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Perception and Production of Lexical Tones by Young Children

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Abstract

The research investigated the development of young children's Cantonese lexical tone perception and production abilities. Sixty-five normally developing children, divided into four age groups (2 - 2;11, 3 - 3;11, 4 - 4;11 and 5 - 5;11), were tested on their tone perception and production abilities. Fifteen adult participants were involved in the tone production task and formed the control group (22 - 22;11). For tone perception, children across all age groups attained with the highest percentage accuracy in perceiving high-level and high-rising (HL-HR) and high-level and low-level (HL-LL) tonal contrasts. Children showed the greatest confusion in perceiving mid-level and low-level (ML-LL), high-rising and low-rising (HR-LR), low-rising and low-level (LR-LL) tonal contrasts. These patterns of perception responses could be explained on the basis of the similarities or differences in the fundamental frequency (f_0) level and the contour between the members of the tonal contrast. For tone production, high-level (HL) and mid-level (ML) tones were first acquired by age group 2 - 2;11 and low-level (LL) tone was subsequently acquired by age group 3 - 3;11. All six tones were acquired by the age group 4 - 4;11. Low-rising (LR) tone was the latest to be acquired and it was predominantly substituted with high-rising tone (HR). This could be explained by the confusion of the similarities of f_0 onset and the rising contour pattern between these tones.

Introduction

Cantonese tonal system

Tones carry heavy functional load in Cantonese because different fundamental frequency (f_0) patterns on the same segment convey different semantic meanings (Bauer & Benedict, 1997; So & Dodd, 1994). According to Bauer & Benedicts (1997), a tone contour has both a vertical dimension of pitch height (high, mid and low) and a horizontal dimension of the direction of pitch movement (level, rising and falling). Pitch is the perceptual correlate of dynamic changes in f_0 (Bauer & Benedict, 1997; Ciocca & Lui, 2003). Basically, there are six contrastive tones in Cantonese. They are: high-level (55), high-rising (25), mid-level (33), low-falling (21), low-rising (23) and low-level (22). In this study, abbreviations were used for the six lexical tones: HL (high-level), HR (high-rising), ML (mid-level), LF (low-falling), LR (low-rising) and LL (low-level). In addition to the above tones, there are also three entering tones, namely high-stopped (5), mid-stopped (3) and mid-low stopped (2), but they are considered as the variations of the three level tones (Bauer & Benedict, 1997).

Ching (1984) claimed that the processing ability of temporal and frequency information of tones was innate in the intact normal auditory mechanism. However, the perceptual skills of tone normalization were not innate and a learning process existed at the basic level of lexical tone learning. Subsequently, various studies using different methodologies were conducted to investigate the tone perception and tone production skills during the course of children's development.

The development of tone perception in Cantonese-speaking children

Ching (1984) had investigated the acquisition of tone in Cantonese-speaking children from aged 4;00 to 10;00 with an equal number of male and female subjects. There were seven age groups

and each group consisted of ten subjects. The syllable /ji/ with six contrastive tones was used to form six different meaningful words. They were clothing (‘衣’, /ji55/), chair (‘椅’, /ji25/), the first word of spaghetti (‘意’, /ji33/), child (‘兒’, /ji21/), ear (‘耳’, /ji23/) and two (‘二’, /ji22/). The target words were presented in isolation by an open-reel tape-recorder and a loudspeaker. The subjects were required to identify the corresponding written word among the six choices. The study reported that LF tone was best identified in children as there is only one falling tonal contour pattern in Cantonese lexicon. However, children had confusions in the identification of ML-LL tonal contrast and LR-LL tonal contrast. Her study reported that children aged four would be able to recognize isolated lexical tone and make confident judgments in tones identification by the age of 10;00. Nevertheless, her study had a few limitations. Since there were six alternatives to choose from, this might have exceeded the cognitive capacity of young children. The participants were required to match the presented tone with the six written words but young children might not know these written words prior to the test. As the stimuli were presented in isolation, there was also no chance for the subjects to accommodate for the speaker’s overall fundamental frequency range before making the tone perception judgment (Kent, 1997). Her study did not measure the adult’s tone identification performance, which should act as a control group to compare with the children’s performance. Therefore, the age at which children achieved adult’s performance in tone perception could not be confirmed (Sze, 2004).

Ciocca and Lui (2003) carried out a study, which was modified from Ching’s study (1984), to investigate the development of tone perception in sixty Cantonese-speakers who were divided into four age groups (4;00 – 4;11, 6;00 - 6;11 and 10;00 – 10;11, and adults). In the study, the performance of tone identification of adults was compared with that of children. The number

of choices in the identification task was reduced from six to two to determine the effect of the number of choices on tone perception. The syllable /ji/ was employed similar to Ching's study (1984) and formed eight pairs of tonal contrast. They were HL-LL, HL-ML, ML-LL, HL-HR, LF-LR, LR-LL, LF-LL and HR-LR tonal contrasts. Moreover, pictures were used to match with the presented tones instead of written words so that the young children were not hampered by their knowledge of the written words (Sze, 2004). In addition, the target word was presented in the middle of a carrier phrase (for example: 'I will read **chair** aloud to you'; '我會讀**椅**俾你聽'; /ŋɔ23 wui33 tuk2 **ji25** pei35 lei23 tɛŋ55/) to accommodate for the speaker's overall fundamental frequency range (Kent, 1997) and to avoid 'sentence-final tone lowering effects' (Vance as cited in Ciocca and Lui, 2003). The study found that children aged 4;00 – 4;11 performed at chance level on ML-LL and HR-LR tonal contrasts out of the eight tonal contrasts. They also found that the ML-LL and HR-LR were the most difficult tonal contrasts to be identified. The results of the great confusion in identification between the ML-LL tonal contrast replicated that in Ching's study (1984) which was explained by the similar pitch pattern and the small f_0 separation. Based on this finding, Ciocca and Lui (2003) hypothesized that the similarity in the f_0 pattern and the contour between the members of a contrast would lead to confusion. Moreover, the study showed that children could perceive as accurately as adults by the age of 10;00. Although several modifications had been made in Ciocca and Lui's study (2003), some of the words used in the study, for example, /ji55/ (clothes), /ji25/ (chair) and /ji21/ (son), might not be familiar to children as these words are used in written Chinese but they are not colloquial Cantonese terms (Sze, 2004). The young children might not have the lexical knowledge of these words which might have undermined the children's ability in the tone identification task.

