu33/, "symbol"/fu21/, "woman"/fu23/, "father"/fu22/, respectively. At the semantic level, lexical tones are used to contrast the meanings of individual words (Fromkin, 2000; Matthews & Yip, 1994). The change of tones for an identical syllable can represent completely different meanings, such as the spoken syllable /fu/ means "father" /fu22/, but it means "tiger"/fu25/ with different tones. Three hypotheses can be derived from the proposed model namely that (1) acoustic features, (2) segmental contexts, and (3) semantic levels will each contribute to perception of lexical tones. These were tested in two experiments; Experiment 1 tested the first hypothesis by comparing the relative ease of young native Cantonese-speaking children perceiving and identifying tone contrasts differing in pitch height and pitch contour. Experiment 2 tested the second hypothesis via systematic variation of the segmental context (vowels and consonants), within and across syllables, in which children's tone perception performance was tested. The third hypothesis was tested in both Experiments 1 and 2 by evaluating the unique contribution of tone perception to early Chinese vocabulary learning and word reading in young kindergartners and (Experiment 1), and to vocabulary learning in Chinese and word reading in both Chinese and English in older children (Experiment 2). Below, we review research regarding acoustic features, segmental contexts and the semantic level that derives hypotheses for our studies.

Previous studies on both normal-hearing and hearing-impaired Cantonese speakers have shown that the acoustic features of lexical tones (pitch height and pitch contour) play an important role in perceiving and distinguishing contrastive tone pairs (Ching, 1984, Ching, 1988; Fok, 1984; Varley & So, 1995); and differences in the weighting of pitch height and pitch contour have been found in lexical tone perception (Ching, 1984, Ching, 1988; Ciocca & and Lui, 2003; Lee, Chiu & Van Hasselt, 2002). Early studies showed that hearing-impaired children relied more on pitch height in tone identification (Fork, 1984, Ching, 1988), but, in contrast, normal-hearing adults were found to attend to pitch contour differences in discriminating different tone contrasts (Ching, William & Van Hasselt, 1994). There is also evidence that both pitch height and pitch contour are important for tone perception (Varley & So, 1995).

A recent study by Lee, Chiu and Van Hasselt (2002) found that Cantonese-speaking children as young as age 2 were equally able to identify contrasts between high level (55)-low falling (21) and highlevel (55)-high rising (25), and had greater difficulty with the high rising (25)-low falling (21) contrast; they concluded that the difference of the onset and offset of the fundamental frequency of tone contrasts may determine the ease of tone perception. Ciocca and Lui (2003) compared tone perception performance of Cantonese-speaking 4-, 6-, and 10-year-old children with that of adults, finding that participants of all ages tended to have more difficulty in identifying tone contrasts mid level (33)-low level (22) and high rising (25)-low rising (23), which have smaller differences in either pitch contour or height, as compared with other tone contrasts. Therefore, it is possible that the similarity in either pitch height or contour influences the ease of tone perception in children.

Findings of previous studies reinforce the first hypothesis that acoustic cues (the height and contour of the pitch) play a role in tone perception. However, in the studies described above, there are variations in obtained difficulty for particular tone contrasts, possibly due to differences in the number of available tone pairs used in the studies, as well as the ages studied. In Experiment 1 we extend previous studies by including more comprehensive tone contrasts to assess tone perception performance of young Cantonese-speaking children at age of 5, and to test how Cantonese-speaking children's tone perception performance is affected by the difference of pitch-contour salience.

