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Project title:

Production of the English vowels in Cantonese and Japanese children

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Abstract

This study investigates the production of English vowels in L2 by two groups of children whose L1 is Cantonese or Japanese. An acoustical analysis was carried out for measurements of the formant frequencies (F_1F_2) of the English vowels /i ɪ ɛ æ u ʊ ɔ ʌ ɒ ɑ ɜ(ɝ)/ produced by four Cantonese children and four Japanese children, male and female, of 6-7 years of age. In comparison with the vowel formant data from a native English child of the same age group, errors in pronunciation of the English vowels are observed in the speech of both Cantonese and Japanese children. In general, Japanese children performed better than Cantonese children in producing the English vowels. The English vowels are basically distinguishable in the speech of Japanese children, while Cantonese speakers tend to merge some English mid and low vowels, such as the mid vowels /ɛ ɔ/ and low vowels /æ ɒ/. The different performance between Cantonese and Japanese children is assumed due to weak phonological awareness in Cantonese speakers. Similar errors in English vowel production for Cantonese and Japanese children are reported in adult speech of both languages in the previous studies, suggesting that age may not be an important factor in L2 acquisition of the English vowel sounds. The L2 vowel production data from the two groups of children in this study are also discussed in connection to Flege's (1997) Speech Learning Model of the acquisition of L2 sounds.

Content

1. Introduction

English is an international language widely spoken in the world. It is a popular second language (L2) taught in schools in many non-English countries. A lot of research has been conducted on L2 acquisition of English sounds in non-native speakers with different first language (L1) backgrounds for understanding the influence of L1 transfer on L2 acquisition. This project aims (i) to investigate the production of English vowels in L2 for two groups of children whose L1 is Cantonese or Japanese and (ii) to find out the cross-language differences and similarities in L2 vowel acquisition.

1.1. Use of English in Hong Kong and Japan

Cantonese, a Chinese dialect, is dominantly used for daily communication by people in Hong Kong. Meanwhile, Hong Kong has been a bilingual city since it was a British colony in 1841, adopting English as one of its official languages, besides Chinese. Even though Cantonese is the L1 of most people in Hong Kong, English being an international language has a more prestigious status than Cantonese and learning English is seriously taken by Hong Kong people. English is a compulsory subject taught in schools and is used as a language medium in education. There has been an increasing number of children in Hong Kong who are raised in the bilingual English-Cantonese families which use both languages and preferably more English in everyday speech communication.

Different from the case of Hong Kong, Japanese is the only official language in Japan. The use of English in Japan is not as prominent as in Hong Kong, and Japanese is the major language used in workplace and education by Japanese people. Most of the Japanese children are raised in the monolingual Japanese-speaking families. Nonetheless, English is a popular L2 learned by Japanese people and it is one of the foreign language subjects commonly taught in schools in Japan.

1.2. Vowel Systems of English, Cantonese, and Japanese

1.2.1. English vowel system

England and the United States of America are the two countries with the largest number of native English speakers. British English and American English are the two major varieties commonly taught in the schools in non-English countries. The differences between the two English varieties are mainly in their vowel systems. Both British English and

American English have a set of monophthongal vowels and diphthongs. It is generally considered that British English has 11 vowels, namely /i ɪ ɛ æ u ʊ ɔ ʌ ɜ ɒ ɑ/, that can occur in monosyllables, whereas American English has 10 vowels in monosyllables, i.e., /i ɪ ɛ æ u ʊ ɔ ʌ ɝ ɑ/ (Ladefoged and Johnson, 2015). Thus, the differences in vowel system between the two varieties include (i) the occurrence of the rounded low back vowel /ɒ/ in British English, which has merged into the unrounded equivalent /ɑ/ in American English, and (ii) the addition of rhoticity or r-color to the mid central vowel /ɝ/ in American English. It should be noted that according to Ladefoged and Johnson (2015), any vowels in American English followed by the syllable-final /r/ are rhotacized towards the end of the vowels, but only the mid central vowel /ɝ/ is completely rhotacized and coalesced with the final /r/. In British English, /r/ is not pronounced or deleted in a syllable-final position, resulting in no r-color associated with the vowels.

All the monophthongal vowels /i ɪ ɛ æ u ʊ ɔ ʌ ɜ ɒ ɑ/ in British English and /i ɪ ɛ æ u ʊ ɔ ʌ ɝ ɑ/ in American English can occur in closed syllables with a final consonant. But, only the long or so-called tense vowels /i u ɔ ɜ ɑ/ (British English) and /i u ɔ ɝ ɑ/ (American English) can occur in open syllables without a final consonant. In the two English varieties, the final consonants in closed syllables may be any one of the plosives /b d g p t k/, fricatives /θ ð f v s z ʃ ʒ/, affricates /tʃ dʒ/, nasals /m n ŋ/, and approximants /l r/.

1.2.2. Cantonese vowel system

In Cantonese, there are 11 vowels /i y u ɪ ʊ ɛ œ ɵ ɔ ɐ a/ that can occur in monosyllables (Zee, 1999). Of the 11 vowels, /i y u ɛ œ ɔ a/ are long vowels that can occur in both open and closed syllables, whereas /ɪ ʊ ɵ ɐ/ are short vowels that can occur in closed syllables only. In closed syllables, the final consonants may be any one of the plosives /p t k/ or nasals /m n ŋ/.

A comparison of the vowel systems of English and Cantonese shows that the front vowels in English contrast in three levels of vowel height, i.e., the high vowels /i ɪ/, mid vowel /ɛ/, and low vowel /æ/, whereas Cantonese only has the high front vowels /i ɪ/ and mid front vowels /ɛ œ/, missing the low front /æ/. In Cantonese, the low vowel /a/ is produced with central quality, although it is transcribed with the front vowel symbol (Zee, 1999). The back vowels in English also contrast in three levels of vowel height, with the high vowels /u ʊ/, mid vowels /ɔ ʌ/, and low vowels /ɒ ɑ/, whereas Cantonese only has the high back vowels /u ʊ/ and mid back vowel /ɔ/, missing the mid and low back vowels /ʌ ɒ ɑ/. As for the central vowels, there are two in Cantonese, i.e., the mid central /ɵ/ and low central /ɐ/, but there is only one in English, i.e., the mid central /ɜ/ or /ɝ/.

It should be noted that the high tense and lax vowels in Cantonese are in complementary distribution when they occur in closed syllables. For instance, while the tense front vowel /i/ can be followed by the syllable-final bilabial and alveolar consonants /p m t n/, such as in [jip, jim, jit, jin] (page, test, hot, appear), the lax counterpart /ɪ/ can only be followed by the syllable-final velar consonants /k ŋ/, such as in [jɪk, jɪŋ] (wings, admit). Similar pattern of complementary distribution in closed syllables is observed for the tense back vowel /u/ and lax vowel /ʊ/ in Cantonese, with /u/ followed by the alveolar consonants /t n/, such as in [mut, mun] (none, bored), and /ʊ/ followed by the velar consonants /k ŋ/, such as in [mʊk, mʊŋ] (wood, dream). In English, however, both the tense vowels /i u/ and lax vowels /ɪ ʊ/ can occur in syllables closed by the same final consonant, such as the alveolar consonants /t d/ as in the words 'seat, sit, suit, soot' [sit, sɪt, sut, sʊt] and 'heed, hid, who'd, hood' [hid, hɪd, hud, hʊd].

1.2.3. Japanese vowel system

In Japanese, the vowel system is rather simple, relative to the vowel systems of English and Cantonese. Japanese only has 5 basic monophthongal vowels, /i u e o a/, while the five vowels have phonemic contrast in length, resulting in the split into two sets, i.e., the long vowels /iː uː eː oː aː/ and short vowels /i u e o a/ (Okada, 1991).

Compared with the vowel system of English, Japanese has no lax counterparts /ɪ ʊ/ for the high tense vowels /i u/. Furthermore, different from English, the Japanese high back vowel /u/ is produced with no lip rounding, which may be transcribed as [ɯ] phonetically (Okada, 1991). The two mid vowels, the front /e/ and back /o/, in Japanese, are slightly higher than the mid vowels /ɛ ɔ ʌ ɜ/ in English as indicated in the IPA transcription of the vowels. As for the low vowels, Japanese only has one, the low vowel /a/, which is produced with central quality, missing the low vowels /æ ɒ ɑ/ that occur in English.

In view of the differences in vowel system between English and Cantonese and between English and Japanese, Cantonese and Japanese speakers are expected to have difficulty in producing the vowels in English due to the influence of their L1.

1.3. Theories of Second Language Acquisition

There has been a number of research regarding the effects of learners' L1 on the production and perception of L2 sounds. Major (2008) presented a summary of the effects of L1 transfer on L2 sound acquisition and the claims of two classic theories of L2 acquisition, and it is restated below.

Lado (1957) proposed the Contrastive Analysis Hypothesis (CAH) which predicts that the sounds in L2 that are similar to those in L1 are easy to be acquired, but the sounds and suprasegmental features which are unique to L2 or different from those of L1 are difficult for L2 learners. Lado's CAH, however, is not supported by the data obtained in the subsequent experiments. Oller and Ziahosseiny (1970) revised Lado's CAH and proposed that "Similar phenomena are more difficult to learn than dissimilar phenomena." (from Major, 2008). But, the revised CAH still encounters difficulty in explaining some pronunciation errors observed in L2.

A new proposal, the Speech Learning Model (SLM) of L2 acquisition, was put forward by Flege (1997). It is considered that the speech sounds in L2 are divided into three types and classified as "identical", "similar", and "new" in comparison with those in L1. The SLM predicts that the "identical" sounds in L2 are acquired effortlessly, as they are the same as the L1 sounds. The "new" sounds in L2, which are distinctive and perceptually different from those in L1, are also easily acquired and able to be produced with native-like qualities. The "similar" sounds in L2 with perceptual quality similar to those in L1 are however difficult to be acquired and easily be substituted with the L1 sounds. Flege's SLM was on the basis of the observation that inexperienced English-speaking learners of French are not aware of the difference between the French /t/ and the English /t/ and commonly substitute the "similar" French /t/ with the English /t/.

In addition to the effect of L1, a lot of recent research reveal that L2 phonological acquisition is related to other factors, such as perceptual ability, language experience, and age of acquisition of L2 learners. For instance, Munro, et al. (1996) reported that the L2 speech is more native-like for those who started learning L2 since a younger age than for those who started learning L2 at a later age, suggesting that age is a crucial factor in L2 production. Cowie, et al. (1991) observed the effect of learning experience that Korean speakers who are more experienced in speaking English can produce native-like English vowels, but those who are less experienced in speaking English cannot.

1.4. ESL (English as a Second Language) Studies

1.4.1. Cantonese speakers

Most of the ESL studies of Cantonese speakers are concerned with learners' perceptual ability and training (Chan, 2007, 2009) and production errors (Chan, 2000). In Chan's studies, several problems with the pronunciation of English vowels are identified for Cantonese-speaking university students, such as the substitution of the low front /æ/ with the mid front /ɛ/ and confusion on the high tense /i u/ and lax /ɪ ʊ/ vowels in English. The author suggested that Cantonese speakers, even those at the tertiary level, need to improve their skill in both the production and perception of English vowels. Hung (2000) conducted an acoustic analysis of the consonants and vowels in "Hong Kong English" which were also collected from Cantonese-speaking university students. The author proposed a set of vowels in the inventory of "Hong Kong English", namely /i ɛ u ɔ ʌ ɜ ɑ/, in which some of the vowels in British or American English have been merged.

There are also some investigations of the production of English consonants and vowels in Cantonese students of secondary schools (Chiu, 2006) and Cantonese adult speakers (Yeung, 2007). However, the information on the L2 acquisition of English vowels in Cantonese children is scarce. Speech data from L2 learners at younger age are called for, which can contribute to our understanding of the effect of language experience (Cowie, et al., 1991) and the development in English vowel production by comparing with the data from adolescents and adults reported in the previous studies. The findings can also provide more information for designing and improving strategies in teaching English to Cantonese speakers.

1.4.2. Japanese speakers

The ESL studies of Japanese speakers are carried out mainly by performing contrastive analysis of the phonological systems of Japanese and English (Ohata, 2004; Walker, 2006). Ohata (2004) reported the problems with prosody in L2 English for Japanese speakers, such as inability (i) to distinguish between mora and syllable units and (ii) to identify the stress and intonation patterns of English. Walker (2006) compared the Japanese vowels represented in the *kana* writing system with the English vowel phonemes. He suggested that *kana* may be used as a supplementary tool to help Japanese speakers to distinguish the tense and lax vowels in English which are non-occurring in Japanese.

However, Walker's method falls short of the differentiation of vowels with different tongue height and backness.

Tsukuda (1999) is one of the small number of acoustic studies of the production of English sounds in Japanese speakers. The author measured the formant frequencies and duration of the English vowels from Japanese speakers. The data demonstrate the difficulties of Japanese speakers in making length contrast in English vowels and producing some English vowels in similar position of the acoustical vowel space.