Lee, Chiu and van Hasselt (2002) investigated the tone perception ability in thirty-one

children aged 2;09 - 3;03 and they adopted words in those children's receptive vocabulary repertoire for the stimuli to eliminate the problem of words familiarity in young children. Three pairs of tonal contrasts (HL-HR, HL-LF and HR-LF) of words and non-words (using the vowel /a/) stimuli were used to determine whether the pitch height or the contour was the more salient cue in tone perception. The HL-HR tonal contrast was hypothesized to be the most difficult tonal contrast to be identified because the members of the tonal contrast differed only in the contour while the HL-LF and HR-LF tonal contrasts differed in both f_0 and contour. Live voice was used to maximize the response success rate of young children (Kirk & Lento as cited in Lee et al., 2002). In addition, the stimuli were presented in isolation so that the pitch differences among isolated tones were greater than within a sentence frame (Fok as cited in Lee et al., 2002). They found that children perceived better when using word stimuli than non-word stimuli. Also, HL-HR tonal contrast and HL-LF tonal contrast were easier to be identified than the HR-LF tonal contrast which was found to be disagreed with their initial hypothesis. They reported that f_0 onset was more important than f_0 offset for tone identification as the study discovered that HR tone was difficult to perceive with LF tone. However, there were some limitations in the study. The use of live voice presentation might be less well controlled when compared with recorded speech (Barton, 1980). Non-verbal cues, e.g. eye gaze or body movement towards the correct response, might be given by the speakers subconsciously (Barton, 1980). Moreover, the speakers might have provided extra stress on the tone contour pattern. These additional cues might have helped the children to identify the corresponding tone, resulting in better performance in the tone identification task (Sze, 2004). Also, since only three tonal contrasts were used, the results might not truly reflect children's perception ability of all the tones.

Sze (2004) investigated the perception of various Cantonese tonal contrasts as a function

of age and word familiarity on eighty participants. Sixteen subjects were selected from five age groups (2;09 - 3;03, 4;00 - 4;11, 6;00 - 6;11, 10;00 - 10;11 and adults). There were two tasks in her study. In one task, the stimuli consisted of six contrastive tones with the syllable /ji/ used in the study of Ciocca and Lui (2003). In the other task, sixteen familiar words that are minimally contrasted in lexical tones were used (Refer to Appendix B). The subjects heard the target word within a carrier phrase ('I will read ___ aloud to you'; '我會讀___俾你聽'; /ŋɔ23 wui33 tuk2 ___ pei35 lei23 tɛŋ55/) in both tasks and identified it by selecting one out of two pictures. Half of the participants completed the task using colloquial Cantonese terms before the task using stimuli in Ciocca and Lui's study (2003). The remaining half completed the tasks in reverse order so as to balance the effect of fatigue (Sze, 2004). The results showed that significant improvement in tone perception was observed from the ages 2;09 - 3;03 to 4;00 - 4;11, 4;00 - 4;11 to 6; 00 - 6; 11 and 6;00 - 6;11 to 10;00 - 10;11. The children achieved adult performance in tone perception by age 10;00, which replicated the results in Ciocca and Lui's study (2003). The HR-LR, ML-LL and LR-LL tonal contrasts were relatively the most difficult contrasts to be identified. The HL-HR and HL-LL tonal contrasts were relatively the easiest contrasts to be identified. Findings of Sze (2004) also replicated the results of Ciocca and Lui's study (2003) on the greatest confusion in perceiving HL-HR and ML-LL tonal contrasts. In addition, it replicated the results of the easiest perception for HL-HR tonal contrast in Lee et al.'s study (2002). This result also re-confirmed that the similarity in f_0 onset and contour between the members of the tonal contrasts might lead to the confusion during tone perception. Moreover, the children of age group 2;09 – 3;03 did better at discriminating the HL-HR and HL-LL tonal contrasts when colloquial Cantonese terms were used instead of written Cantonese terms. This showed that word familiarity effect affected the tone perception in children younger than the age 3;03. Therefore,

colloquial Cantonese terms should be used in further study on tone perception in young children.

The development of tone production in Cantonese-speaking children

Some previous studies have claimed that the acquisition of tone production is completed by the age of 2;00 (Fong, 2004; So & Dodd, 1995; Tse, 1978). There were variations in the children's tone production patterns in different studies.

The longitudinal case study of Tse (1987) hypothesized that the order of tone acquisition would follow some universal principles. At Stage one, children aged 1;02 - 1;04 would acquire HL and LF tones. At Stage two, children aged 1;05 - 1;08 would acquire ML, HR and the three entering tones. At Stage three, children aged around 1;09 would acquire LR and LL tones. His study further reported that LR tone was more difficult to acquire than the HR tone. However, Tse's study was based on a single case study, and therefore it was not representative for the whole population. His findings on tone acquisition combined both tone production and perception data and he had made an assumption that there were close correlations between tone production and tone perception, but without further explanations given. The study was also not systematically planned as it was a naturalistic observation without citing the criteria for determining whether the tones were acquired (Sze, 2004). Therefore, it was necessary to conduct further studies and draw conclusions on the basis of a more representative number of studies, sample size and language samples.

So and Dodd (1995) also carried out a longitudinal study of tone acquisition using a picture naming task on four Cantonese-speaking children aged 1;02 to 2;00 and a cross-sectional study of tone production on two hundred and sixty-eight Cantonese-speaking children aged 2;00 to 6;00 using a picture naming task and a story retelling task. In both studies, a tone was judged

to be acquired when it was used contrastively on at least 50% opportunities or correctly on 90% of opportunities. Both studies reported that children firstly acquired HL and ML tones, and then acquired HR tone. The children acquired the rest of the tones simultaneously by age 2 with individual variations. However, the studies did not report the acquisition sequence of the other three tones and the tonal error patterns made by the children on various tones. Also, only inter-rater reliability was reported for children's production of vowels and consonants, but not for tones. Their study did not investigate the children's tone perception ability, therefore their conclusion that the children acquired all tones by the age of 2 was only based on the children's tone production ability.