Apart from the acoustic features, vowels and consonants are phonological elements necessary for carrying tone. In Cantonese, changes in tone, vowel and consonant can occur independently, and independently affect the word meaning. For example, the vowel of a tonal syllable/fu55/(skin) can change to/aa1/ to represent the meaning of /faa55/ (flower) without changing its tone and consonant. Similarly, the consonant of the syllable /fu55/ can change to /h/ without changing its vowel and tone, to represent "breath" /hu55/. Further, both the vowel and consonants of the tonal syllable/fu55/ can change without changing its tone, like /haa55/ referring to "shrimp". However, tonal information can carry over to segmental features, in that pitch contour may impact the pitch and intensity of a vowel's expression; it is possible, therefore, that segmental contexts (vowels and consonants) would influence the ease of children's tone perception. Two development theories, which both address the difference in weighting acoustic cues in perceiving speech contrasts between children and adults, may provide indirect evidence that the segmental contexts of the lexical tones play a role in tone perception. According to developmental weighting shift theory (Nittrouer, Miller, Crowther, & Manhart, 2000), children process speech in a global manner and tend to attend to syllable-like units. The general central auditory theory (Eisenberg, Shannon, Schaefer Martinez, Wygonski, & Boothroyd, 2000; Sussman, 2001) proposes that children are more attentive to acoustic cues that are longer, louder, or more spectrally informative than alternative cues. Both of these theories lend credence to our second hypothesis that children's tone perception performance would be influenced by the transition of the vowel and consonants within a syllable,such as the consonant change within syllable /pei23/ (quilt), /lei21/(pear) , /kei21/(flag), /mei21/(brow), and the vowel change within syllable/si55/(lion), /sau25/(hands), /sam55/ (heart), /seng55/ (stars), and the vowel and consonant change across syllables /faa55/(flowers),/hoi25/ (sea),/ce55/ (car), /bat55/(pen).

As can be seen in Figure 1, a complete representation of lexical tones should occur at the semantic level, which embodies the unification of the segmental components and acoustic features. There is some evidence that tone sensitivity is associated with both first-language and second-language word reading. A 1-year longitudinal study by McBride-Chang, Tong et al. (2008) tested young Hong Kong Cantonese-speaking children learning English as a second language on a tone detection task, and found that children's early tone detection performance is uniquely associated with Chinese word reading, but not with English word reading, after controlling for age, nonverbal ability, vocabulary knowledge, and other reading-related skills. Additionally, Wang, Perfetti,

and Liu (2005) have shown a cross-language association of lexical tones with English word reading; tone sensitivity was positively associated with English pseudo-word reading in American Chinese-English children. Although these two studies show that tone sensitivity plays an important role in learning to read in both first and second languages, the finding of a cross-language association (Wang, et al. 2005) is inconsistent with the lack of such a finding by McBride-Chang et al. (2008). Moreover, the age (5 versus 8) and language background (Cantonese vs. Mandarin) of children in two studies vary substantially. These results raise an intriguing question about the relationship between tone sensitivity and first- and second-language reading: Does the relationship of tone sensitivity to first- and second-language word reading change across age? Thus, we test the third hypothesis regarding the semantic representation of lexical tones by evaluating the contribution of tone perception to language learning in first- and second-language across ages. In this study, we extended previous research (McBride-Chang, Tong et al., 2008; Wang et al., 2005) on word reading by investigating the contribution of tone sensitivity to Chinese word reading, Chinese vocabulary knowledge and English word reading in three different levels of readers: kindergartners (beginning readers), second-graders (intermediate readers), and fifth-graders (advanced readers) .

To summarise, we address three primary research questions in two experiments.
1. Whether young Cantonese-speaking children's tone perception ability is affected by acoustic cues (pitch height and pitch contour).
2. How the segmental contexts (transition of vowels and consonants) of tones affect second- and fifth-graders' tone discrimination.
3. Whether tone sensitivity is an important contributor to Cantonese-speaking children's first- and second-language learning achievement, and how the relationship changes across ages.

2. Experiment 1

In this experiment we examine research questions 1 and 3. More specifically, we examined five-year-old Cantonese-speaking children's perceptual identification of lexical tone contrasts in which we systematically manipulated eight minimum lexicon tone contrasts, outlined below, of six lexical tone in two Cantonese syllable /ji/ and /fu/. Furthermore, we evaluated the contribution of tone perception to first-language learning ability across oral and written language in Chinese, (word reading and vocabulary production).

2.1. Method

2.1.1. Participants

199 kindergartners (102 girls and 97 boys) were recruited from six Cantonese kindergartens in New Territories, Kowloon, and Hong Kong Island, the three different districts of Hong Kong. The mean age were 5; 10 (S.D. = 6 months). All were native Cantonese-speakers, and they were from families with a medium income level according to the Hong Kong Census and Statistics Department (2006). All children were typical developing and they had no language disorder or hearing deficit, according to school and parental report.

2.1.2. Measures

Nonverbal ability. A book form of Raven's Colored Progressive Matrices (RCPM; Raven, Court, & Raven, 1995) asked children to choose which of six picture patterns, is the missing portion of a target picture. There were 24 items selecting from sets A and B.