Similar to the ESL studies of Cantonese speakers, all the above-mentioned studies of Japanese speakers are based on speech data mainly from adult speakers. The speech data collected from Japanese children are rare.

1.5. Purposes of the Present Study

The present study investigates the production of English vowels in Cantonese-speaking and Japanese-speaking children through performing acoustic analysis of the formant frequencies of the vowels. For comparison purposes, speech data from a native English child are also obtained. On the basis of the vowel data from the three groups of children, discussion is made about (i) the influence of different L1 backgrounds on L2 English vowel production and (ii) the cross-language differences and similarities in L2 phonology acquisition. The findings of this project are also used (i) to address the theories of L2 acquisition for determining whether the "identical", "similar", and "new" sounds in L2 relative to those in L1 are easy or difficult to be produced, and (ii) to compare with the L2 English vowel data from Cantonese and Japanese adult speakers reported in the previous studies for determining the effect of language experience and the differences in English vowel production between L2 learners of different age groups.

2. Methodology

2.1. Subjects

For the present study, nine children were invited to take part in the individual audio recording sessions to provide speech samples. The nine children were divided into three groups, consisting of (i) 2 male and 2 female Cantonese-speaking children, (ii) 2 male and 2 female Japanese-speaking children, and (iii) 1 male native English-speaking child. All the children were aged 6-7 years and they were born and grew up in monolingual families.

The four Cantonese children were born in Hong Kong and grew up in Cantonese-speaking families. All of them were P1 students of the local primary schools in Hong Kong, using Cantonese in daily social communication. They have been learning and using English in school for about three years.

The four Japanese children were born in Japan, but their families moved to Hong Kong afterward. Two Japanese children have been living in Hong Kong for 5-6 years since 1-year-old, and the other two have been living in Hong Kong for 2-3 years since age 4. The parents of all Japanese subjects were born in Japan and were native speakers of Japanese. Japanese was their only language used at home and the dominant language used in daily social communication. The four Japanese children were the first-grade students of a Japanese-speaking primary school in Hong Kong. Similar to the four Cantonese children, the four Japanese children have been learning English in school for about three years.

The English speaker in the present study was an American-born male child who grew up in Hong Kong and was raised in an American English-speaking family. He was the first-grade student of an international school in Hong Kong. The speech data from him were used as reference for comparing with those from the two groups of non-English children.

2.2. Test Materials

The three groups of children were asked to produce 22 monosyllabic English words as presented in Table 1. The test words contain the vowels /i ɪ ɛ æ u ʊ ɔ ʌ ɜ ɒ ɑ/ and /i ɪ ɛ æ u ʊ ɔ ʌ ɝ ɑ/ in the two major varieties of English, British English and American English, respectively. The two English accents are both taken into consideration in the present study, as they are commonly taught in the schools over the world. For each English vowel, it occurs in two test words, with the exception of the vowel /ɑ/ in American English which occurs in four test words due to the merger of the two low back vowels /ɒ/ and /ɑ/ in this variety.

Vowels	Test words	IPA transcription	Vowels	Test words	IPA transcription
i	feet seat	UK US /fit/ UK US /sit/	ɪ	fish pig	UK US /fɪʃ/ UK US /pɪg/
ɛ	bed head	UK US /bɛd/ UK US /hɛd/	æ	hat sad	UK US /hæt/ UK US /sæd/
u	boot soup	UK US /but/ UK US /sup/	ʊ	foot good	UK US /fʊt/ UK US /gʊd/
ɔ	fork short	UK /fɔk/ US /fɔrk/ UK /ʃɔt/ US /ʃɔrt/	ʌ	bus duck	UK US /bʌs/ UK US /dʌk/
ɑ	card park	UK /kɑd/ US /kɑrd/ UK /pɑk/ US /pɑrk/	ɒ/ɑ	hot dog	UK /hɒt/ US /hɑt/ UK /dɒg/ US /dɑg/
ɜ/ɝ	church bird	UK/tʃɜtʃ/ US /tʃɝtʃ/ UK/bɜd/ US /bɝd/			

Table 1: 22 test monosyllabic words and the IPA transcription of the words in British (UK) and American (US) English.

All the test words have a monosyllabic structure of $C_1V(C)C_2$. C_1, a syllable-initial consonant, and C_2, a syllable-final consonant, are one of the obstruent consonants, including the plosives /p b t d k g/, fricatives /f s ʃ h/, and affricate /tʃ/, in English. V is one of the vowels /i ɪ ɛ æ u ʊ ɔ ʌ ɜ ɒ ɑ/ in British English or /i ɪ ɛ æ u ʊ ɔ ʌ ɝ ɑ/ in American English. The differences in the vowels between the two accents are only in (i) the low back rounded vowel /ɒ/ which has merged into the unrounded equivalent /ɑ/ in American English and (ii) the rhoticity or r-color which is added to the mid central vowel /ɝ/ in American English, but not to /ɜ/ in British English. (C) is an optional consonant in the coda position of four test words (i.e., 'fork, short, card, park'), which is always the approximant /r/. The /r/ sound in a coda position is deleted in British English, as in 'fork' /fɔk/, 'short' /ʃɔt/, 'card' /kɑd/, and 'park' /pɑk/, but it is retained in American English, i.e., 'fork' /fɔrk/, 'short' /ʃɔrt/, 'card' /kɑrd/, 'park' /pɑrk/. All the selected test words are meaningful and have been taught in the schools to the children who participated in the present study.

2.2. Speech Data Collection

The 22 test words were randomized and presented to the speakers on PowerPoint slides on a computer during the recordings. Each test word was accompanied by a picture which illustrates the meaning of the word. The speakers were asked to produce the test words shown on the computer screen one by one at a normal speech rate and a moderate volume. Audio recordings were conducted in a quiet room at the homes of the children, using a portable high-quality digital recorder. Four repetitions of each test word were recorded from each speaker, making up a total of 792 (22 test words x 4 repetitions x 9 speakers) speech samples for subsequent acoustical analysis.

2.3. Data analysis

Out of the 792 speech samples collected, 462 speech samples were finally analyzed for this three-month project due to the time constraint and huge amount of the recorded samples. The analyzed speech samples included 3 tokens of each of the 22 test words from four Cantonese children (a total of 264 tokens = 22 test words x 3 repetitions x 4 speakers), 2 tokens of each test word from four Japanese children (a total of 176 tokens = 22 test words x 2 repetitions x 4 speakers) and 1 token of each test word from the native English child (a total of 22 tokens = 22 test words x 1 repetition x 1 speaker).

Spectral analysis was carried out using the speech analysis software, CSL (Computerized Speech Lab) Model 4500 of KayPENTAX in the Phonetics Lab of the Department of Linguistics and Translation, City University of Hong Kong. Autocorrelation LPC (Linear Predictive Coding) analysis was performed at the temporal mid-point of the steady-state portion of each test vowel, which is taken as the vowel target for the measurements of the F_1 and F_2 values.

The obtained F_1 and F_2 values of the test vowels were then plotted on a graph using Microsoft Excel to show the positions of the vowels in the F_1F_2 plane, with F_1 on y-axis and F_2 on x-axis, for the different groups of children. The mean F_1F_2 values were also calculated for each test vowel by averaging across all the tokens of the vowel for each group of children of the same language and/or the same gender. Based on the mean F_1F_2 values for the vowels, the vowel loops for the English vowels from each group of children were obtained, and then the areas of the acoustical vowel space for different groups of children were calculated and compared.

3. Results

This section presents the formant frequency values for the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ(ɝ)/ produced by (i) one male English child, (ii) two male and two female Cantonese children, and (iii) two male and two female Japanese children. Comparisons of the English vowels for the three groups of children are made by plotting the vowel formant frequencies in the F_1F_2 plane, with the F_1 on y-axis and F_2 on x-axis indicating the positions of tongue height and backness during the vowels. Comparisons are also made about the areas of the vowel loops for the seven English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ from each of the three groups of children for determining the differences in the acoustical vowel space across the three groups.

3.1. Vowel Formant Frequencies

3.1.1. A male English child

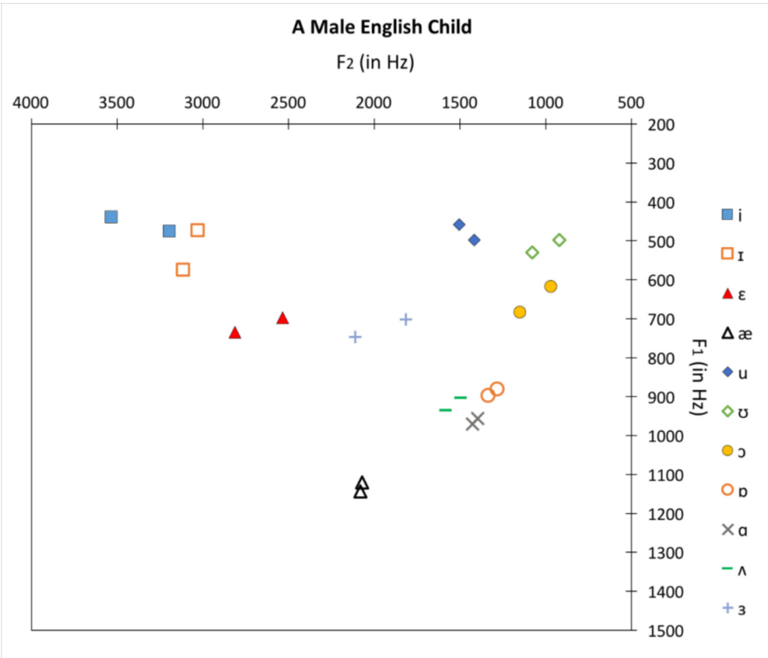

Fig. 1: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɝ/ in the F_1F_2 plane for a male English child.

Fig. 1 shows the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɝ/ in the F_1F_2 plane for a male English child. Each vowel was produced in two test $C_1V(C)C_2$ syllables as presented in Table 1. As shown in the figure, in general, the vowels for this English child are distinct from each other, occupying different positions in the F_1F_2 plane. The vowels /ʌ/ (in bars), /ɒ/ (in empty circles), and /ɑ/ (in crosses) may be the exceptions, as they are close to each other in the low back position of the acoustical vowel space and the F_1F_2 values for /ʌ/ (918 Hz, 1539 Hz), /ɒ/ (890 Hz, 1307 Hz) and /ɑ/ (964 Hz, 1411 Hz) are similar. The English child in the present study is a native speaker of American English. In view of the fact that the rounded low back vowel /ɒ/ has merged into the unrounded equivalent /ɑ/ in General American English (Ladefoged and Johnson, 2015), it may be considered that the vowels /ɒ/ and /ɑ/ are not distinguished in the speech of the English child in the present study.

With regards to the vowel height, as expected, the relative position in the F_1F_2 plane is higher for the four high vowels /i ı u ʊ/ (in squares or diamonds), followed by the three mid vowels /ɛ ɔ ɝ/ (in filled triangles, pluses, or filled circles) and then the three low vowels /æ ɒ ɑ/ (in empty triangles, empty circles, or crosses). The mid vowel /ʌ/ (in bars) however is positioned more downward in the F_1F_2 plane than the other mid vowels /ɛ ɔ ɝ/ and closer to the two low back vowels /ɒ ɑ/. For the low vowels /ɒ/ and /ɑ/, it should be noted that they are positioned more upward than the low front vowel /æ/ in the F_1F_2 plane.

With regards to the vowel backness, the positions of the vowels /i ı ɛ æ/ are relatively in the front, the vowel /ɝ/ in the center, and the vowels /u ʊ ɔ ʌ ɒ ɑ/ in the back of the F_1F_2 plane. For the front and back vowels, the position is generally more centralized for the ones with a low vowel height. Thus, among the four front vowels /i ı ɛ æ/, the low vowel /æ/ is positioned more backward than the mid vowel /ɛ/ and the high vowels /i ı/. Similarly, among the back vowels /u ʊ ɔ ʌ ɒ ɑ/, the mid vowel /ʌ/ and low vowels /ɒ ɑ/ are positioned more forward than the high vowels /u ʊ/. The mid vowel /ɔ/ however is positioned more backward, close to the high vowels /u ʊ/.

For the four English high vowels /i ı u ʊ/, the English child produces differently the tense and lax vowels in both the high front pair /i/-/ı/ (in filled and empty squares) and high back pair /u/-/ʊ/ (in filled and empty diamonds). For the two high front vowels /i/ and /ı/, the lax /ı/ is centralized in the F_1F_2 plane, due to an increase in F_1 (524 Hz) and a decrease in F_2 (3071 Hz), relative to the F_1F_2 for the tense /i/ (457 Hz, 3362 Hz). As for the two high back vowels /u/ and /ʊ/, on the contrary, the position of the tense /u/ is centralized, being more forward in the F_1F_2 plane with a larger F_2 (1461 Hz) than the lax /ʊ/ (999 Hz). According to Harrington, Kleber and Reubold (2011), the diachronic back vowel [u]-fronting in English has happened in many varieties of English, such as American, Southern British, Australian, and New Zealand. Thus, the centralization of /u/ in the English child of the present study is considered due to the fronting of the vowel.