Fong (2004) conducted a cross-sectional study on fourteen children of ages ranging from 12 to 24 months and a longitudinal study on five of the children among the group. The acquisition criterion was set at 5% occurrence in a ten-minute spontaneous speech sample during a one-hour play. The study reported that HL tone emerged at 12 months of age and it was followed by ML and HR which emerged at 15 months of age. Then it was followed by LF and LR which emerged at age 21 months of age, and finally by LL which emerged at 24 months of age. The HL and ML tones which were relatively early emerged in tone production were in agreement with So and Dodd's study (1995). Some general patterns of tone production acquisition were observed in the studies. High tones preceded low tones, level tones preceded contour tones and rising tone preceded falling tones. The duration of tone acquisition was found to last for approximately 10 months. There were some limitations in the studies as the data collection was based on the ten-minute spontaneous speech sample which might not include all the tones that the child could produce. A relative small sample size of each age group (n = 2 or 3) was used to draw conclusions on tone production abilities on that particular age range and the

trend of tone acquisition patterns. In the studies, standard deviations or standard errors were not reported to indicate the individual differences in the children tone production differences.

All the above findings showed that Cantonese tone production was roughly completed by the age of 2, however the order of acquisition of the six tones and their respective tonal error patterns were not clearly determined.

A Mandarin study on children's lexical tone perception and production development

Wong, Schwartz and Jenkins (2005) investigated thirteen 3-year-old children's perception and production abilities of the four Mandarin lexical tones (level, rising, dipping and falling) in monosyllabic words using picture pointing and picture naming tasks respectively. Although the study was on the four Mandarin lexical tones, the methodology of the study provided insights for this current research. The criterion used in tone production task was that a tone was considered to have 'emerged' when it was produced spontaneously or imitatively at least once. It was reported that children perceived the level, rising and falling tones with relatively high accuracy. The children produced and perceived dipping tones with the greatest difficulties. There was great variability for the best tone produced by the children.

Purpose of the Study

This research will investigate children of the younger age group starting from age 2;00 to age 5;11 so as to get a better picture of child's tone perception and tone production developmental milestones. The research will be based on the methods and designs used in the study of Ciocca and Lui (2003), Sze (2004) and Wong et al. (2005). The tone perception ability will be examined by picture pointing task and the tone production ability will be investigated by picture naming

task. Target words using colloquial Cantonese words will be placed in the medial position of the audio stimuli to avoid 'sentence final tone lowering' effect (Kent as cited in Sze, 2004; Vance as cited in Ciocca and Lui, 2003), and the number of choices provided to the children for perception task will be limited to two so as to reduce the children's cognitive loading. This research will conduct an in-depth investigation about the child's tone perception developmental milestones (which tonal contrast is easier or harder to perceive for each age group) and tone production developmental milestones (the order of acquisition and the tonal error patterns of each age group). Furthermore, the findings of this research can be applied in the clinical assessment and rehabilitation for child's tone perception and production errors.

In the current study, two main research questions will be focused. The first research question is to investigate the pattern of perception of various tonal contrasts as a function of age group in comparison with the findings of Ching (1984), Ciocca and Lui (2003), Lee et al. (2002) and Sze (2004). This current study will provide more information on which tonal contrasts are easier to be identified and which tonal contrast leads to the greatest confusion across age groups and within each age group.

The second research question is to investigate the tone production pattern of various tones as a function of age group in comparison with the findings of Fong (2004) and So and Dodd (1995). This current study will provide more information on which tones are produced with the highest accuracy and the lowest accuracy across age groups and within each age group, and their corresponding tonal error patterns.

Methodology

Participants

Sixty children participants aged 2;00 to 5;11 and fifteen female adult participants aged 22;00 to 22;11 were recruited. Consent forms for the children to participate in the research were signed by their caregivers (Refer to Appendix A). All the children participants used Cantonese as their mother tongue with no known prior language or speech disorder. They have normal intelligence, hearing and visual abilities according to the child assessment reports in the Maternal and Child Health Clinic (MCHC) provided by their caregivers through telephone interviews. The children participants were selected at random from two normal kindergartens mainly using Cantonese as the medium of instruction. All the female adult participants, who were selected from the population of the university students in Hong Kong, had received 4 years of phonetic training in the Department of Speech and Hearing Sciences. The female adults were recruited for this research because the f_0 of female is closer to the f_0 of the children for the ease of tone production comparison (Refer to Table 1).

Table 1: The subject distribution for this tonal project

Age ranges	Number of participants
Aged 2;00 - 2;11	15 participants (7 females, 8 males)
Aged 3;00 - 3;11	15 participants (6 females, 9 males)
Aged 4;00 - 4;11	15 participants (6 females, 9 males)
Aged 5;00 - 5;11	15 participants (7 females, 8 males)
Aged 22;00 - 22;11	15 participants (All females)

Stimuli and materials

Eight contrastive tonal pairs with a total of sixteen colloquial Cantonese targets were selected for both tone perception and tone production task (Refer to Table 2). The HL-ML, HL-LL and ML-LL tonal contrasts were chosen since the members of the contrasts were different in height of f_0. The LR-LF tonal contrast was chosen as the members of the contrasts differed in terms of the direction of f_0 production. The HL-LR, LR-LL and LF-LL tonal contrasts were chosen because the member of the contrasts differed in terms of their contour patterns.

Table 2: Sixteen colloquial Cantonese targets for tone production and perception tasks

Target word	Target word	Label for tonal contrast
臂 (/bei33/, 'arm')	鼻 (/bei22/, 'nose')	ML - LL
煲 (/bou55/, 'pot')	布 (/bou33/, 'cloth')	HL - ML
鞋 (/haai21/, 'shoe')	蟹 (/haai23/, 'crab')	LF - LR
魚 (/jy25/, 'fish')	雨 (/jy23/, 'rain')	HR - LR
老 (/lou23/, 'old')	路 (/lou22/, 'road')	LR - LL
棉 (/min21/, 'cotton')	麵 (/min22/, 'noodle')	LR - LL
書 (/sy55/, 'book')	樹 (/sy22/, 'tree')	HL - LL
湯 (/tong55/, 'soup')	糖 (/tong25/, 'sweet')	HL - HR

For the tone perception task, the stimuli recording was carried out with a Macintosh Power Mac 7100 computer in a soundproof room. A male native Cantonese speaker was employed for the speech recording. The distance between the speaker's mouth and the microphone was kept constant at 10 cm to ensure the recording level was similar for all stimuli. The sentence stimuli were recorded five times at a random sequence. Three native Cantonese

listeners who have received four years auditory training were employed to listen to all the sentence stimuli. The sentence stimuli which were best identified were chosen and re-synthesized so that the tones had the same f_0 values. Then, another three native Cantonese listeners who have received four years auditory training were employed to check the stimuli again. The computer program written with the HyperCard 2.2 software development package (Apple Computer, Inc. 1993) with headphones Sennheiser HD 280 was used for the presentation of the auditory input at a comfortable listening level and the visual stimuli for the tone identification task.