Tone detection. This test assesses tone perception by asking children to identify a match for a target tone from one of two pictures representing a given contrastive tone pair, e.g., for the high level (55)-mid level (33) contrast matching a spoken word, /fu/ (either 55 or 33 tone on different trials) with a picture of the skin /fu55/vs. a pair of trousers /fu33/. The items for this test were constructed on the basis of prior research by Ciocca and Lui (2003). The eight minimal pair tone contrasts included High Level (55)-Mid Level (33), High Level (55)-Low Level (22), Mid Level (33) -Low Level(22), High Rising (25)-Low Rising(23), Low Rising(23) -Low Level (T5/T6), High Level -High Rising(T1/T2), Low Falling (21)-Low Level (22), Low Falling(21)-Low Rising (23). Each of these pairs was presented three times, and 24 items were produced by two monosyllables, /ji/ and /fu/. The first set of six lexical tones stimuli based the syllable /ji/ were /ji1/ (clothing), /ji2/ (chair), /ji3/ (first character of spaghetti), /ji4/ (son), /ji5/(ear), and /ji6/ (two) produced on the basis of the monosyllable /ji/. The second set of six lexical tone stimuli created with syllable/fu/ were /fu1/(skin), /fu2/(tiger), /fu3/ (trousers), /fu4/ (symbol), /fu5/ (woman), and /fu6/ (father), created on the basis of /fu/. Each set of stimuli generate 24 tone contrasts, and with a total of 48 items.

Syllable and phoneme-onset deletion. This test includes two tasks: syllable deletion and phoneme-onset deletion. The first task (29 items) asked children to say a polysyllabic or monosyllabic word without a designed syllable, e.g., " say ***big-clumsy-elephant*** without saying ***clumsy*** "(correct answer: big elephant). " The second task (21 items) was to ask children to say a syllable without saying the initial sound, e.g., " say /hon2/ without saying the initial sound" (correct answer: /on2/).

Chinese character recognition. Children were asked to read a list of real words of increasing difficulty. There were 27 single Chinese character words and 184 two-character words. Some words were adopted from the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (Ho, Chan, Tsang, & Lee, 2000). All children started at the beginning of the word list and testing was stopped when the children failed on 15 consecutive items. The raw score of this test was the total accurate responses.

Chinese vocabulary definition. This test assesses children's understanding of word meanings by asking them to orally explain the meaning of a two-character Chinese word. Children' answers were scored according to a 0-, 1-, or 2-point scoring system adopted from the Stanford-Binet Intelligence Scale vocabulary subtest (Thorndike, Hagen, & Sattler, 1986). The scoring scheme for each word was designed as a reference based on a Chinese dictionary (Lau, 1999, with the highest scores representing a correct, complete explanation of the meaning of the words. There were 53 items. Testing stopped when child obtained a zero score on five consecutive items.

2.2 Procedure

All measures were administered to children individually in a quiet room in the child's school by trained psychology majors. The order of the tasks was counterbalanced and varied from child to child. All the tests were administered in a single session, lasting about 30-40 minutes. Breaks were given when the child was fatigued.

2.3 Results

2.3. 1 Relative ease of perceiving different tone contrasts

The results for the mean percentage of correct responses of eight pairs of tone contrasts are shown in Figure 2.Young kindergarteners' tone perception differs across tone contrasts, F (7, 1386)= 137.30, p <.001. Pairwise comparisons with Bonferroni adjustment further revealed children's performance for high level (55) – high rising (25) was higher than that of for all other contrasts (ps<.001), with performance on the mid level (33) –high level (22) contrast being poorer than that of any other tone contrasts (ps<.001). There was no significant difference between the pairs of high level (55)–mid level (33) and high level (55)-low level (22), high rising (25)-low rising (23) and low rising (23)-low level (22), high level (55) –mid level (33) and Low falling (21)-low level (22) (ps >.05).