3.1.2. Two male Cantonese children

Fig. 2 shows the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ(ɝ)/ in the F_1F_2 plane for two male Cantonese children. In the figure, each vowel has a total of twelve tokens, produced with three repetitions in each of the two test $C_1V(C)C_2$ syllables (see Table 1). A comparison of the vowel data of the two male Cantonese children (Fig. 2) with those of the male English child (Fig. 1) shows that some of the English vowels in the Cantonese children are not clearly distinct from each other, occupying similar positions in the F_1F_2 plane. The overlap in position is in particular pronounced between the vowels (i) /u/ and /ʊ/, (ii) /ɛ/ and /æ/, (iii) /ɔ/ and /ɒ/, and (iv) /ɑ/ and /ʌ/.

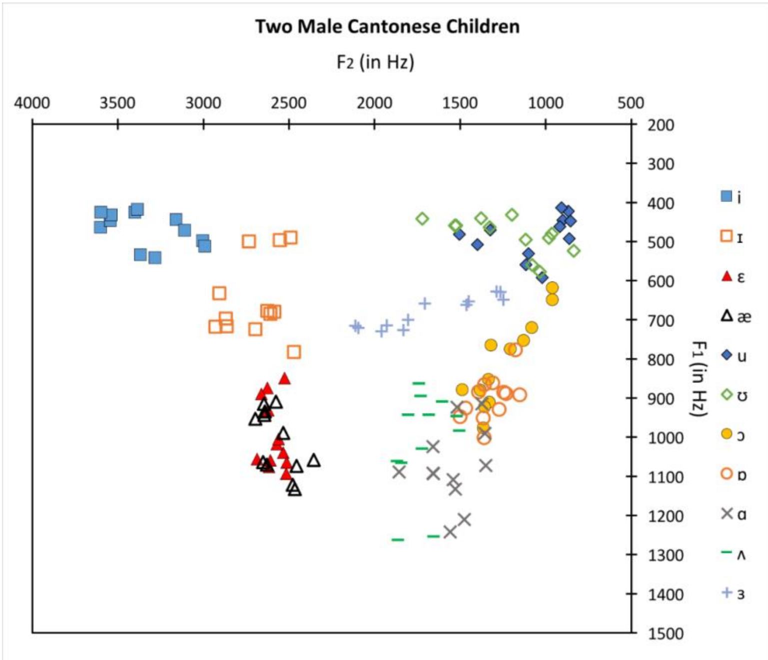

Fig. 2: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ(ɝ)/ in the F_1F_2 plane for two male Cantonese children.

Different from the male English child (Fig. 1), there is extensive overlap in position in the F_1F_2 plane between the two high back vowels /u/ (in filled diamonds) and /ʊ/ (in empty diamonds) for the two male Cantonese children (Fig. 2), indicating that the Cantonese children are not able to distinguish the two English vowels. The overlap between the two vowels is mainly due to the centralization of the tense /u/ in some tokens for Male Cantonese Child 1 as shown in the left panel of Fig. 3. In Fig. 3, the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ are shown separately for each of the two male Cantonese children, Male 1 (left panel) and Male 2 (right panel).

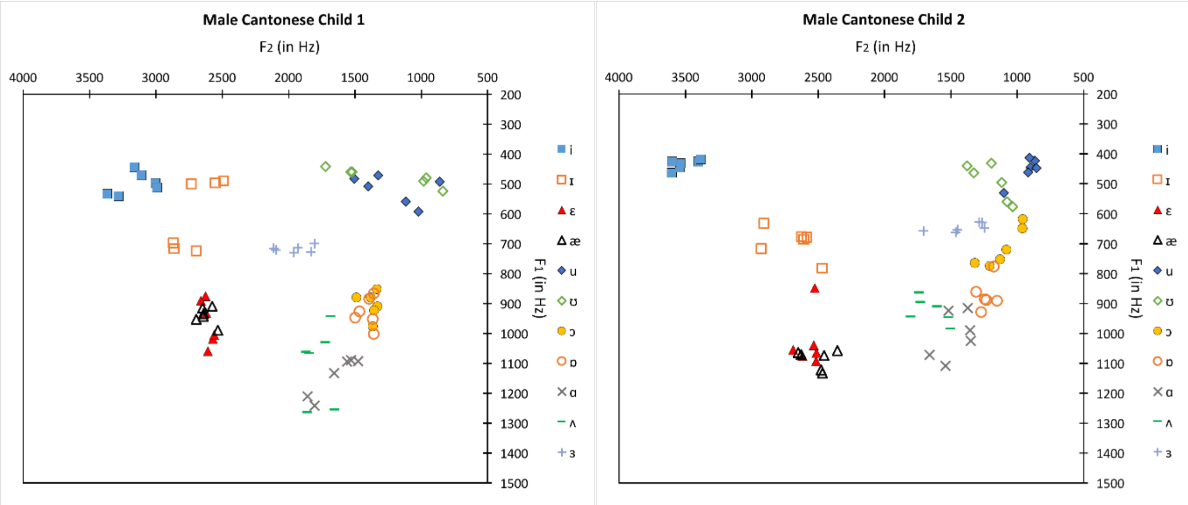

Fig. 3: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ(ɝ)/ in the F_1F_2 plane for Male Cantonese Child 1 (left panel) and Male Cantonese Child 2 (right panel).

For Male Cantonese Child 1, the mean F_1F_2 values for the tense /u/ (517 Hz, 1205 Hz) and lax /ʊ/ (476 Hz, 1260 Hz) are very similar, suggesting that the speaker has merged the two high back vowels /u ʊ/ into one. The F_1F_2 values for /u ʊ/ for this Cantonese child are similar to those for the male English child's /ʊ/ (512 Hz, 999 Hz), which may indicate that Male Cantonese Child 1 pronounces the two high back vowels /u ʊ/ as the lax /ʊ/. As for Male Cantonese Child 2 as shown in the right panel of Fig. 3, the tense /u/ and lax /ʊ/ are clearly distinct from each other, except for one token of /u/ which becomes similar to the lax /ʊ/. In general, for the two male Cantonese children, the lax /ʊ/ is more centralized with a larger F_2 (1224 Hz) than the tense /u/ (1065 Hz). Thus, the back [u]-fronting as observed in the speech of the male English child (Fig. 1) is not true for the two male Cantonese children.

For the high front tense vowel /i/ (in filled squares) and lax vowel /ɪ/ (in empty squares), they are clearly distinct in position in the F_1F_2 plane, with /ɪ/ being more centralized due to an increase in F_1 and a decrease in F_2, for the two male Cantonese children (Fig. 2). The degree of centralization of the lax vowel /ɪ/ is more pronounced in Male Cantonese Child 2, with a larger difference in F_1F_2 between the tense /i/ (436 Hz, 3510 Hz) and lax /ɪ/ (696 Hz, 2731 Hz) than that between Male Cantonese Child 1's /i/ (501 Hz, 3151 Hz) and /ɪ/ (605 Hz, 2670 Hz). Furthermore, for Male Cantonese Child 2, the lax vowel /ɪ/ is positioned more backward and downward than the tense vowel /i/ in all the tokens of the two test words (right panel of Fig. 3). However, for Male Cantonese Child 1 (left panel of Fig. 3), the centralization of the lax vowel /ɪ/ varies in the two test words, where the lax /ɪ/ mainly shifts backward in the test word "fish", but shifts backward and downward in the test word “pig”. This indicates that the target position for the lax vowel /ɪ/ is less consistent in Male Cantonese Child 1.

Aside from the high vowels, the two male Cantonese children both have a difficulty in distinguishing between the mid and low vowels in English. For instance, the mid front vowel /ɛ/ and low front vowel /æ/ overlap extensively in the F_1F_2 plane (Fig. 2), and the mean F_1F_2 values for the vowels /ɛ/ (996 Hz, 2587 Hz) and /æ/ (1014 Hz, 2565 Hz) are similar. The F_1F_2 for the two Cantonese children’s /ɛ/ and /æ/ are not similar to the English child’s /ɛ/ (716 Hz, 2674 Hz) nor /æ/ (1132 Hz, 2076 Hz). The data may indicate the Cantonese children merge the two English vowels /ɛ/ and /æ/ into a ‘new’ front vowel.

The merger of the mid back vowel /ɔ/ and low back /ɒ/ in English is also observed in the speech of the two male Cantonese children, as evidenced by the fact that the positions of their vowels /ɔ/ and /ɒ/ overlap extensively in the F_1F_2 plane (Fig. 2). The overlap between the two vowels is especially pronounced for Male Cantonese Child 1, with similar F_1F_2 for /ɔ/ (904 Hz, 1374 Hz) and /ɒ/ (930 Hz, 1405 Hz), as compared with the vowels /ɔ/ (714 Hz, 1108 Hz) and /ɒ/ (873 Hz, 1230 Hz) for Male Cantonese Child 2. The data indicate that Male Cantonese Child 1 merges the two English vowels /ɔ/ and /ɒ/, producing the vowels with the F_1F_2 similar to those of the low back /ɒ/ (890 Hz, 1307 Hz) for the male English child (Fig. 1).

Similarity is also observed between the vowel /ɒ/ and the other two back vowels /ɑ/ and /ʌ/ in the speech of the two male Cantonese children, as in the case of the male English child (Fig. 1). As shown in Fig. 2 and Fig. 3 for the two male Cantonese children, the positions of the three vowels /ɒ ɑ ʌ/ are close to each other in the F_1F_2 plane. This is especially for the vowels /ɑ/ and /ʌ/, where their positions have some overlap. Among the three vowels for the two Cantonese children, the vowel /ʌ/ tends to be more centralized, with a larger F_2 value (1712 Hz) than the vowels /ɒ/ (1317 Hz) and /ɑ/ (1557 Hz). This is similar to the pattern of the F_2 difference in the English child’s vowels /ʌ/ (1539 Hz), /ɒ/ (1307 Hz), and /ɑ/ (1411 Hz), despite the difference in the absolute value between the two groups of children. For the vowels /ɒ/ and /ɑ/, they are similar in both the F_1F_2 values for the English child, indicating the merger between the two vowels (Fig. 1). The merger of this case is not pronounced in the two Cantonese children (Fig. 2), where the F_1F_2 values are larger for /ɑ/ (1075 Hz, 1557 Hz) than /ɒ/ (901 Hz, 1317 Hz).

As for the central vowel /ɜ/, no significant problem in pronunciation is observed among the two male Cantonese children, except for a reduction in the degree of rhoticity or r-color associated with the vowel as compared with the English child's rhotacized /ɝ/. For the two male Cantonese children, the vowel /ɜ/ is in a central position, distinguishing from all the other English vowels in the F_1F_2 plane. The centralization of the vowel /ɜ/ is particularly noticeable for Male Cantonese Child 1 (left panel of Fig. 3), and the F_1F_2 for the vowel (718 Hz, 1956 Hz) are similar to those for the English child's /ɝ/ (725 Hz, 1963 Hz).

3.1.3. Two female Cantonese children

The problems in the production of English vowels for the two male Cantonese children (Fig. 2 and Fig. 3), including the merger between the high back tense vowel /u/ and lax vowel /ʊ/, between the mid front vowel /ɛ/ and low front vowel /æ/, between the mid back vowel /ɔ/ and low back vowel /ɒ/, and between the low back vowel /ɑ/ and mid back vowel /ʌ/, are also observed in the speech of the two female Cantonese children. Fig. 4 shows the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for the two female children, and Fig. 5 shows the positions of the English vowels separately for Female Cantonese Child 1 (left panel) and Female Cantonese Child 2 (right panel).

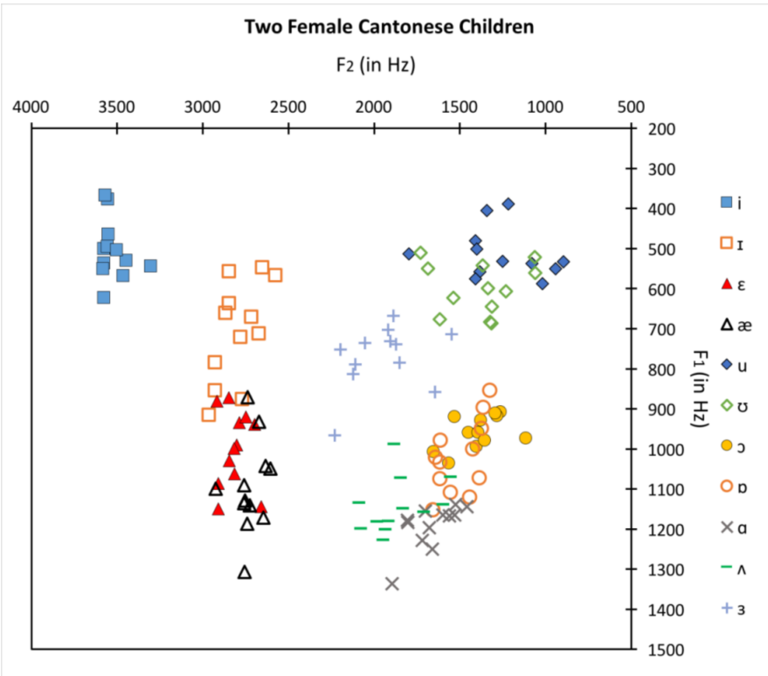

Fig. 4: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for two female Cantonese children.