For tone production, the participants' productions were recorded by digital recording pen USB-350 and MD discs using Sony MZ-R91 with a microphone Sony ECM-717. The sixteen pictures used for elicitation of tone production were shown in Appendix B and the charting form for the tone productions was shown in Appendix C.

Testing procedures

There were two tasks in this research: the tone perception and tone production tasks. The children participants were involved in both the tone perception and production tasks with their caregivers, while the adult participants were only involved in the tone production task. Each child attended a one-hour testing session for both the production and perception tasks, while each adult attended a 15-minute testing session for production task. The tone production task was carried out prior to the tone perception task to ensure the children were familiar with the target words and their corresponding pictures for the tone perception task. The data of the children were collected in a quiet classroom in the kindergartens. The data of the adults were collected in a soundproof room at the Department of Speech and Hearing Sciences in the Prince Philip

Dental Hospital.

Firstly, the investigator introduced each word stimuli and the corresponding pictures with semantic cues given to ensure that all participants had the lexical knowledge of the words stimuli. Four of the sixteen words stimuli (手臂, /sau25 bei33/, 'arm'; 落雨, /lok6 jy23/, 'rain'; 老伯伯, /lou23 bɒk33 bɒk33/, 'old' and 綿花, /min21 fa55/, 'cotton') were introduced in disyllabic or polysyllabic words to preserve the semantic meaning corresponding to the pictures, while the rest of words stimuli were presented as monosyllabic word. Then the participants were asked to name the pictures in random order using prompting questions (for example: 'What's this?'; '咩來架?'; /mɛ55 lei21 ka33/). After naming the sixteen targets once, a sticker was given to each child participant as a reward. The participants were then asked to name the pictures in random order again to find if there were inconsistent tone productions and stickers were also given to them as rewards at the end. Thus, thirty-two tone productions sample would be collected from each participant. If the target word was not elicited using prompting questions, the investigator would provide semantic cues to the participants. If the participants failed to produce the target word with semantic cues and prompts, an imitation was elicited to ensure equal exposure of the target and a symbol 'IM' was recorded in the corresponding target in the tone production charting form.

Tone perception task would be carried out immediately after tone production task for the child participants. In the tone perception task, there were four trials for each of the eight tonal contrasts as shown in Table 2. The trials were presented in random order. For each trial, four repetitions were carried out whenever possible, and thus making a total of one hundred and twenty-eight trials (8 tonal contrasts x 4 trials for each tonal contrast x 4 repetitions). There was a

possibility that child participants might select pictures randomly from the two pictures. Therefore, clear instructions and five modelings were given to the children at the beginning of the perception task. There was also a possibility that children might get the correct picture by chance, so four repetitions with a total of one hundred and twenty-eight trials were conducted in this task. In order to prevent the participants from feeling fatigue and exhausted, the task was divided into two parts (each consisting of two repetitions with a total of sixty-four trials) and the participants were given a ten-minute short break and reinforcement (snacks) after completing sixty-four trials. Lastly, the investigator would encourage the child to continue and complete another sixty-four trials for some bigger reinforcements (snacks and a paper puppet).

Due to the children's short attention span and the possibility of getting fatigue, 51% of the children participants were not able to complete a total of one hundred and twenty-eight trials (four repetitions). The actual number of trials for the tone perception task was listed in Table 3.

Table 3: The distribution of participants in accomplishing a certain number of trials in the tone perception task across four age groups

Age group	2 - 2;11	3 - 3;11	4 - 4;11	5 - 5;11
Completed 64 trials (2 repetitions)	11	7	13	1
Completed 96 trials (3 repetitions)	1			
Completed 128 trial (4 repetitions)	3	8	2	14

After five modelings were given by the investigator, the child was asked to point to either one out of two pictures after hearing the stimuli ('I will read fish aloud to you'; '我會讀魚俾你聽'; /ŋɔ23 wui33 tuk2 jy25 pei35 lei23 tɛŋ55/) through the headphones Sennheiser HD 280.

Two pictures representing each tonal contrast were presented side by side on the screen. One picture was on the right side of the screen and the other on the left side of the screen. Then the participant was required to point to the picture that corresponded to the word he had heard. The investigator clicked on the corresponding button on the screen by using the mouse pad. After each selection, the program moved on to the next trials. The results were saved in a computer file for later analysis.

Data Analysis

For tone perception results, the percentage of accuracy for identifying each tonal contrast was analyzed using a 2-way ANOVA (4 x 8) to compare the performance of eight tonal contrasts within and across four age groups. Post-hoc Tukey HSD test was used to investigate the interaction effect among the two factors (the performance of the four age groups and the eight tonal contrasts) and locate the source of the significant differences.

For tone production results, inter-rater reliability was measured by asking two Year Four students who have received four years of phonetic training from the Department of Speech and Hearing Sciences to listen to the children's production separately from the MDs and use the charting forms (Refer to Appendix C) to record the children's productions. They transcribed the children's production using International Phonetic Alphabet (IPA) symbols. Inter-rater reliability using point-to-point agreement was calculated between twenty-eight participants' productions, each with thirty-two productions, and therefore, making a total of eight hundred and ninety-six tone productions. If there was a difference between inter-rater tonal judgments, the final decision of the child's tone production would be based on the on-line charting of the child's production at the kindergartens.

Results

Results for tone perception

The mean percentage of accuracy for the tone perception task was presented in the Figure 1. The upward going arrow indicated the statistically significant differences between age groups for each tonal contrast.