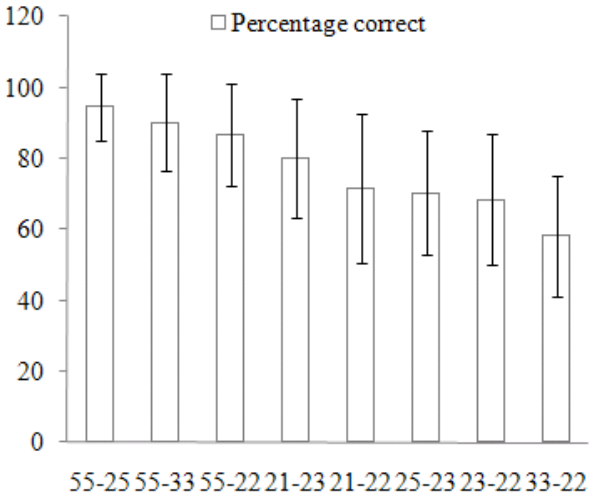

Figure 2. Mean percentage of correct detection of the target tones across different tone contrast for young Hong Kong Chinese kindergartners

2.3. 2 Prediction of lexical tone to word reading and vocabulary learning

To examine the contribution of tone perception to Chinese word reading and vocabulary learning, a set of multiple hierarchical regression analyses were conducted, separately predicting Chinese word reading and Chinese vocabulary from all measures. Across regression equations, the nonverbal ability and vocabulary definition (or Chinese character recognition) were first entered as the control of general language/reading ability. Syllable and phone-onset deletion were entered in the second step for the control of segmental phonological awareness. Tone detection was entered in the final step to evaluate its unique contributions after controlling all other linguistic and cognitive skills. Table 1 reports the standardized betas, R^2 and R^2 change.

Table 1. Predicting Chinese Word Reading and vocabulary

	Chinese character recognition			Vocabulary knowledge		
Steps and predictor	R^2	ΔR^2	β	R^2	ΔR^2	β
1. Nonverbal ability	.06	.06***	.07	.10	.10***	.17*
Vocabulary/reading control [a]			.10			.10
2. Syllable and phoneme-onset deletion	.09	.03*	.14*	.12	.02*	.11
3. Tone detection	.14	.05***	.24**	.17	.05***	.25***

Note. Vocabulary definition is a control variable in predicting Chinese character recognition while Chinese character recognition is the one in predicting vocabulary definition.

Tone detection independently accounted for 5% of variance in both Chinese word reading and vocabulary knowledge, after controlling for nonverbal ability, general language skills, and segmental level phonological awareness. The final standardized betas further suggest that tone detection is uniquely associated with Chinese word reading (β =.24) and vocabulary (β=.25).

Together the results of Experiment 1 show that distinctiveness of the height and contour influences young Cantonese-speaking children's tone perception. Moreover, tone sensitivity uniquely contributes to early Chinese word reading and vocabulary learning.

3. Experiment 2

Experiment 2 addressed research questions 2 and 3. Specifically, we examined whether segmental context (vowels and consonants) influences tone perception performance in older children who have developed adequate ability in labelling the six different lexical tones (Lee et al., 2002). Furthermore, this study extends previous work to examine the relationship between tone perception and language learning ability in both the first- and second-language.

3.1.1. Participants

153 children each in 2nd (69 girls and 84 boys) and 5th (73 girls and 80 boys) grade were recruited from five Cantonese-medium primary schools in Hong Kong. The mean age were 8; 01 (S.D. = 6 months) and 11; 01 (S.D.=6 months). All were native Cantonese-speakers, and they were from families with a medium income level according to the Hong Kong Census and Statistics Department (2006). All children were typical developing and they had no language disorder or hearing deficit, according to school and parental report.

3.1.2. Measures

The same tasks of nonverbal ability, syllable and phoneme onset deletion, Chinese character recognition and vocabulary definition described in Experiment 1 were also used for Experiment 2. They are graded tasks which have been successfully used to test a wide range of ages of children in prior research (Tong, McBride-Chang et al., 2009). Three new tests were added.

English word reading. Children were asked to read a list of 60 English words of increasing difficulty. The first 30 words were adopted from prior research (McBride-Chang & Kail, 2002). The other 30 words were selected from English textbooks that were most often used in Hong Kong Chinese schools. Both groups of children were tested from the first item, and testing stopped when children had 15 consecutive incorrect responses. The raw score of this test was the total accuracy.

Rhyme production. This task was adopted from The Hong Kong Test of Specific Learning Difficulties in Reading and Writing (Ho, Chan, Tsang, & Lee, 2000). Children were asked to produce real new monosyllables containing a target rhyme and tone, such as/aa1/. The target rhyme was orally presented in 3 monosyllables sharing the same rhyme and tone for each item,e.g., /gaa1/ (home), /faa1/ (flower), /haa1/ (shrimp), containing a common rime (also the target rime) /aa1/ and the high level tone. There were 16 items. One score was given for each item with one or more correct responses.