As shown in Fig. 4, for the two female Cantonese children, the high front tense vowel /i/ and lax vowel /ɪ/ are clearly separate in the F_1F_2 plane, but the high back tense vowel /u/ and lax vowel /ʊ/ are not. For the two high front vowels, the lax /ɪ/ is centralized, positioned in a more backward and downward position relative to the position for the tense /i/. The degree of centralization of the lax vowel /ɪ/ is in particular pronounced for Female Cantonese Child 1 (left panel of Fig. 5). For Female Cantonese Child 2 (right panel of Fig. 5), relative to the tense /i/, the lax /ɪ/ is positioned more backward and downward in the test word “pig”, but mainly shifts to backward in the test word “fish”.

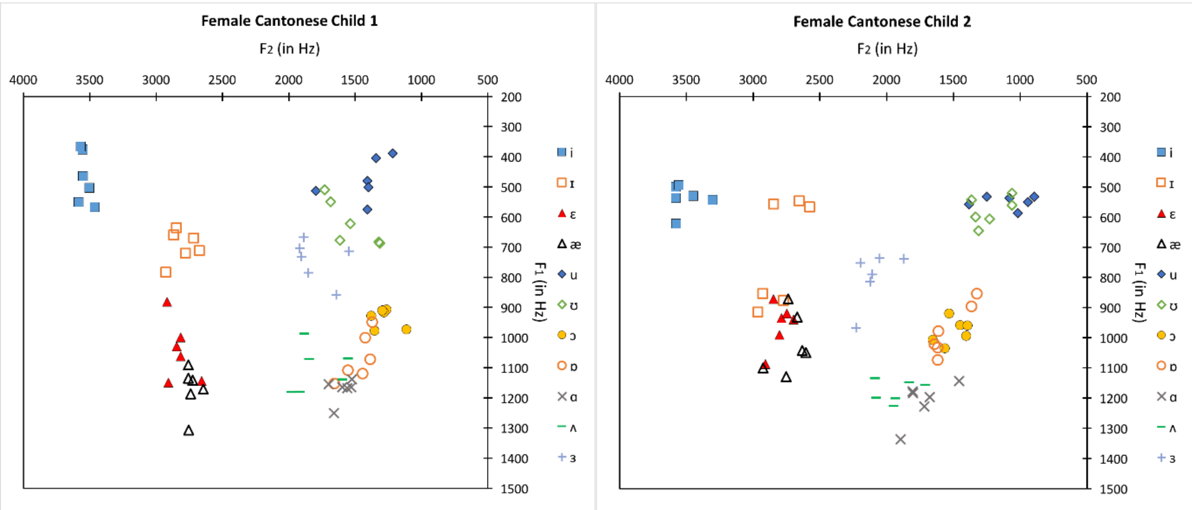

Fig. 5: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for Female Cantonese Child 1 (left panel) and Female Cantonese Child 2 (right panel).

As for the two high back vowels /u/ and /ʊ/, they overlap in the F_1F_2 plane for the two female Cantonese children (Fig. 4), especially for Female Cantonese Child 2 (right panel of Fig. 5), where the mean F_1F_2 values for /u/ (549 Hz, 1095 Hz) and /ʊ/ (579 Hz, 1228 Hz) are similar. The data indicate that the two vowels are not distinguishable in the two female Cantonese children. In general, the lax vowel /ʊ/ tends to be more centralized, being more downward and forward in the F_1F_2 plane than the tense vowel /u/. Thus, similar to the case of the male Cantonese children (Fig. 2 and Fig. 3), there is also no back vowel [u]-fronting for the female Cantonese children (Fig. 4 and Fig. 5), which is observed in the speech of the male English Child (Fig. 1).

Also similar to the male Cantonese children, the two female Cantonese children have difficulty in distinguishing between the mid front vowel /ɛ/ and low front vowel /æ/ in English, as indicated by the extensive overlap in position in the F_1F_2 plane (Fig. 4) and the striking similarities in the F_1F_2 values between the vowels /ɛ/ (1001 Hz, 2813 Hz) and /æ/ (1096 Hz, 2726 Hz). Comparing with the front vowels /ɛ/ and /æ/ for the English child, the female Cantonese children's /ɛ/ and /æ/ are similar to the English child's /æ/ in F_1 (1132 Hz), but similar to the English child's /ɛ/ in F_2 (2674 Hz). The data indicates that the female Cantonese children merge the two English vowels /ɛ/ and /æ/ into a 'new' front vowel.

The mid back vowel /ɔ/ and low back vowel /ɒ/ in English are also not distinguishable in the two female Cantonese children, as the positions of the two vowels overlap extensively in the F_1F_2 plane (Fig. 4). The similarity between the two vowels is particularly pronounced in F_2, i.e., 1241 Hz for /ɔ/ and 1317 Hz for /ɒ/, while the F_1 tends to be slightly smaller for the mid vowel /ɔ/ (809 Hz) than the low vowel /ɒ/ (902 Hz). The F_1 is larger for the two female children's vowels /ɔ/ and /ɒ/ than the English child's /ɔ/ (651 Hz), but similar to the English child's /ɒ/ (890 Hz). This suggests that the two female Cantonese children merge the mid back /ɔ/ into the low back /ɒ/.

As in the case of the male Cantonese children, the vowels /ɒ/, /ɑ/, and /ʌ/ for the female Cantonese children (Fig. 4) are also similar in the formant pattern. The similarity in F_1F_2 tends to be slightly larger between the vowels /ɑ/ and /ʌ/ than between the vowels /ɒ/ and /ɑ/. The position is more downward and centralized in the F_1F_2 plane due to the larger F_1F_2 values for both the vowels /ɑ/ (1192 Hz, 1661 Hz) and /ʌ/ (1141 Hz, 1864 Hz) than the vowel /ɒ/ (1022 Hz, 1499 Hz). The data may indicate that the female Cantonese children's vowels /ɑ/ and /ʌ/ tend to merge, but the vowels /ɒ/ and /ɑ/ remain distinct.

It is also similar to the male Cantonese children that the female Cantonese children have no obvious problem in the production of the English vowel /ɜ/. The vowel is located in the mid central position of the F_1F_2 plane (Fig. 4), while it tends to be positioned more backward for Female Cantonese Child 1 (left panel of Fig. 5) than Female Cantonese Child 2 (right panel of Fig. 5). The F_1F_2 for Female Cantonese Child 2's /ɜ/ (799 Hz, 2097 Hz), rather than Female Cantonese Child 1's /ɜ/ (743 Hz, 1793 Hz), are close to those for the English child's /ɝ/ (724 Hz, 1963 Hz), although the degree of rhoticity associated with the vowel is less pronounced in the Cantonese children.

3.1.4. Two male Japanese children

Fig. 6 shows the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for two male Japanese children. Fig. 7 shows the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ separately for Male Japanese Child 1 (left panel) and Male Japanese Child 2 (right panel).

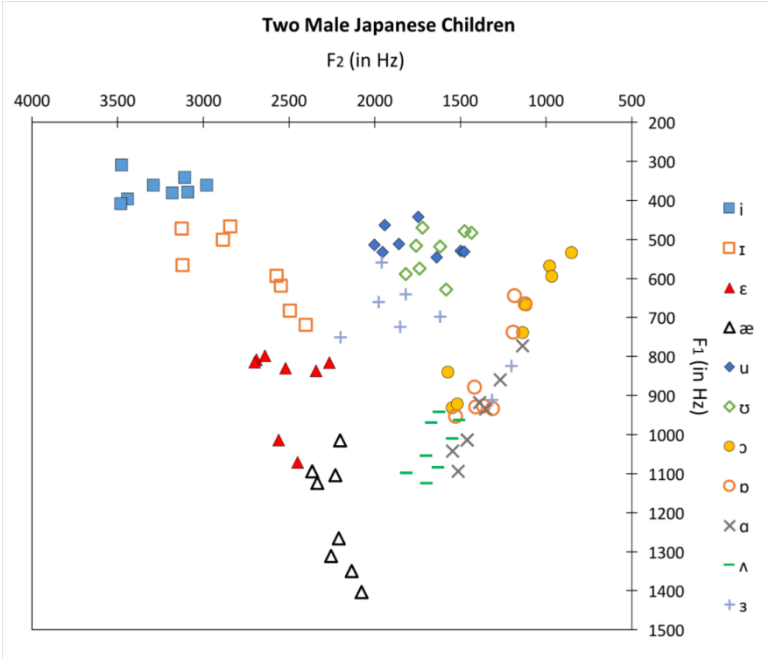

Fig. 6: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for two male Japanese children.

Fig.7: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for Male Japanese Child 1 (left panel) and Male Japanese Child 2 (right panel).

A comparison of Fig. 6 for the two male Japanese children with Fig. 1 for the male English child shows that some of the English vowels are also not clearly distinct or tend to merge in the speech of the two male Japanese children. For the two male Japanese children (Fig. 6), the formant patterns for the high vowels /i ɪ u ʊ/ are similar to those for the

Cantonese children, male (Fig. 2) and female (Fig. 4), that the front tense /i/ and lax /ɪ/ are clearly separated in the F_1F_2 plane, but the back tense /u/ and lax /ʊ/ are not. For the two front vowels, the lax /ɪ/ is centralized, positioned more downward and backward than the tense /i/ in the F_1F_2 plane. This is similar to the pattern of the relative positions of the tense /i/ and lax /ɪ/ for the male English child (Fig. 1).

For the two high back vowels /u/ and /ʊ/, they overlap in the F_1F_2 plane for the two male Japanese children (Fig. 6), which is also the case for the male (Fig. 2) and female (Fig. 4) Cantonese children. For the two male Japanese children, the mean F_1F_2 for /u/ (509 Hz, 1765 Hz) and /ʊ/ (533 Hz, 1644 Hz) are similar and closer to the F_1F_2 for the male English child's tense vowel /u/ (478 Hz, 1461 Hz), rather than the lax equivalent /ʊ/ (514 Hz, 999 Hz). The data indicate that the Japanese children merge the two high back vowels /u/ and /ʊ/ into the tense vowel /u/, but it becomes fronted in the acoustical vowel space with a larger F_2 than the vowel /u/ for the male English child.

As for the mid front vowel /ɛ/ and low front vowel /æ/, they are basically distinct in the F_1F_2 plane for the two male Japanese children, but the mid back vowel /ɔ/ and low back vowel /ɒ/ are not (Fig. 6). For Male Japanese Child 1, as shown in the left panel of Fig. 7, the vowel /ɛ/ is located in the mid front position and the vowel /æ/ in the low front position in the F_1F_2 plane, similar to the relative positions of the two vowels for the male English child (Fig. 1). As for Male Japanese Child 2 (right panel of Fig. 7), the vowel /ɛ/ is positioned more downward and closer to the position of the vowel /æ/ in the F_1F_2 plane. Basically, the two vowels /ɛ/ and /æ/ are distinguishable for the two male Japanese children, which is different from the case of the Cantonese children, male (Fig. 2 and Fig. 3) and female (Fig. 4 and Fig. 5).

As for the mid back /ɔ/ and low back /ɒ/, they overlap extensively in the F_1F_2 plane for the two male Japanese children (Fig. 6), which is similar to the case of the Cantonese children (Fig. 2). The mean F_1F_2 for the vowels /ɔ/ (725 Hz and 1209 Hz) and /ɒ/ (835 Hz and 1314 Hz) are similar, and they are close to the F_1F_2 for the male English child's /ɒ/ (890 Hz, 1307 Hz), rather than /ɔ/ (651 Hz, 1058 Hz). The data may suggest that the two back vowels /ɔ/ and /ɒ/ merge into the low back vowel /ɒ/ for the two male Japanese children.

The merger between the vowels /ɒ/ and /ɑ/ is also observed in the two male Japanese children (Fig. 6), although it is less pronounced for Male Japanese Child 2 (right panel of Fig. 7) than Male Japanese Child 1 (left panel of Fig. 7). For Male Japanese Child 1, the F_1F_2 values for /ɒ/ (923 Hz, 1428 Hz) and /ɑ/ (1010 Hz, 1456 Hz) are similar to those for the English child's /ɒ/ (890 Hz, 1307 Hz) and /ɑ/ (964 Hz, 1411 Hz), suggesting that this Japanese child similar to the English child merges the two vowels into one. Such kind of merger is less pronounced for Male Japanese Child 2, as the difference in F_1F_2 between /ɒ/ (746 Hz, 1186 Hz) and /ɑ/ (903 Hz, 1325 Hz) is increased. This is also not observed in the speech of the Cantonese children, both male (Fig. 2 and Fig. 3) and female (Fig. 4 and Fig. 5).