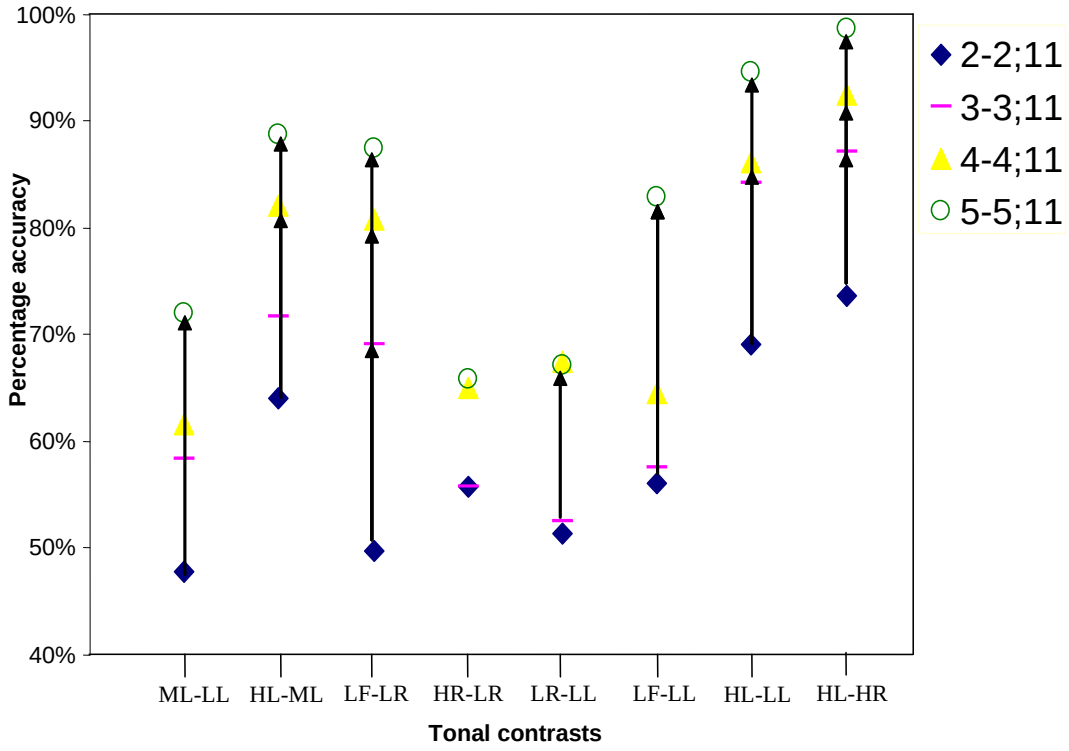

Figure 1. The mean percentage of correct responses for all tonal contrasts and age groups

There was a general trend of increase in the mean tone perception accuracy across the four age groups except for the tonal contrast LR-LL for age groups 4 - 4;11 and 5 - 5;11 which had a decrease for 1% of accuracy.

Results in Binomial Test

Since there were only two choices in each trial during the tone perception task, binomial test was employed to find out whether the subjects responded above chance for each contrast (Sigel & Castellan, 1988, pp. 42-44). The following equation was used:

$$Z = \frac{(Y \pm 0.5) - Np}{\sqrt{Npq}}$$

N represented the total number of trials for each tonal contrast in each task in each age group. p represented the probability of getting the correct response in each trial, which was 0.5. As q was equal to p, q was also 0.5. Y represented the total number of correct trials for each tonal contrast in each age group. 0.5 was subtracted from Y when the value of Y was greater than Np (Sigel & Castellan, 1988).

Table 4: Tone perception task results and standard errors for four age groups

Tonal contrast (**Lowest %**, *Highest %*)	% accuracy for age group 2 - 2;11 (Standard error)	% accuracy for age group 3 - 3;11 (Standard error)	% accuracy for age group 4 - 4;11 (Standard error)	% accuracy for age group 5 - 5;11 (Standard error)
ML-LL	**48%** (5%)	58% (3%)	**62%** (4%)	72% (4%)
HL-ML	64% (4%)	72% (5%)	82% (5%)	89% (4%)
LF-LR	50% (4%)	69% (5%)	81% (5%)	88% (5%)
HR-LR	56% (3%)	56% (4%)	65% (4%)	**66%** (5%)
LR-LL	51% (3%)	**53%** (3%)	68% (5%)	67% (4%)
LF-LL	56% (4%)	58% (4%)	65% (6%)	83% (5%)
HL-LL	69% (4%)	84% (3%)	86% (5%)	95% (3%)
HL-HR	*74%* (4%)	*87%* (4%)	*93%* (2%)	*99%* (1%)

The performance in each tonal contrast in each age group was significant and above chance level (Age 2, N=148, p < .05; Age 3, N=184, p <.05; Age 4, N=136, p <.05; Age 5,

N=232, p <.05), except for the tonal contrasts of ML-LL, LF-LR, HR-LR, LR-LL and LF-LL in age group 2 - 2;11 and HR-LR and LR-LL in age group 3 - 3;11 which were underlined in Table 4.

ANOVA of Variance was used to compare the performances across age groups and across different tonal contrasts. There were significant tonal contrast effect (F (7, 98) = 40.46, p <0.01) and interaction effect between age and tonal contrast (F (21, 294) = 1.75, p < 0.05).

Post-hoc results of the interaction effect of eight tonal contrasts

There were significant improvements in perceiving all tonal contrasts except for the tonal contrast of HR-LR (F (3, 42) =1.813, p >.1). Significant differences in tone perception performance were found for the tonal contrasts of LR-LL (F (3, 42) = 5.80, p<.005), HL-LL (F (3, 42) = 7.05, p<.001), ML-LL(F (3, 42) = 5.19, p <.005), HL-HR (F (3, 42) = 14.17, p <.001), LL-LF (F (3, 42) = 7.62, p <.001), HL-ML (F (3; 42) =8.32, p <.001) and LF-LR (F (3, 42) =12.169, p <.001).

HL-HR and HL-LL tonal contrasts were perceived significantly better than ML-LL, HR-LR, LR-LL and LF-LL (Tukey HSD, p <.005). HL-HR tonal contrast was also perceived significantly better than ML-LF (Tukey HSD, p <.05). HL-ML tonal contrast was perceived significantly better than ML-LL, HR-LR and LR-LL (Tukey HSD, p <.05).

The order of tonal contrast perception accuracy in general was presented from the easiest to the hardest tonal contrasts: HL-HR and HL-LL, HL-ML, ML-LF, LF-LL, ML-LL, LR-LL and HR-LR.

Post-hoc results of the interaction effect of the four age groups and the eight tonal contrasts

Six tonal contrasts were found to have significant interaction effect across the age groups.