Tone discrimination. This odd-one-out task was designed for testing tone perception in older children, who may be able to consciously perceive and distinguish six different lexical tones in Cantonese. The six lexical tones were presented in three different segmental contexts (8 items for each) : same onset/different rime, e.g., */**si**1/* (lion), */**sam**1/* (hand), */**seng**1/* (heart), and */**sau**2/* (star); different onset/same rime, e.g., */**lei**4/*(pear),*/**kei**4*(flag), */**mei**4* (eyebrow), and */**pei**5/*(quilt), or different onset/different rime, e.g. /faa1/ (flower) , /hoi2/(sea), /ce1/(vehicle), /bat1/ (pen). Children were asked to choose which of four monosyllable words, spoken by experimenter and presented by pictures, with three of them containing the same tone, is different from other three. The total accuracy is the number of correct responses.

3.2 Procedure

The procedure is the same as that of Experiment 1.

3.3 Results

3.3.1. Effects of segmental contexts

The results of children's performance on different segmental contexts by grade are shown in Figure 3. A two-way factorial repeated measure ANOVA was conducted with segmental contexts (SO/DR, DO/SR, and DO/DR) as a within-subjects factor, and grade was a between-subjects factor (grade 2 and grade 5). The main effect of segmental contexts was significant, F (2, 608) = 77.93, p< .001, η^2 =.20, with pairwise comparisons showing that percentage correct scores for both DO/SR and SO/DR were higher than those for DO/DR. Moreover, children's tone performance for SO/DR was significant lower than that for DO/SR. There was no significant interaction between segmental contexts and grade.

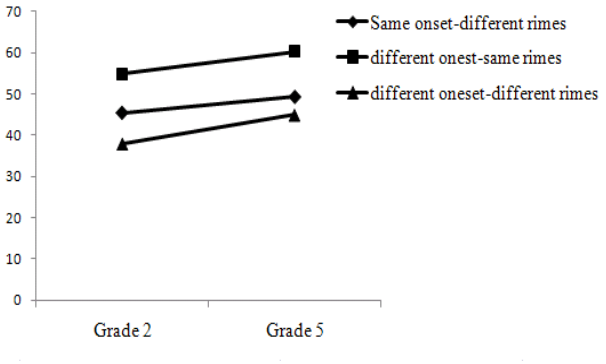

Figure 3. Children's performance by grade and tonal context in tone discrimination task

3.3.2. Prediction to Chinese reading, vocabulary and English word reading

To examine the unique contributions of tone discrimination to Cantonese-speaking children's first - and second-language achievements, we conducted multiple hierarchical regression analyses explaining Chinese character recognition, Chinese vocabulary and English word reading separately. Results of these analyses are reported in Tables 2, 3, and 4 including standardized betas, R^2 and R^2 change.

Table 2 shows the results of the regression equation predicting Chinese word reading from tasks of tone discrimination and all other measures. There was no significant association between tone discrimination and Chinese word reading in grade 2 and 5 when nonverbal ability, vocabulary knowledge, and segmental level of phonological awareness were statistically controlled.

Table 2. Predicting Chinese word reading

	G2 Chinese word reading			G5 Chinese word reading		
Steps and predictor	R^2	ΔR^2	β	R^2	ΔR^2	β
1. Nonverbal ability	.161	.16***	.06	.118	.12***	-.04
Vocabulary definition			.39***			.32***
2. Syllable and phoneme-onset deletion	.167	.01	.09	.154	.04*	.23**
Rhyme production	.170		-.04	.159		.01***
3. Tone discrimination		.00	-.06		.01	-.08

However, as shown in Table 3, tone discrimination uniquely explained approximately 2% and 3% of variance of Chinese vocabulary in grade 2 and grade 5, respectively, even after controlling for segmental level phonological awareness, word reading, and nonverbal ability.

Table 3. Predicting Chinese vocabulary

	G2 Chinese vocabulary			G5 Chinese Vocabulary		
Steps and predictor	R^2	ΔR^2	β	R^2	ΔR^2	β
1. Nonverbal ability	.208	.21***	.13	.173	.17***	.14
Chinese word reading			.33***			.30***
2. Syllable and phoneme-onset deletion	.260	.05**	.19*	.192	.02	.06
Rhyme production	.283		.03	.219		.03
3. Tone discrimination		.02*	.16*		.03*	.19*

Table 4 shows the results of the analysis for English word reading. Tone discrimination independently contributed 2% of variance of English word reading in grade 2, but not in grade 5, even after accounting for the variance of Chinese word reading, vocabulary, segmental levels of phonological awareness, and nonverbal ability.