For the two male Japanese children, the vowels /ɑ/ and /ʌ/ are similar in F_1F_2, while the vowel /ʌ/ tends to be more centralized in the F_1F_2 plane (Fig. 6). The similarity between /ɑ/ and /ʌ/ and the tendency of centralization for the vowel /ʌ/ is observed in each of the two male Japanese children (Fig. 7) as well as the male and female Cantonese children (Fig. 2-5) and the English child (Fig. 1).

For the vowel /ɜ/, it is located in the mid central position in the F_1F_2 plane, distinguishing from all the other vowels for Male Japanese Child 1 (left panel of Fig. 7). For Male Japanese Child 2 (right panel of Fig. 7), the position of the vowel /ɜ/ varies largely in the F_1F_2 plane, overlapping with some other vowels, such as the vowels /ʊ/, /ɒ/, and /ɑ/, in different tokens. The data indicate that Male Japanese Child 2 is not sure of the target position for the central /ɜ/.

3.1.5. Two female Japanese children

For the two female Japanese children, the variation in the formant patterns for the English vowels is large, due to the large between-speaker difference, as compared with the cases of the male Japanese children and the male and female Cantonese children in this study. A comparison of the positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for both the two female Japanese children (Fig. 8) or separately for each of the two female Japanese children (Fig. 9) with those for the English child (Fig. 1) shows that most of the English vowels for the female Japanese children are widely spread and overlap with other vowels in the acoustical vowel space.

As shown in Fig. 8 for the two female Japanese children, the positions for the two high front vowels /i/ and /ɪ/ in the F_1F_2 plane are near to each other. This is especially pronounced for Female Japanese Child 1 (left panel of Fig. 9), and the F_1F_2 values for her vowels /i/ (612 Hz, 3549 Hz) and /ɪ/ (652 Hz, 3354 Hz) are similar to the English child's vowels /i/ in F_2 (3362 Hz) and /ɪ/ in F_1 (524 Hz). The data indicate that the two high front vowels merge to become a form with the mixed formant patterns for the English vowels /i/ and /ɪ/. For Female Japanese Child 2 (right panel of Fig. 9), the F_1F_2 values between the vowels /i/ (513 Hz, 3412 Hz) and /ɪ/ (641 Hz, 3007 Hz) are also similar, though no overlap in position between the two vowels in the F_1F_2 plane is observed. Female Japanese Child 2's /i/ and /ɪ/ are closer to the English child's /ɪ/ (524 Hz, 3071 Hz), rather than /i/ (457 Hz, 3362 Hz), due to an increase in F_1.

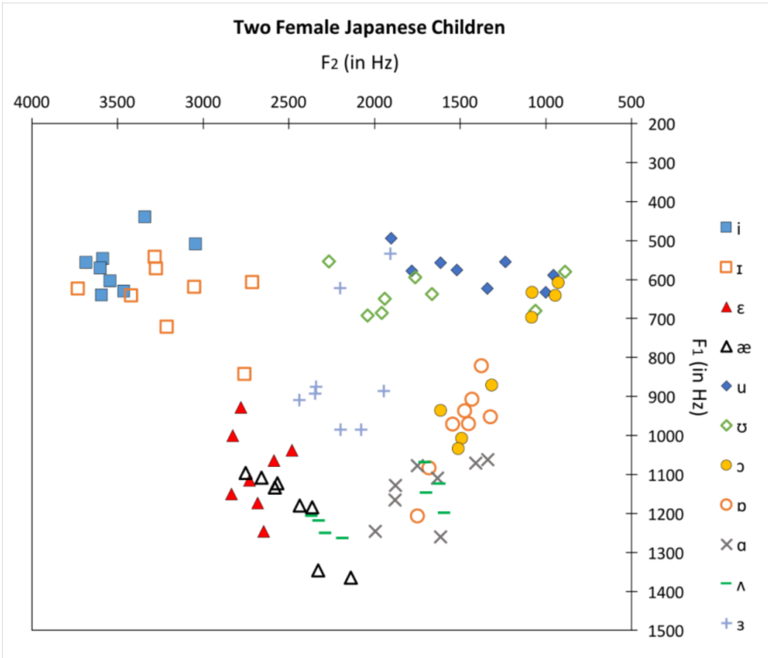

Fig. 8: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for two female Japanese children.

Fig. 9: Positions of the English vowels /i ɪ ɛ æ u ʊ ɔ ɒ ɑ ʌ ɜ/ in the F_1F_2 plane for Female Japanese Child 1 (left panel) and Female Japanese Child 2 (right panel).

Similarity in F_1F_2 is also observed between the two high back vowels /u/ and /ʊ/ in the two female Japanese children (Fig. 8). This is especially pronounced for Female Japanese Child 2 (right panel of Fig. 9), with similar F_1F_2 for the vowels /u/ (568 Hz, 1275 Hz) and /ʊ/ (623 Hz, 1344 Hz). For Female Japanese Child 1 (left panel of Fig. 9), the F_1 for the vowels /u/ (583 Hz) and /ʊ/ (645 Hz) are similar, while the F_2 is much larger for /ʊ/ (2052 Hz) than /u/ (1565 Hz) indicating the fronting of /ʊ/. The two female Japanese children's /u/ and /ʊ/ are similar to the English child's /ʊ/ in F_1 (514 Hz) and /u/ in F_2 (1461 Hz), demonstrating an increase in the degree of centralization for the two high back vowels in their speech.

As shown in Fig. 8, the mid front vowel /ɛ/ and low front vowel /æ/ also overlap in the F_1F_2 plane for the two female Japanese children. But, different from the four high vowels /i ɪ u ʊ/, the overlap between the two vowels /ɛ/ and /æ/ mainly happens in Female Japanese Child 1 (left panel of Fig. 9). For Female Japanese Child 1, the F_1F_2 for /ɛ/ (1171 Hz, 2724 Hz) and /æ/ (1115 Hz, 2641 Hz) are close to each other and similar to the English child's /æ/ in F_1 (1132 Hz) and /ɛ/ in F_2 (2674 Hz), indicating that the two vowels for Female Japanese Child 1 merge and become a 'new' form with the mixed formant patterns for the English vowels /ɛ/ and /æ/. As for Female Japanese Child 2, the mid front /ɛ/ has a smaller F_1 (1008 Hz) and a larger F_2 (2669 Hz), as compared with the F_1F_2 for the low front /æ/ (1269 Hz, 2318 Hz), and the relative difference in F_1F_2 between the two vowels is similar to that for the English child's vowels /ɛ/ (716 Hz, 2674 Hz) and /æ/ (1132 Hz, 2076 Hz).

For the back vowels, the mid /ɔ ʌ/ and low /ɒ ɑ/, the formant patterns largely vary between the two female Japanese children. In the F_1F_2 plane for Female Japanese Child 1 (left panel of Fig. 9), overlap is observed between the vowels /ɔ/ and /ɒ/ and between the vowels /ɒ/ and /ɑ/, and the vowel /ʌ/ is located in the low central position close to the vowel /ɑ/. The similarities in F_1F_2 between /ɔ/ (963 Hz, 1482 Hz) and /ɒ/ (1058 Hz, 1605 Hz) and between /ɒ/ (1058 Hz, 1605 Hz) and /ɑ/ (1154 Hz, 1876 Hz) for Female Japanese Child 1 are also observed in the speech of the two male Japanese children (Fig. 6 and Fig. 7) and the four Cantonese children (Fig. 2-5). For the English child (Fig. 1), the F_1F_2 for the vowels /ɒ/ (890 Hz, 1307 Hz) and /ɑ/ (964 Hz, 1411 Hz) are similar, indicating the merger between the two vowels in the Japanese and Cantonese children is not a major problem. However, the F_1F_2 for the English child's vowels /ɔ/ (651 Hz, 1058 Hz) and /ɒ/ (964 Hz, 1411 Hz) are still distinct, which is not the case for the Japanese and Cantonese children. This suggests that the non-English children have a difficulty in differentiation of the two back vowels /ɔ/ and

/ɒ/. For Female Japanese Child 1, the F_1F_2 for the vowel /ʌ/ (1234 Hz, 2293 Hz) are similar to the low vowels /ɒ/ and /ɑ/ in F_1, but more centralized in the F_1F_2 plane with a larger F_2, similar to the pattern of the differences in F_1F_2 between the vowels /ʌ/ and /ɒ ɑ/ for the English child.

For Female Japanese Child 2 (right panel of Fig. 9), there is no overlap between the vowels /ɔ/ and /ɒ/ in the F_1F_2 plane. The F_1F_2 values for her vowels /ɔ/ (646 Hz, 1008 Hz) and /ɒ/ (905 Hz, 1399 Hz) are similar to the English child's /ɔ/ (651 Hz, 1058 Hz) and /ɒ/ (964 Hz, 1411 Hz). However, the English child's /ɔ/ is located in the mid back position of the F_1F_2 plane, whereas Female Japanese Child 2's /ɔ/ overlaps in position with /u/, due to an increase in F_1 for /u/. As for the two low vowels /ɒ/ and /ɑ/, there is also no overlap between their positions in the F_1F_2 plane. The F_1F_2 values for Female Japanese Child 2's /ɒ/ (905 Hz, 1399 Hz) are smaller than those for /ɑ/ (1126 Hz, 1499 Hz), which is different from the merging pattern for the vowels /ɒ/ and /ɑ/ observed in the English child. As for Female Japanese Child 2's vowel /ʌ/, it is closer to the position of the low vowel /ɑ/ in the F_1F_2 plane, as compared to the relative positions of the vowels /ʌ/ and /ɑ/ in all the other children.

For Female Japanese Child 1, the vowel /ɜ/ is clearly separated from all the other English vowels, located in the mid central position of the F_1F_2 plane. Comparing with the F_1F_2 for the English child's /ɜ/ (725 Hz, 1963 Hz), there is an increase in both F_1F_2 for Female Japanese Child 1's /ɜ/ (939 Hz, 2264 Hz). The F_1F_2 for Female Japanese Child 2's /ɜ/ (733 Hz 2101 Hz) are similar to those for Female Japanese Child 1's one. However, there is a larger intra-variation in F_1F_2 for different tokens of the vowel /ɜ/ in Female Japanese Child 2 than in Female Japanese Child 1. The variation in the degree of rhoticity associated with the vowel /ɜ/ is also observed between the two female Japanese children.

3.2. Acoustical Vowel Space

In order to show the differences in the acoustical vowel space for the production of English vowels between the different groups of children, the vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ are drawn, by connecting the positions of the seven vowels in the F_1F_2 plane based on the mean F_1F_2 values for each vowel averaging across all the tokens for children, male and/or female, with the same L1. Comparisons of the vowel loops for the Cantonese and Japanese children with that for the English child as well as those for the male and female children of Cantonese or Japanese are presented below.

3.2.1. Vowel loops for English and Cantonese children

Fig. 10 shows the superimposed vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ in the F_1F_2 plane for the male English child (in grey line) and four Cantonese children (in black line), male and female. The positions of the non-peripheral vowels /ɪ ʊ ʌ ɜ/ are also shown in the figure, in order to show the relative positions of all the 11 English vowels for the two groups of children.

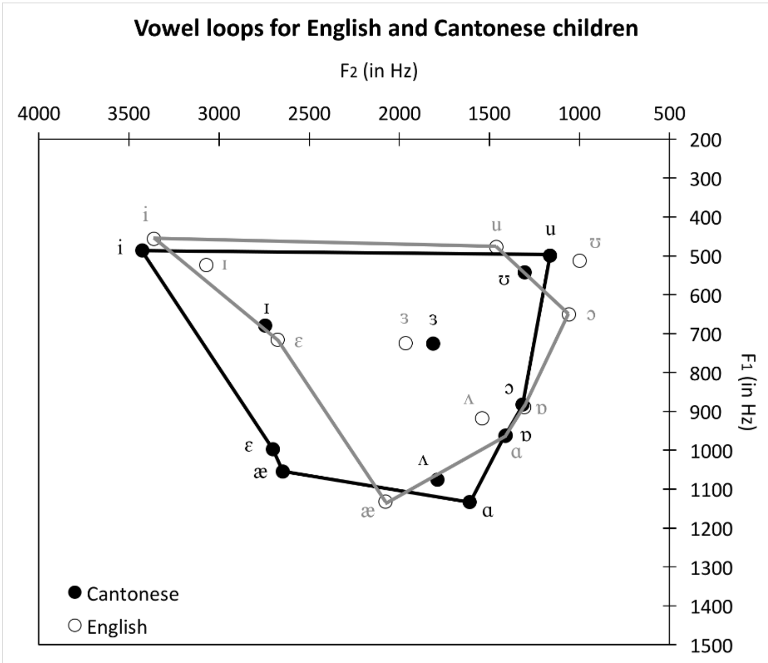

Fig. 10: Vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ in the F_1F_2 plane for an English child and four Cantonese children.

As shown in Fig. 10, the vowel loop is slightly larger for the Cantonese children than the English child, mainly due to the more forward positions for the front vowels /i ɛ æ/ and the more backward position for the vowel /u/ in the Cantonese children. A comparison of the positions for the corresponding vowels from the two groups of children shows that the problems for the Cantonese children in producing the English vowels are in the front vowels /ɪ ɛ æ/ and back vowels /u ʊ ɔ ɑ ʌ/.