For ML-LL tonal contrast, the perception performance of the age group 5 - 5;11 was significantly better than the age group 2 - 2;11 (Tukey HSD, p <.001).

For HL-ML tonal contrast, the perception performance of the age group 4 - 4;11 was significantly better than the age group 2 - 2;11 (Tukey HSD, p <.001).

For ML-LF tonal contrast, the perception performance of the age groups 3 - 3;11, 4 - 4;11 and 5 - 5;11 were significantly better than the age group 2 - 2;11 (Tukey HSD, p <.05). The perception performance of the age group 5 - 5;11 was significantly better than the age group 3 - 3;11 (Tukey HSD, p <.05).

For LF-LL tonal contrast, the perception performance of the age groups 4 - 4;11 and 5 - 5;11 were significantly better than the age group 3 - 3;11 (Tukey HSD, p <.05). The perception performance of the age group 5 - 5;11 was also significantly better than the age group 2 - 2;11 (Tukey HSD, p <.001).

For HL-LL tonal contrast, the perception performance of the age group 5 - 5;11 was significantly better than the age group 2 - 2;11 (Tukey HSD, p <.001).

For HL-HR tonal contrast, the perception performance of the age groups 4 - 4;11 and 5 - 5;11 were significantly better than the age group 2 - 2;11 (Tukey HSD, p <.05).

Furthermore, all four age groups were found to have significant interaction effect across tonal contrasts.

For age group 2 - 2;11, the children perceived HL-LL and HL-HR tonal contrasts significantly better than ML-LL and ML-LF (Tukey HSD, p <.005). They also perceived HL-HR tonal contrast significantly better than LF-LR (Tukey HSD, p <.005).

For age group 3 - 3;11, the children perceived HL-LL and HL-HR tonal contrasts

significantly better than ML-LL, HR-LR, HL-ML and LF-LL (Tukey HSD, p <.001). They perceived HL-LL tonal contrast significantly better than LR-LL (Tukey HSD, p <.05).

For age group 4 - 4;11, the children perceived HL-LL and HL-HR tonal contrasts significantly better than ML-LL, HR-LR, LR-LL and LF-LL (Tukey HSD, p <.05). They perceived HL-ML and ML-LF tonal contrasts significantly better than ML-LL (Tukey HSD, p <.05).

For age group 5 - 5;11, the children perceived HL-LL and HL-HR tonal contrasts significantly better than ML-LL, HR-LR and LR-LL (Tukey HSD, p <.05). They perceived HR-LR and LR-LL tonal contrasts significantly better than HL-ML and ML-LF (Tukey HSD, p <.01).

Perceptual judgment of tone production results

Point-to-point inter-rater reliability was calculated with 88% agreement for twenty-eight children production samples with a total of eight hundred ninety-six tonal trials (28 children x 32 tone productions for each child). In this study, a tone was judged to be acquired when it was produced correctly on 90% of opportunities.

Overall, the tone production of the age group 2 - 2;11 resulted with a mean of 88% accuracy and the tone production accuracy improved across the age groups from 93% accuracy for age group 3 - 3;11, 96% accuracy for age group 4 - 4;11, 98% accuracy for age group 5 - 5;11 and 99% accuracy for the adult group.

In Table 5, the percentages of tone production errors that were presented in bold type were considered as not yet acquired as that particular age group had made more than 10% of that tonal error. HR, LF, LR and LL tones had not yet been acquired by age group 2 - 2;11. HL and

ML tones were first acquired at age group 2 - 2;11. LL tone was acquired by the age group 3 - 3;11, but HR, LF and LR tones were not yet acquired by age group 3 - 3;11. All six tones were acquired by age 4 - 4;11. LR tone was produced less accurately with 11.7% of tonal errors made by age group 5 - 5;11 and 5% of tonal errors made by the adult group when compared with the other five tones.

Table 5: Percentage of tonal error distribution among the five age groups

Age group	2 - 2;11	3 - 3;11	4 - 4;11	5 - 5;11	22 - 22;11
% of HL tonal error	5%		7%		
% of HR tonal error	**11.7%**	**11.7%**	8.3%		
% of ML tonal error	6.6%	1.7%		1.7%	
% of LF tonal error	**18.4%**	**16.7%**	6.7%		
% of LR tonal error	**13.3%**	**17.8%**	3.3%	**11.7%**	5%
% of LL tonal error	**10.8%**	1.7%	2.5%	1.7%	

Table 6. Tone production information across the 5 age groups

Age group	2 - 2;11	3 - 3;11	4 - 4;11	5 - 5;11	22 - 22;11
Percentage of target produced upon imitation (occurrence / total number of words)	13.76% (66/480)	9.58% (46/480)	1.46% (7/480)	0% (0/480)	0% (0/480)
Percentage of target produced in duplication (occurrence / total number of words)	22% (107/480)	2% (11/480)	3% (14/480)	1% (4/480)	0% (0/480)
Percentage of target produced in polysyllabic word (occurrence / total number of words)	37% (178/480)	36% (175/480)	31% (151/480)	34% (164/480)	32% (153/480)

In addition to the above results, Table 6 shows some factors that should be considered

when interpreting the results. As the younger age groups had limited vocabulary size, the targets might be elicited upon imitation rather than spontaneous production. In addition, the targets that were produced as disyllabic or polysyllabic words might have co-articulation effects of the tone that followed or preceded. For example, the child produced 'fish' /jy25 jy25/ two times. The second /jy25/ would be affected by the preceding /jy25/ and produced with a higher f_0 onset. The first target word production would be considered as the child's production, and the same criteria were applied for the rest of the children's production consistently.

Another factor to be considered when interpreting the results was that the target tones were determined with the support of lexical, semantic, syntactic and contextual cues (Chao, Clumeck as cited in Wong et al., 2002) which created tone expectations that might have influenced the transcription of the raters. However, this biased tone transcription was not easy to be eliminated. Raters in this current study were reminded to focus only on the target tone productions and ignore the lexical, semantic, syntactic and contextual cues if present.

Discussion

Tone perception results

There was significant improvement shown in the four age groups in perceiving the seven tonal contrasts except for HR-LR tonal contrast. HR-LR tonal contrast was difficult to perceive accurately due to their similarity in f_0 onset and both having a rising contour pattern. Besides, the difference in f_0 offset for HR-LR was small (less than 4Hz) according to Bauer & Benedict (1997).