Table 4. Predicting English word reading

	G2 English word reading			G5 English word reading		
Steps and predictor	R^2	ΔR^2	β	R^2	ΔR^2	β
1. Nonverbal ability	.258	.26***	.08	.337	.34***	.03
Vocabulary definition			.14†			.08
Chinese word reading			.20**			.40***
2. Syllable and phoneme-onset deletion	.406	.15***	.31***	.458	.12***	.25**
Rhyme production	.431		.15*	.458		.23**
3. Tone discrimination		.02*	.17*		.00	.02

Together these results show that the segmental contexts (vowels and consonants) account for difference in tone perception in Cantonese-speaking children. Moreover, tone perception is uniquely associated with vocabulary learning across grades, and English word reading in grade 2 but not grade 5. There is no association between tone sensitivity and Chinese word reading in either grade 2 and 5.

4. General Discussion and Conclusion

The results of this study suggest that the distinctiveness of acoustic cues (pitch height and pitch contour) and the nature of the segmental context (vowels and consonants) account for individual differences in perceiving and distinguishing lexical tone for native Cantonese tone speakers. Furthermore, lexical tone perception ability is strongly associated with Chinese vocabulary learning (decontextualized oral language skills) in both young and older children. It also uniquely contributes to young (kindergartener) Cantonese-speaking children's reading performance in both Chinese and English. These findings provide good initial support for the hierarchical compositional model of lexical tones in Cantonese proposed earlier, in which it is proposed that there are three key components of lexical tone representation: segmental, acoustic and semantic, with both segmental components and acoustic features are essential to a full semantic representation of lexical tones. The three key layers jointly contribute to lexical tone perception.

With regard to the first hypothesis concerning acoustic features, young Cantonese-speaking children's tone perception performance difference in tone contrasts support the existence of acoustic processing by young Cantonese-speaking children. Furthermore, there is differential weight in the reliance of pitch height and pitch contours among young children when consciously perceiving and identifying different tones. Our 5-year old Cantonese-speaking kindergarteners were almost perfectly able to perceive the difference between high level (55)-high rising (25); the overall accuracy was 95%. In contrast, they experienced more perceptual difficulty to distinguish the contrast of mid level (33)-low level (22) as compared with other tone contrasts. Such a striking performance difference in identifying these target tone in seems to reflect the relative importance of different acoustic cues in tone perception: the high level (55)-high rising (25) are distinguishable in terms of the pitch contour (the change of pitch over time), but have the same pitch height. In contrast, the mid level (33)-low level (22) are indistinguishable in pitch contour, and there exists a small difference in pitch height (approximately 7 Hz for the male Cantonese speakers, see Ciocca & Lui, 2003). This means that young Cantonese-speaking children are more attentive to pitch contour in perceiving and distinguishing tone contrasts. Such results support the relative importance of pitch height and pitch contour in lexical tone perception across different developmental periods (Ciocca & Lui, 2003). However, we need to be cautious to explain the differential roles of pitch height and pitch contour in tone perception. Apart from the apparent difference in perceiving the target tone in the contrasts of high level (55)-high rising (25) and mid level (33)-low level (22), we also found that children performed equally in tone contrasts between high-rising (25)-low rising (23) and low rising (23) –low level (22), high rising (25)-low rising (23) and low falling (21)-low level (22) differing either pitch height or pitch contour. The absence of a difference of children's tone perception in these pairs reflects the joint contribution of pitch height and pitch contour in lexical tone perception (Lee et al., 2002), which supports the lexical tone model we proposed. In addition, the results of 5-year old Cantonese-speaking children focusing on different acoustic cues in tone perception is an extension of previous study (e.g., Ciocca & Lui, 2003) showing native Cantonese speakers' difficulty in distinguishing high level (33)-low level (22) contrast by systematically varying tone pair contrasts in two monosyllables, and this may therefore increase the generality of the results.