For the English child, relative to the high front tense /i/, the lax /ɪ/ is slightly centralized, shifting downward and backward in the F_1F_2 plane. However, for the Cantonese children, while the lax /ɪ/ is also centralized in the F_1F_2 plane, the degree of centralization for /ɪ/ is much increased, with the large F_1F_2 (680 Hz, 2744 Hz) similar to the F_1F_2 for the mid front vowel /ɛ/ (716 Hz, 2674 Hz) in the English child. As for the Cantonese children's vowel /ɛ/, it is positioned more downward and forward in the F_1F_2 plane than the English child's /ɛ/, with an increase in both F_1F_2 (998 Hz, 2700 Hz) maintaining the distinction between the vowels /ɪ/ and /ɛ/. The Cantonese children, however, merge the English vowels /ɛ/ and /æ/, producing the F_1F_2 for /æ/ (1055 Hz, 2645 Hz) similar to those for /ɛ/. The vowel /æ/ in the Cantonese children is more forward in the F_1F_2 plane, as compared with the F_1F_2 for the English child's /æ/ (1132 Hz, 2076 Hz).

Concerning the back vowels, the fronting for the tense /u/, relative to the lax equivalent /ʊ/, as observed in the English child is not true for the Cantonese children. For the Cantonese children, the difference between the tense /u/ and lax /ʊ/ is in the centralization of /ʊ/ in the F_1F_2 plane, indicated by the increase in both F_1F_2 for the lax /ʊ/ (543 Hz, 1303 Hz), relative to the tense /u/ (499 Hz, 1164 Hz). This resembles to the pattern of the difference in F_1F_2 between the high front tense /i/ and lax /ɪ/.

Similar to the case of the mid front vowel /ɛ/, the Cantonese children produce the mid back vowel /ɔ/ in a more downward and peripheral position in the F_1F_2 plane, with a large increase in both F_1F_2 (884 Hz, 1315 Hz), as compared with the vowel /ɔ/ for the English child (651 Hz, 1058 Hz). For the Cantonese children, the change in F_1F_2 for the vowel /ɔ/ leads to the proximity to the F_1F_2 for the vowel /ɒ/ (962 Hz, 1408 Hz), indicating the merger between the two vowels in their speech.

For the English child, the F_1F_2 values for the two low vowels /ɑ/ (964 Hz, 1411 Hz) and /ɒ/ (890 Hz, 1307 Hz) are similar, indicating the merger between the two vowels in his speech. For the Cantonese children, the difference in F_1F_2 between the vowels /ɑ/ and /ɒ/ is increased, where the F_1F_2 are larger for /ɑ/ (1133 Hz, 1609 Hz) than /ɒ/ (962 Hz, 1408 Hz).

Between the Cantonese children and the English child, there is also a difference in the production of the vowel /ʌ/, which is positioned in a more downward and central position in the F_1F_2 plane for the Cantonese children than the English child. However, for the Cantonese children, the F_1F_2 for the vowel /ʌ/ (1077 Hz, 1788 Hz) remain close to those for the vowel /ɑ/ (1133 Hz, 1609 Hz), similar to the case of the proximity of the vowels /ʌ/ (918 Hz, 1539 Hz) and /ɑ/ (964 Hz, 1411 Hz) for the English child.

3.2.2. Vowel loops for English and Japanese children

Comparison of the acoustical vowel space is also made between the Japanese children and the English child. Fig. 11 shows the superimposed vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ in the F_1F_2 plane for the four male and female Japanese children (in black line) and the English Child (in grey line). The positions of the four English non-peripheral vowels /ɪ ʊ ʌ ɜ/ from the two groups of children are also shown in the figure.

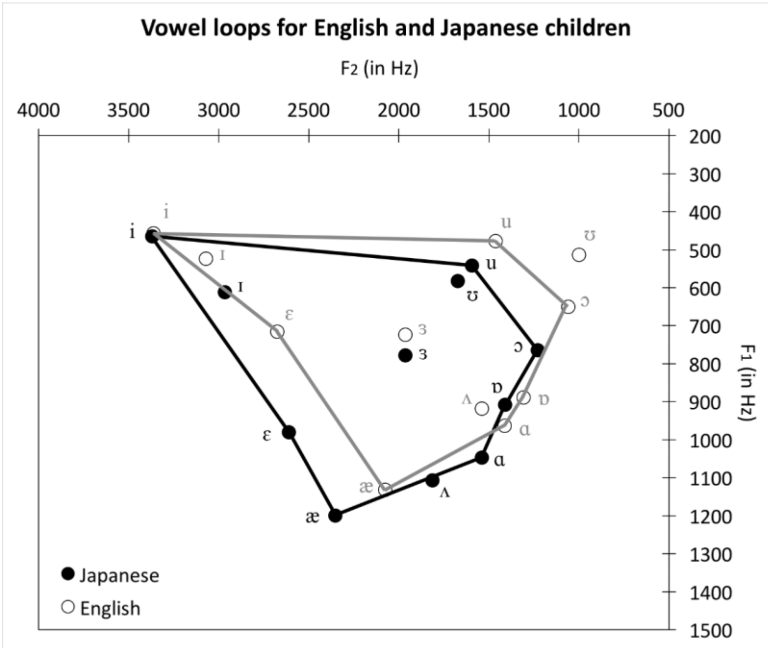

Fig. 11: Vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ in the F_1F_2 plane for an English child and four Japanese children.

As shown in Fig. 11, the shape and the size of the vowel loops are generally similar between the Japanese and English children, while the Japanese vowel loop is positioned more downward and forward in the F_1F_2 plane than the English one. The shift in the vowel loop position is due to the displacement of the peripheral vowels /ɛ æ ɑ ɔ u/ in the Japanese children. For the two front vowels /ɛ/ and /æ/ in the Japanese children, there is a large downward shift for /ɛ/ due to an increase in F_1 (981 Hz) and a large forward shift for /æ/ due to an increase in F_2 (2353 Hz), relative to the F_1 for /ɛ/ (716 Hz) and F_2 for /æ/ (2076 Hz) for the English child. Due to the shift in the two front vowels for the Japanese children, the mid front vowel /ɛ/ becomes closer to the low front vowel /æ/ in the acoustical vowel space, as compared to the relative positions of the vowels /ɛ/ and /æ/ for the English child. Nonetheless, the F_1F_2 for the vowels /ɛ/ (981 Hz, 2609 Hz) and /æ/ (1200 Hz, 2353 Hz) in the

Japanese children are still clearly distinct, which is different from the case of the merger between /ɛ/ and /æ/ observed in the Cantonese children (Fig. 10).

Similarity in the relative positions for the two high front vowels /i/ and /ɪ/ in the F_1F_2 plane is also observed between the Japanese and English children (Fig. 11), while the degree of centralization for the lax /ɪ/ relative to the tense /i/ is larger for the Japanese children than the English child. As for the two high back vowels /u/ and /ʊ/, the centralization of the lax /ʊ/ relative to the tense /u/ is observed in the Japanese children, different from the fronting of the tense /u/ in the English child. Furthermore, both the vowels /u/ and /ʊ/ are positioned more downward and forward in the F_1F_2 plane for the Japanese children than the English child, leading to the overall shift of the vowel loop for the Japanese children.

The downward and forward shift is also observed for the back vowels /ɔ ɑ ʌ/ in the Japanese children, as compared to the positions of the three back vowels for the English child. This is due to the larger F_1F_2 for the Japanese children's vowels /ɔ/ (765 Hz, 1227 Hz), /ɑ/ (1048 Hz, 1539 Hz), and /ʌ/ (1107 Hz, 1811 Hz) than the English child's /ɔ/ (651 Hz, 1058 Hz), /ɑ/ (964 Hz, 1411 Hz), and /ʌ/ (918 Hz, 1539 Hz). For these three back vowels, they are clearly distinct in both the F_1F_2 values for the Japanese children, but the vowels /ɑ/ and /ʌ/ tend to merge in the English child. Merger due to the similarity in F_1F_2 is observed between the back vowels /ɑ/ (964 Hz, 1411 Hz) and /ɒ/ (890 Hz, 1307 Hz) in the English child. But the difference in F_1F_2 between /ɑ/ (1048 Hz, 1539 Hz) and /ɒ/ (908 Hz, 1408 Hz) is increased in the Japanese children.

3.2.3. Vowel loops for male and female children

Comparison of the vowel loops for the English vowels between male and female children is also made for determining the gender difference in the acoustical vowel space for the production of English vowels. In Fig. 12, the left panel shows the superimposed vowel loops for the English vowels in the F_1F_2 plane for two male Cantonese children (in black line) and two female Cantonese children (in grey line). The superimposed vowel loops for the English vowels for the male (in black line) and female (in grey line) Japanese children are shown in the right panel of Fig. 12. As shown in the figure, it can be seen that for both the Cantonese and Japanese groups, the vowel loop for the female children is positioned more downward and forward in the F_1F_2 plane than the vowel loop for the male children, due to a general increase in the F_1F_2 for the female vowels than male ones. The data indicate that the gender difference in formant frequencies appears in children at the ages of 6-7 years.

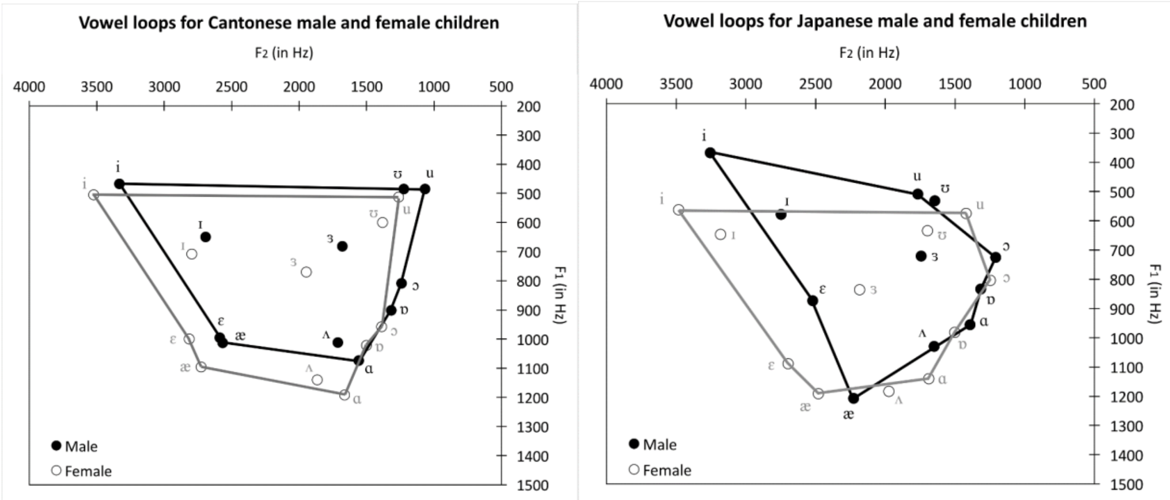

Fig. 12: Vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ in the F_1F_2 plane for male and female children of Cantonese (left panel) and Japanese (right panel).

For Cantonese children (left panel of Fig. 12), the relative positions of the English vowels are generally similar for male and female, in spite of the difference in the absolute F_1F_2 values between the two genders. For instance, a similar degree of centralization for the lax vowel /ɪ/ relative to the tense vowel /i/ is observed in both the Cantonese male and female children. Furthermore, for the Cantonese children of both genders, the positions for the front vowels /ɛ/ and /æ/, the back vowels /ɔ/ and /ɒ/, and the back vowel /ʌ/ and /ɑ/ are close to each other in the F_1F_2 plane, indicating a tendency of merger between the two vowels in each of the three pairs. A more obvious difference between the male and female Cantonese children is in the relative positions for the high back vowels /u/ and /ʊ/ in the F_1F_2 plane. For the male Cantonese children, the lax /ʊ/ shifts forward from the position for the tense /u/, with an increase in F_2. For the female Cantonese children, the lax /ʊ/ shifts not only forward but also downward with an increase in both F_1F_2, relative to the tense /u/.

As for the Japanese children (right panel of Fig. 12), the relative positions for the high front tense /i/ and lax /ɪ/ are similar between male and female, but it is not the case for the other two front vowels /ɛ/ and /æ/. For the male Japanese children, the mid front vowel /ɛ/ is generally positioned in between the high front /i/ and low front /æ/, but it is positioned closer to the low front /æ/ and more forward in the F_1F_2 plane for the female Japanese children. For the two high back vowels /u/ and /ʊ/, centralization with the downward and forward displacement is observed in the lax /ʊ/ for the female Japanese children, but /u/-fronting is observed in the male Japanese children.

Furthermore, the three back vowels /ɔ ɒ ɑ/ are clearly separated in the F_1F_2 plane for the female Japanese children. For the male Japanese children, while the positions for the vowels /ɔ ɒ ɑ/ are still distinct, they are crowded in the mid back position of the F_1F_2 plane.