There was abrupt improvement in the perception of several tonal contrasts: LF-LR between age groups 2 - 2;11 and 3 - 3;11, LR-LL between age groups 3 - 3;11 and 4 - 4;11, LF-

LL between age groups 4 - 4;11 and 5 - 5;11, and HL-HR between age groups 2 - 2;11 and 3 - 3;11.

The best performances in identifying tonal contrasts were HL-LL and HL-HR which were in agreement with findings of Sze (2004). This finding also supported Lee et al.'s study (2002) that that f_0 onset was more important than fundamental frequency offset for tone identification as both HL-LL (25.8Hz) and HL-HR (36.7Hz) according to Bauer & Benedict (1997) were differentiated by their initial f_0 onset. Also, HL-HR tonal contrast had different contour patterns which are perceptually salient to listeners.

The lowest performances in identifying tonal contrast were ML-LL and HR-LR, which were in agreement with Ciocca & Lui's findings (2003), and LR-LL which was in agreement with Sze's findings (2004). The main confusion for ML-LL tonal contrast was due to the small f_0 separation (less than 10Hz) according to Bauer & Benedict (1997) and with the same level contour pattern. And the main confusion for LR-LL tonal contrast was due to many overlaps in the frequencies between the members of this tonal contrast and the similar f_0 offset with a difference of 9Hz according to Bauer & Benedict (1997).

Tone production results

Children made steady improvement in their tone production development. HL and ML tones were first acquired by age group 2 - 2;11 and LL tone was subsequently acquired by age group 3 - 3;11. Production of three level tones had been acquired earlier since less than 10% tonal errors were observed for the age group 3 - 3;11. This finding was in agreement with So and Dodd's findings (1995) of relatively earlier acquisition of HL and ML tones and Fong's findings (2004) that the production of level tones was acquired prior to contour tones. All six tones were

acquired by age group 4 - 4;11 which was later than the age of 2 reported by Fong (2004) and So and Dodd (1995). This finding might be due to different criterion of acquisition of tone production in the studies.

Children up to age 5 - 5;11 still made tonal errors for LF, LR and LL tones due to the similarity in the f_0 onset, however, no tonal error was observed for HL, HR and LF tones. 5% of the adult group produced tonal error for LR tone and confused it with HR tone due to the similarity in the f_0 onset and the similarity of rising contour pattern.

The various patterns of tonal errors made by the participants are shown in Appendix D. Most tonal errors were recorded for HR, LF and LR tones and these tones were not acquired by aged 3 - 3;11 in the current study, which was later than the age reported in Fong's study (2004). This finding might be due to the different criteria used and the different methodologies adopted in different studies.

Both adults and children made tonal errors for LR tone. This might indicate that the LR tone was the latest and hardest to acquire. Errors that persisted in LR tones for children of age group 5 - 5;11 and even in the adult group might indicate that errors in LR tones probably appeared in the population normally and thus further investigation was needed.

Some patterns of tonal errors were observed across the five age groups. 75% (31/41) of the total LR tone production errors was substituted by HR tone and 79% (15/19) of the tone production errors of HR tone from age 2 – 4;11 was substituted by LR tone which are due to similarities in the f_0 onset and rising contour pattern of the tones. 76% (19/25) of the total LF tone production errors was substituted by LL tone across the five age groups. This error could be explained by the similarities of the f_0 onset and confusion of the contour pattern of the tones.

Conclusion

In the current study, significant improvement in tone perception was observed for all age groups except for HR-LR tonal contrast. ML-LL, HR-LR and LR-LL were relatively the most difficult contrasts to identify with steady improvement during the course of development. This result re-confirmed that similarity in f_0 onset and contour between the tones of the contrasts might lead to confusion during perception (Ciocca & Lui, 2003). HL-LL and HL-HR contrasts were relatively the easiest contrasts to identify for all age groups with an abrupt improvement in identifying HL-HR tonal contrast from age 2 - 2;11 to 3 - 3;11.

It was observed that three level tones (HL, ML and LL) were acquired earlier than the other three tones across the four children's age groups. LR tone was the latest to be acquired and it was predominantly substituted with HR tone. The error patterns made could be explained by the confusion of the similarities between their f_0 and their contour pattern of these tones.

Clinical Implication

This study can provide more insights on the tone developmental patterns and errors in normally developing children. It has important implication for designing pattern-based speech skill training and assessment strategies for children with auditory dysfunction or children with tonal errors which adversely affect their speech intelligibility.

When choosing treatment targets for auditory training on tones, ML-LL, HR-LR and LR-LL tonal contrasts could be targeted at a later stage as they were relatively more difficult to be identified. However, HL-HR and HL-LL tonal contrasts could be chosen at an early stage since they were easier to be identified.

When assessing children's phonological development using a 90% criterion, the current study's tone production sequence could be taken into account. HL and ML tones were acquired

by age 2 - 2;11 and LL tones were acquired by age 3 - 3;11. All tones should be acquired by age 4 - 4;11.

Limitations and Further Research

The short attention span and the possibility of getting fatigue were the factors affecting the children's performance in the tone identification task. The children, in particular those as young as two years old, might be easily distracted by the environment during the task. 51% of the children participants were not willing to complete one hundred and twenty-eight tone perception trials.

For the tone production task, co-articulation effects in disyllabic and polysyllabic words should be avoided by selecting words that have lexical meaning in monosyllabic word level or collecting productions from participants in fixed lexical words so as to reduce the co-articulation effect that varied across age groups.

Among the tone production results of children aged 2 - 2;11, 63% (74/119) of the imitation productions were elicited for the production of 'old' (老). Using a picture of a 'mouse' (老鼠) instead of an 'old man' (老伯伯) to elicit the word 'old' (老) would be more familiar to the young children and effectively reduce the number of imitation trials.

In future study, all these factors and appropriate modifications should be considered in order to increase the validity of the results. Further study is needed to examine the acoustic details of children's tone production in comparison with the adult's tone production and the relationship between tone perception and production development.

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Appendix A

Information to parents and consent form

Cantonese tone identification and oral production ability
(廣東話聲調辨認及朗讀能力)
Research information
(有關研究計劃資料)

以下謹向各位家長介紹《廣東話聲調辨認及朗讀能力》研究計劃。這個計劃的目的是要研究兒童對廣東話聲調的辨認能力。所搜集的資料將有助我們更深入了解不同年紀的兒童對廣東話聲調辨認及朗讀的能力。

The following is an introduction to all parents about the research on "Cantonese Tone Identification and Production Ability". The objective of the research is to study the ability of children in identifying Cantonese tones. The data collected will help us have a deeper understanding of the ability of children of various age groups in identifying Cantonese tones and their production ability.