With regard to the second hypothesis, concerning segmental context, a robust effect of segmental contexts on tone perception was uncovered in both grade 2 and 5 children, in that children's tone performance significantly decreased as the distinctiveness of segmental contexts (vowels and consonants) increased. More specifically, children experienced more difficulty to perceiving and distinguishing lexical tones in the condition of different onset and different rimes relative to the other two conditions sharing a common onset or rime. These findings are partly in concert with the prediction of a class of models, i.e., developmental weighting shift theory (e.g., Nittrouer et al., 2000) and general central auditory theory (e.g., Eisenberg, et al., 2001) in which children are sensitive to syllable-unit transition cues in perceiving and identifying speech contrasts. Furthermore, a consistent pattern of tone perception performance in three different segmental contexts across grades provides evidence for segmental representation of lexical tone, as proposed in a hierarchical composition model of lexical tones in which that tone perception is determined by the salience of segmental components (vowels and consonants) within or across syllables. We are the first to show that the segmental context, i.e., the transition of the vowel and consonants within and across syllables, affects native tonal speakers' perception of differing tone contrasts.This helps to specify a potential explanation of difference in tone perception in older children or adults who have developed adequate ability to perceive and label different tones.

With regard to the third hypothesis, concerning semantic representation in first and second language learning, we found that, at least for 5-years old Cantonese-speaking children, tone perception is uniquely associated with Chinese and English word reading. Moreover, tone perception is strongly associated with Chinese vocabulary across three grades of children. The contribution of tone perception to word reading in Chinese and English reported here extends earlier findings of the relationship between tone sensitivity and word reading in young Hong Kong Chinese children (McBride-Chang, Tong et al., 2008; Wang et al., 2005). McBride-Chang et al. (2008) reported evidence of a link between tone sensitivity and Chinese word reading but failed to find such a link between tone sensitivity and English word reading. Wang et al. (2005) found that tone sensitivity is linked with English pseudoword reading in Mandarin-English bilingual learners. Our study is the first to investigate the relationship of tone sensitivity to oral vocabulary learning, word reading in both first- and second-language in three different developmental levels of Cantonese-speaking children (kindergartener, second graders and fifth graders). Findings of our study support a link between tone sensitivity and word reading in both Chinese and English in young Cantonese-speaking children, and show the strong association between tone sensitivity and Chinese vocabulary learning in different ages of children.

There are at least two explanations for the changes in relative contribution of tone sensitivity to Chinese word reading across young and older children. The first lies in developmental growth of tone sensitivity across ages. According to previous findings regarding Cantonese-speaking children's tone development (Ching, 1984; Ching, 1990, Lee et al., 2002), children have difficulty in correctly identifying and labeling all six lexical tones before the age of 10. There is also evidence that children at age of 10 can perform equally well as adults in tone perception (Ciocca & Lui, 2003). Regarding our participants, the young 5-year-old kindergartners in Experiment 1 show great variation in identifying different tones contrasts (see Figure 2). In contrast, the second-and fifth-graders fifth graders in Experiment 2 are at the age (8 and 11 year) at which children have been found to be able to identify the six lexical tones (Ciocca & Lui, 2003). The variance in tone perception performance is relatively small which may limit the capacity for the prediction of word reading.

The second explanation of change of roles of tone sensitivity in Chinese word reading concerns the hierarchy of acoustic, segmental, and semantic levels of lexical tone representation, as shown in Figure 1. It is possible, that the younger Cantonese-speaking children give greater weight to acoustic and segmental levels of information of lexical tone, and so they are more likely to encode lexical tone in terms of segmental and acoustic dimensions - essential components of phonological representation of words across languages. There is substantial empirical evidence that phonological awareness is important to early Chinese word reading (e.g., McBride-Chang et al., 2008). This is perhaps the primary reason why tone sensitivity contributes to early English word reading. As children grow with increasing long-term exposure to lexical tones, they may develop a much more language-specific representation of lexical tone, and become more likely to encode lexical tone in terms of the semantic dimension. Moreover, this may then become an essential part of the Cantonese word itself, such that lexical tone is not conceptually distinguished from the psycholinguistic representation of word.

In sum, both acoustic (pitch height and pitch contour) and segmental context (vowels and consonants) dimensions of tones influence tone perception in Cantonese-speaking children. There is a strong link between tone perception and oral vocabulary learning in Chinese. However, tone perception contributed uniquely to word reading in both Chinese and English but only for the younger, Grade 2, participants. These findings support a hierarchical representation model of lexical tones in which tone perceptions are determined by the connections of acoustic, segmental and semantic cues. Further research will examine this model in a fine-grained design investigating the developmental, cognitive and neurological mechanisms of lexical tone perception.

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