Differences between the male and female Japanese children are also observed in the positions for the vowels /ʌ/ and /ɜ/. For the male Japanese children, the position for the vowel /ʌ/ is slightly lower than that for the low back vowel /ɑ/ and greatly higher than the position for the low front vowel /æ/. For the female Japanese children, the vowel /ʌ/ is in the low central position, generally in between the positions for the low front vowel /æ/ and low back vowel /ɑ/. As for the mid central vowel /ɜ/, it is generally located in the center of the F_1F_2 plane for the female Japanese children, but positioned more backward for the male Japanese children.

3.2.4. Vowel loop areas for children of different languages

Table 2 presents the areas of the vowel loops for the English vowels, based on the mean F_1F_2 values for each of the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/, for the different groups of children, including the English child, male and female Cantonese children, and male and female Japanese children, in this study.

L1	Number of children	Vowel loop area
English	One male child	825048
Cantonese	Two male children	954701
	Two female children	1074030
	All four children	1014623
Japanese	Two male children	820503
	Two female children	951582
	All four children	889212

Table 2: Areas (in Hz^2) of the vowel loops for the English peripheral vowels /i ɛ æ ɑ ɒ ɔ u/ for English, Cantonese, and Japanese children, male and female.

The data presented in Table 2 show that the area of the vowel loop is noticeably larger for Cantonese children than English and Japanese children. This is true for comparing the vowel loops for all the four male and female Cantonese children (1014623 Hz^2) or separately for the two male (954701 Hz^2) or two female (1074030 Hz^2) Cantonese children with those for the English child (825048 Hz^2), four male and female Japanese children (889212 Hz^2), two male Japanese children (820503 Hz^2), and two female Japanese children (951582 Hz^2). The data indicate that the English vowels are more peripheral in the acoustical vowel space and have a wider spread for Cantonese children, male and female, than English and Japanese children.

For the Japanese children, the area of the male vowel loop (820503 Hz^2) is similar to that of the English child (825048 Hz^2), indicating that the acoustical vowel space for the English vowels in the male Japanese children is similar to the native one. The area of the vowel loop for the female Japanese children (951582 Hz^2) is also close to that for the male English child, indicating that the acoustical vowel space for the English vowels is also native-like in the female Japanese children.

Comparing the areas of the vowel loops for the two genders of the same L1, i.e., Cantonese or Japanese, the female one is larger than the male one. This is true for both Cantonese and Japanese, suggesting a universal gender difference in the acoustical vowel space for children at the ages of 6-7 years. A larger acoustical vowel space may be due to the larger formant values for female than male as observed in both the Cantonese and Japanese children in this study.

4. Discussion

This project has presented the formant frequencies for the English vowels produced by two groups of non-English speakers, Cantonese-speaking and Japanese-speaking children, with comparison of those for the vowels from a male native English child. The formant data demonstrate the difficulties in the production of the English vowels for the children with different L1 backgrounds. In the following, the influence of L1 transfer on the L2 English vowel acquisition in Cantonese and Japanese children is discussed.

4.1. Effect of L1 Cantonese on L2 English Vowel Production

For Cantonese children, the major problems in the English vowel production are the mergers (i) between the mid front vowel /ɛ/ and low front vowel /æ/, (ii) between the mid back vowel /ɔ/ and low back vowel /ɒ/, and (iii) between the mid back vowel /ʌ/ and low back vowel /ɑ/. They are observed in both male and female Cantonese children and considered in relation to the influence of their L1 Cantonese.

In Cantonese, there is a mid front vowel /ɛ/, but the low front vowel /æ/ does not occur. Due to the proximity of /æ/ to /ɛ/ in vowel quality, it may explain why the two vowels merge in the speech of the Cantonese children of the present study. Similarly, the mid back vowel /ɔ/, but not the low back vowel /ɒ/, occurs in Cantonese, which also leads to the merger between the vowels /ɔ/ and /ɒ/ in the Cantonese children, in view of the fact that the vowel qualities of /ɔ/ and /ɒ/ are similar. As for the vowels /ʌ/ and /ɑ/, both of them do not occur in Cantonese. These two vowels are similar in F_1F_2 for the English child in the present study, indicating their similarities in vowel quality in English. This may explain why /ʌ/ and /ɑ/ tend to merge in the Cantonese children. However, different from the English child where the vowels /ʌ/ and /ɑ/ are located more upward and close to the mid back vowel /ɔ/ in the F_1F_2 plane, the vowels /ʌ/ and /ɑ/ in the Cantonese children are positioned more downward in the acoustical vowel space. It is perhaps due to the influence of the two low vowels /ɐ/ and /a/ which are produced with similar low central quality in Cantonese (Zee, 1999).

As for the other English vowels, the tense-lax vowel pairs, including the front /i/-/ɪ/ and the back /u/-/ʊ/, are clearly distinct in the Cantonese children. For the front pair, the relative positions for the tense /i/ and lax /ɪ/ as observed in the English child are basically retained in the Cantonese children, though the lax /ɪ/ becomes more centralized in the acoustical vowel space for the Cantonese children. For the back pair, the difference between the tense /u/ and lax /ʊ/ for the English child is in the fronting of the tense /u/, but for the Cantonese children, it is in the centralization of the lax /ʊ/. This may be because in Cantonese the tense /u/ has no fronting and the lax /ʊ/ is centralized.

The English vowel /ɜ/ is clearly distinguished from all the other English vowels and located in the mid central position of the F_1F_2 plane for the Cantonese children. Nevertheless, the degree of rhoticity associated with the mid central vowel /ɜ/ is less pronounced in the Cantonese children than the English child who is an American native in the present study.

For the Speech Learning Model (SLM) of L2 acquisition proposed by Flege (1997), it is claimed that the "identical" sounds which are the same in L1 and L2 and the "new" sounds which occur in L2 but not in L1 are easier to be acquired and produced with native-like qualities, whereas the sounds in L2 "similar" those in L1 are more likely to be substituted by the L1 sounds. The L2 data on the English vowel production for the Cantonese children in the present study are not wholly predicted by the model. For instance, the four high vowels, the tense /i u/ and lax /ɪ ʊ/, occur in both Cantonese and English. While the Cantonese children in the present study can produce the four vowels with the distinct formant patterns, the patterns are not native-like for the two lax vowels /ɪ ʊ/ and the tense vowel /u/. The two lax vowels /ɪ ʊ/ are more centralized for the Cantonese children than the English child, and there is no /u/-fronting observed in the Cantonese children as in the English child. As for the English low front vowel /æ/ and low back vowel /ɒ/, which are non-occurring in Cantonese and considered as the "new" sounds in L2 English for Cantonese speakers, they are the most problematic ones for the Cantonese children. The Cantonese children cannot produce the distinct formant patterns for the low vowels /æ/ and /ɒ/ from the respective mid vowels /ɛ/ and /ɔ/ in English. Similar findings on the confusion between the front /æ/ and /ɛ/ and between the back /ɒ/ and /ɔ/ are also observed in Cantonese adult speakers as reported in Chan (2007, 2009) and Hung (2000). Since Cantonese has both the front /ɛ/ and back /ɔ/, the findings may indicate that Cantonese speakers substitute the "new" vowels /æ/ and /ɒ/ in L2 English with the L1 Cantonese vowels /ɛ/ and /ɔ/. This case is different from what the SLM predicts. However, for some other "new" vowels in L2 English, such as the vowels /ʌ/, /ɑ/, and /ɜ/ that are non-occurring in Cantonese, they are produced with the formant patterns in the Cantonese children similar to those in the English child, supporting the prediction of the SLM.

4.2. Effect of L1 Japanese on L2 English Vowel Production

For the Japanese children in the present study, the acoustical vowel space for the English vowels is similar to the English child's one, though there are also some differences in the relative positions of the English vowels in the vowel space between the Japanese and English children. The error patterns are presumably due to the effect of L1 of the Japanese children, as some of them are not observed in the Cantonese children.

The problems for the Japanese children are mainly in the production of the back vowels in English. For the two English high back vowels /u/ and /ʊ/, a significant forward shift in the F_1F_2 plane is observed for the Japanese children, which is due to the large F_2 for the two vowels. Similar findings are also observed for Japanese adult speakers as reported in Tsukada (1999). The fronting or large F_2 for the English back vowels produced by Japanese speakers may be related to the de-rounding of the high back vowel /u/ in Japanese (Okada, 1991), as the degree of lip rounding is inversely correlated to the frequency value of F_2 (Ladefoged and Johnson, 2015). Thus, this may be considered as a case of L1 transfer to L2. It should be added that the high back vowels /u/ and /ʊ/ are produced with similar F_1F_2 values in the Japanese children of the present study, indicating the merger between the two vowels. This merger of the English vowels /u/ and /ʊ/ may be related to the fact that there is only one high back vowel and no lax vowel /ʊ/ in Japanese (Okada, 1991). As a result, the Japanese children use the de-rounded /u/, i.e., [ɯ], in their L1 Japanese to substitute the two high back vowels /u/ and /ʊ/ in L2 English. Thus, this case may be considered as the supportive evidence for Flege's (1997) SLM, where the English vowels /u/ and /ʊ/ are the L2 sounds "similar" to the vowel [ɯ] in L1 Japanese and are replaced by L1 vowel [ɯ].

As for the mid and low back English vowels /ɔ ɒ ɑ ʌ/, they are basically distinct from each other and are produced with different formant patterns in the speech of the Japanese children, although the F_1F_2 differences between the mid vowel /ɔ/ and low vowel /ɒ/ are reduced as compared to those for the English child. All these four back vowels /ɔ ɒ ɑ ʌ/ are non-occurring in Japanese and then they are the "new" sounds in L2 English for the Japanese children. Thus, this may also be the evidence to support the SLM that the "new" sounds in L2 are easily acquired.

For the production of the English front /i ɪ ɛ æ/ and central /ɜ/ vowels, no serious problem is observed in the Japanese children. These vowels are clearly distinct with different formant patterns, and their relative positions in the F_1F_2 plane are similar to those for the English child. The only exception is the mid front vowel /ɛ/ which is positioned close to the low front vowel /æ/ in the Japanese children, but not generally in between the positions for the high front /i/ and low front /æ/ as in the English child. In Japanese, the front vowels include /i e a/ (Okada, 1991) only, and /ɪ ɛ æ/ are non-occurring. Thus, the English vowel /i/ can be considered as the "identical" sound and the English vowels /ɪ ɛ æ/ as the "new" sounds for the Japanese children, and all of them support the prediction of Flege's (1997) SLM.

4.3. Other Factors in L2 Acquisition

The L2 vowel production data from the Cantonese and Japanese children in this study demonstrate a significant influence of L1 on L2 sound acquisition, though the findings are not wholly predicted by Flege's (1997) SLM. Compared with the other L2 studies of English vowel production in adult speakers, Cantonese (Chan, 2007, 2009; Hung, 2000) and Japanese (Tsukuda, 1999), similar error patterns are observed in both children and adults. This is different from what suggested in Cowie, et al. (1991) that children are better than adults in acquiring L2 sounds. It follows that the age of L2 learners may not be a significant factor in L2 acquisition.

It is considered that language experience is also a crucial factor in L2 learning. In Hong Kong, students are required to learn English as an L2 in school starting from a very young age until the end of their first degree. However, a strong local accent is still commonly observed in the English speech of most university students in Hong Kong (Chan, 2007, 2009; Hung, 2000), indicating that language experience is not a determining factor of L2 acquisition.

The problems in the production of English sounds for Cantonese speakers in Hong Kong may be due to lack of phonological awareness as pointed out in Yeung (2007). In Hong Kong, students learn English in school starting at word level. They are trained to memorize the pronunciation of the whole English words, without paying attention to the more basic component phonemes contained in the words. This is likely to be in relation to the fact that the orthography of Chinese characters is not phonology based, and each word is associated with a sound, instead of a sequence of component phonemes. It is considered that the lack of phonemic awareness leads to the difficulty for Cantonese speakers in recognizing their problems with the pronunciation of the different types of English sounds.

The problems of students’ English pronunciation may also be related to their English teachers. In Hong Kong, most of the English teachers of local schools are not native English speakers, and they may not have sufficient knowledge of the qualities of the English sounds and the differences in the sound system between Cantonese and English pertaining to the influence of L1 transfer. Thus, more native English teachers and/or more phonological training given to the non-native English teachers in the schools should be crucial for improving the English pronunciation of the non-native students.

5. Conclusion

This project has investigated the L2 production of English vowels in Cantonese and Japanese children through analyzing the formant frequencies of the vowels and comparing with the English vowels from a native American child. A number of errors are observed in both the Cantonese and Japanese children, and most of them are related to the L1 influence of the children. For instance, mergers are observed (i) between the two front vowels, the mid /ɛ/ and low /æ/, and (ii) between the two rounded back vowels, the mid /ɔ/ and low /ɒ/, for the Cantonese children. In each case, the two vowels merge to become a low-mid vowel which is presumably affected by the low-mid vowels /ɛ/ and /ɔ/ in Cantonese. As for the Japanese children, the high back vowels /u/ and /ʊ/ are fronted in the acoustic vowel space, due to a large F_2 which is supposed to be related to the de-rounding of the high back vowel /u/ in Japanese. In either the Cantonese or Japanese children, the pronunciation errors are observed in the so-called “identical”, “similar”, and “new” sounds classified in Flege’s (1997) Speech Learning Model, yet the data for the two groups of children are not wholly predicted by the model.