這個研究計劃將會在幼兒中心進行，會見過程分二個小節進行，每個小節大約 15 至 20 分鐘。在第一小節中，我們會讓 貴子女看圖畫讀字。在第二小節中，我們會讓 貴子女帶著聽筒聽一些字的發音，然後從相近字音的圖畫中（例如「鞋」和「蟹」）指出所聽到的字。資料經分析後，我們願意與你分享研究的結果。

The research study will be held in the kindergarten. The interview will be conducted in 2 sessions, each lasting 15 – 20 minutes. In the first session, we will ask your child to look at some pictures and read the items aloud. In the second session, we will ask your child to wear a headphone and listen to some words. After each word (for example, the Chinese word for "road"), two pictures (for example, the picture of a road and the picture of an old man) will be shown your child will be asked to point at the picture that corresponds to the sound they heard. We would be glad to share the results with you after the analysis of the data is completed.

我們只會在 貴子女願意參與時才進行這些遊戲。若果 貴子女疲倦和不感興趣，我們會停止進行該遊戲。閣下亦可隨時終止參與是項計劃而不受任何影響。所搜集的資料只作撰寫研究論文之用， 貴子女的名字及資料將絕對保密。

We will carry out the activity/activities only when your child is willing to take part in them. When you child is tired or not interested, we will stop the activity/activities. Your child may stop the activity/activities and withdraw from the study at any time. The data collected will be used for only the research study and all information will be kept with the strictest confidence.

<廣東話聲調辨認及朗讀能力研究計劃>

同 意 書

Child's Consent form

父/母姓名 Parent's name：_____

兒童姓名 Child's name：_____ 性別 Sex：_____

兒童出生日期 Date of Birth：_____

聯絡地址 Address：_____

聯絡電話 Telephone No.：_____

本人已獲悉有關這項研究計劃的資料，並同意我的孩子參與是項計劃。有關計劃和孩子要參與的測試活動，已向我解釋清楚，而不明白的地方我亦有機會提問。本人知道可以隨時終止我的孩子參與是項計劃而不會受到任何影響。

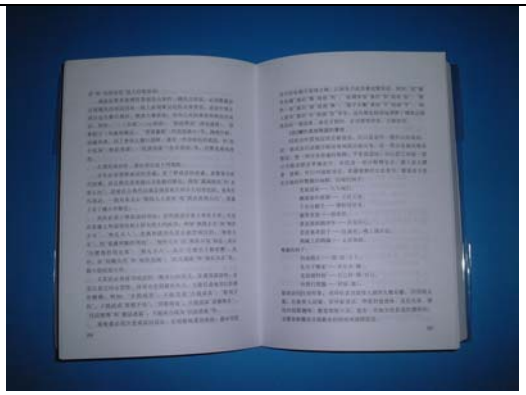
I understand the information provided about the research and I am willing to let my child take part in the research study. The details of the research study and activities have been fully explained to me and I had the chance to ask questions to clarify my doubts. I know that my child will have the right to withdraw from the study at any time.

_____ _____ _____

父/母簽署 研究員/見證人簽署 日期

Appendix B

Pictures for task using colloquial Cantonese terms

	
書 (/sy55/, ‘book’)	樹 (/sy22/, ‘tree’)
	
布 (/bou33/, ‘cloth’)	煲 (/bou55/, ‘pot’)
	
鼻 (/bei22/, ‘nose’)	臂 (/bei33/, ‘arm’)

糖 (/tong25/, ‘sweet’)

湯 (/tong55/, ‘soup’)

鞋 (/haai21/, ‘shoe’)

蟹 (/haai23/, ‘crab’)

老 (/lou23/, ‘old’)

路 (/lou22/, ‘road’)

棉 (/min21/, ‘cotton’)

麵 (/min22/, ‘noodle’)

魚 (/jy25/, ‘fish’)

雨 (/jy23/, ‘rain’)

Appendix C

A sample of the charting form for the tone production task

Name: _____ DOB: _____ Age: ____ Sex: M/F

Testing date: _____ MD no._____ Investigator:_____

Tone production score sheet

Target word	Order of presentation	Production (IM-by imitation)	Order of presentation	Production (IM-by imitation)
鞋 /haai21/				
書 /sy55/				
鼻 /bei22/				
煲 /bou55/				
老/lou23/				
麵 /min22/				
糖 /tong25/				
路 /lou22/				
雨 /jy23/				
棉 /min21/				
蟹 /haai23/				
臂 /bei33/				
魚 /jy25/				
樹 /sy22/				
湯 /tong55/				
布 /bou33/				

Appendix D

Tone production error pattern across five age groups

Age group	2 - 2;11	3 - 3;11	4 - 4;11	5 - 5;11	22 - 22;11
HL	→HR (3.3%; 3/90) →ML (1.1%; 1/90) →LL (2.2%; 2/90)		→ML (4.4%; 4/90) →LL (3.3%; 3/90)		
HR	→HL (5%; 3/60) →LF (1.7%; 1/60) →LR (5%; 3/60)	→LR (11.7%; 7/60)	→LR (8.3%; 5/60)		
ML	→ HR (3.3%, 2/60) →LR (3.3%; 2/60)	→LL (1.7%; 1/60)		→HL (1.7%; 1/60)	
LF	→HR (6.7%; 4/60) → LL (11.7%; 7/60)	→HL (1.7%; 1/60) → LL (15%; 9/60)	→ML (1.7%; 1/60) →LL (5%; 3/60)		
LR	→ HR (6.7%; 6/90) →ML (2.2%; 2/90) →LF (4.4%; 4/90)	→ HR (15.6%; 14/90) →LF (2.2%; 2/90)	→HR (2.2%; 2/90) →LF (1.1%; 1/90)	→HR (10%; 6/60) →LF (1.7%; 1/60)	→ HR (5%; 3/60)
LL	→ HL (5.8%; 7/120) →HR (5%; 6/120)	→HL (1.7%; 2/120)	→HR (0.8%; 1/120) →ML (1.7%; 2/120)	→ LF (1.7%; 2/120)	