In general, the acoustical vowel space for the English vowels is more native-like in the Japanese children than the Cantonese children, and the different English vowels are generally distinct in the Japanese children. This may be considered in relation to the phonological awareness which is weak in Cantonese children, as the orthography of the Chinese characters is not phonology based. But, in Japan, the Japanese Romanization is taught to children in schools, which may help to enhance the children’s competence to recognize and distinguish the different English sounds. Nonetheless, this claim needs to be confirmed with more speech samples from Japanese and Cantonese speakers as well as speakers of other languages for a better understanding of the factors in L2 acquisition.

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7. Appendix

Table 1. Vowel formant frequencies (in Hz) for a male English child.

Vowels	Test words	Sample 1		Mean	
		F_1	F_2	F_1	F_2
i	feet	439.41	3530.24	457.38	3361.55
	seat	475.34	3192.85		
ɪ	fish	575.16	3113.44	524.46	3070.79
	pig	473.76	3028.14		
ɛ	bed	734.66	2812.75	716.20	2673.71
	head	697.74	2534.66		
æ	hat	1120.7	2070.08	1132.32	2075.77
	sad	1143.94	2081.46		
u	boot	497.75	1416.79	477.79	1460.58
	soup	457.83	1504.37		
ʊ	foot	498.13	920.8	513.72	998.90
	good	529.31	1077		
ɔ	fork	618.31	967.57	651.35	1057.74
	short	684.38	1147.9		
ɒ	hot	898.37	1333.22	889.79	1306.89
	dog	881.21	1280.56		
ɑ	card	970.43	1425.51	963.52	1411.12
	park	956.61	1396.72		
ʌ	bus	902.49	1496.22	918.48	1539.15
	duck	934.47	1582.08		
ɜ	church	747.24	2111.54	724.66	1963.30
	bird	702.08	1815.05		

Table 2. Vowel formant frequencies (in Hz) for Male Cantonese Child 1.

Vowels	Test words	Sample 1		Sample 2		Sample 3		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
i	feet	471.86	3107.77	444.75	3159.39	498.36	3002.82	500.65	3151.00
	seat	512.97	2989.74	534.12	3365.3	541.81	3280.97		
ɪ	fish	497.64	2551.89	490.42	2489.26	500.55	2732.93	604.83	2699.92
	pig	697.98	2867.85	725.16	2694.48	717.21	2863.08		
ɛ	bed	931.32	2621.51	874.5	2626.45	1017.93	2570.61	963.05	2608.54
	head	890.04	2660.92	1059.83	2609.79	1004.68	2561.95		
æ	hat	909.43	2576.49	989.43	2533.71	914.87	2647.92	940.57	2623.29
	sad	952.64	2695.82	934.03	2640.63	942.99	2645.15		
u	boot	592.37	1021.55	492.55	862.02	559.29	1116.8	517.44	1204.88
	soup	470.87	1324.5	507.62	1399.73	481.96	1504.7		
ʊ	foot	480.12	963.73	524.19	836.95	490.75	982.34	475.98	1259.69
	good	459.47	1522.28	459.51	1531.96	441.84	1720.87		
ɔ	fork	853.1	1333.16	880.1	1486.59	880.95	1379.83	904.28	1374.13
	short	923.73	1354.72	976.75	1362.44	911.03	1328.04		
ɒ	hot	952.5	1363.67	948.42	1497.36	927.31	1465.13	930.43	1405.04
	dog	1002.3	1357.04	885.02	1391.48	867	1355.56		
ɑ	card	1093.27	1558.51	1089.36	1529.73	1092.69	1477.02	1143.35	1647.08
	park	1241.79	1804.31	1132.61	1655.98	1210.37	1856.95		
ʌ	bus	942.63	1682.89	1065.79	1843.9	1060.72	1868.56	1102.41	1772.81
	duck	1253.89	1655.65	1262.53	1862.08	1028.92	1723.77		
ɜ	church	714.14	1930.83	699.67	1805.4	726.79	1831.18	717.88	1956.06
	bird	730.04	1960.73	720.99	2095.92	715.66	2112.28		

Table 3. Vowel formant frequencies (in Hz) for Male Cantonese Child 2.

Vowels	Test words	Sample 1		Sample 2		Sample 3		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
i	feet	432.22	3535.86	426.34	3399.84	464.4	3600.51	435.91	3509.74
	seat	426.57	3597.46	418.95	3383.67	446.98	3541.07		
ɪ	fish	686.14	2605.98	782.75	2467.64	677.95	2624.24	696.38	2731.17
	pig	679.94	2583.35	633.31	2905.51	718.16	2927.3		
ɛ	bed	1075.4	2617.45	1055.52	2688.03	1039.35	2532.83	1029.46	2565.52
	head	848.78	2526.05	1064.7	2512.64	1093.02	2516.13		
æ	hat	1121.72	2478.68	1132.98	2467.19	1057.92	2355.63	1086.85	2506.19
	sad	1070.81	2628.92	1063.88	2650.59	1073.77	2456.1		
u	boot	447.62	855.96	444.9	900.89	530.58	1101.22	453.44	925.34
	soup	413.36	908.35	461.57	917.33	422.61	868.28		
ʊ	foot	577.16	1035.13	495.61	1117.06	559.98	1078.59	494.76	1188.90
	good	463.73	1328.85	431.56	1196.47	440.51	1377.29		
ɔ	fork	649.86	959.47	618.45	958.23	753.25	1127.48	713.84	1107.92
	short	775.23	1206.18	720.96	1079.31	765.29	1316.85		
ɒ	hot	861.98	1308.6	892.57	1149.69	886.11	1243.47	873.12	1229.65
	dog	930.07	1270.93	777.94	1174.73	890.06	1230.48		
ɑ	card	1024.78	1349.83	915.26	1372.78	923.73	1517.9	1005.75	1466.31
	park	1072.44	1660.11	989.77	1355.64	1108.5	1541.57		
ʌ	bus	894.53	1731.04	862.95	1739.63	908.86	1603.87	923.21	1650.33
	duck	983.42	1504.18	943.15	1803.07	946.36	1520.16		
ɜ	church	627.31	1287.88	628.53	1265.44	658.25	1706.37	646.28	1403.34
	bird	653.31	1449.76	662.17	1463.68	648.09	1246.9		

Table 4. Vowel formant frequencies (in Hz) for Female Cantonese Child 1.

Vowels	Test words	Sample 1		Sample 2		Sample 3		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
i	feet	568.37	3463.22	504.24	3501.97	465.02	3551.02	472.42	3536.53
	seat	551.4	3582.06	367.82	3567.46	377.67	3553.47		
ɪ	fish	661.21	2865.69	712.61	2671.95	670.9	2716.14	697.86	2800.78
	pig	721.5	2778.77	784.29	2926.13	636.68	2846.03		
ɛ	bed	1144.05	2657.98	1062.22	2814.5	881.3	2917.48	1044.24	2826.87
	head	1149.56	2909.36	1029.37	2845.27	998.95	2816.64		
æ	hat	1171.57	2645.65	1134.99	2757.52	1307.45	2755.76	1172.00	2730.44
	sad	1090.28	2757.74	1141.26	2726.36	1186.47	2739.63		
u	boot	388.81	1217.8	404.5	1342.57	575.4	1408.65	477.34	1429.16
	soup	513.39	1795.93	501.28	1400.5	480.7	1409.54		
ʊ	foot	683.01	1321.87	686.67	1315.25	676.82	1616.06	621.44	1534.53
	good	622.46	1537.79	549.59	1686.14	510.14	1730.12		
ɔ	fork	911.39	1293.17	928.64	1376.31	907.93	1261.3	936.52	1279.72
	short	974.17	1112.49	918.18	1282.2	978.84	1352.85		
ɒ	hot	1120.7	1441.65	1109.19	1552.4	949.86	1370.47	1067.99	1471.39
	dog	1153.33	1655.65	1001.39	1422.71	1073.47	1385.48		
ɑ	card	1250.27	1660.82	1154.75	1700.31	1165.16	1597.9	1173.55	1595.54
	park	1138.7	1524.52	1167.56	1560	1164.86	1529.74		
ʌ	bus	1179.72	1916.4	1069.46	1553.55	986.99	1883.95	1104.47	1796.80
	duck	1180.73	1983.45	1138.59	1597.53	1071.38	1845.96		
ɜ	church	703.29	1918.57	667.53	1888.38	785.05	1852.11	743.08	1792.79
	bird	731.18	1905.48	858.13	1643.89	713.35	1548.32		

Table 5. Vowel formant frequencies (in Hz) for Female Cantonese Child 2.

Vowels	Test words	Sample 1		Sample 2		Sample 3		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
i	feet	500.66	3577.29	530.46	3446.88	543.83	3301.92	538.35	3505.78
	seat	495.56	3555.83	622.77	3575.43	536.83	3577.35		
ɪ	fish	567.49	2574.11	547.62	2652.74	557.36	2846.8	720.01	2788.95
	pig	915.66	2964.16	876.85	2769.64	855.06	2926.27		
ɛ	bed	934.64	2787.72	990.1	2802.28	871.61	2847.6	956.90	2798.70
	head	919.78	2748.57	938.71	2697.56	1086.56	2908.44		
æ	hat	931.94	2671.17	1042.18	2633.58	1129.01	2752.51	1020.59	2720.89
	sad	1049.38	2604.6	871.19	2737.66	1099.86	2925.82		
u	boot	587.02	1018.81	532.46	894.38	550.34	942.16	549.36	1094.98
	soup	557.56	1383.72	537.01	1079.69	531.74	1251.12		
ʊ	foot	606.4	1230.33	520.85	1062.85	644.52	1311.64	578.96	1227.84
	good	560.43	1060.82	599	1335.82	542.55	1365.6		
ɔ	fork	994.49	1402.13	920.13	1529.01	959.24	1447.51	979.69	1497.78
	short	960.05	1392.23	1008.1	1653.37	1036.14	1562.45		
ɒ	hot	1074.97	1614.68	854.5	1322.52	896.99	1361.25	976.93	1527.49
	dog	1033.75	1614.62	979.29	1611.4	1022.07	1640.49		
ɑ	card	1196.33	1678.84	1183.01	1804.01	1177.9	1805.01	1211.02	1726.45
	park	1228.23	1717.88	1143.99	1457.74	1336.65	1895.19		
ʌ	bus	1147.76	1832.03	1133.75	2088	1200.84	1935	1177.26	1931.38
	duck	1226.51	1946.6	1198.36	2077.73	1156.32	1708.94		
ɜ	church	735.51	2053.99	751.98	2196.55	738.45	1871.63	799.25	2097.29
	bird	813.53	2122.87	789.41	2109.62	966.61	2229.08		

Table 6. Vowel formant frequencies (in Hz) for Male Japanese Child 1.

Vowels	Test words	Sample 1		Sample 2		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2
i	feet	409.42	3478.95	382.13	3179.75	374.91	3393.49
	seat	310.9	3474.36	397.18	3440.9		
ɪ	fish	619.68	2546.45	684.03	2493.33	654.55	2502.25
	pig	720.44	2399.03	594.04	2570.17		
ɛ	bed	815.09	2700.26	808.01	2691.29	812.83	2638.02
	head	797.69	2639.9	830.54	2520.62		
æ	hat	1403.39	2076.9	1310.41	2254.31	1296.76	2200.24
	sad	1349.35	2134.69	1123.89	2335.06		
u	boot	531.98	1479.24	530.08	1498.15	521.89	1709.93
	soup	511.7	1859.83	513.8	2002.51		
ʊ	foot	629.12	1584.28	574.96	1738.7	577.43	1724.86
	good	589.35	1818.16	516.28	1758.31		
ɔ	fork	739.44	1134.72	931.92	1546.32	858.67	1441.94
	short	922.64	1515.97	840.66	1570.76		
ɒ	hot	928.35	1362.61	930.51	1409.09	923.09	1428.04
	dog	879.02	1414.91	954.47	1525.56		
ɑ	card	1094.06	1512.99	918.27	1388.62	1009.83	1455.81
	park	1013.42	1461.03	1013.58	1460.6		
ʌ	bus	1010.37	1546.83	962.63	1506.97	1045.12	1595.57
	duck	1083.4	1630.49	1124.07	1697.99		
ɜ	church	750.36	2199.71	660.13	1975.99	694.00	1961.28
	bird	724.73	1851	640.77	1818.43		

Table 7. Vowel formant frequencies (in Hz) for Male Japanese Child 2.

Vowels	Test words	Sample 1		Sample 2		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2
i	feet	362.27	3288.61	342.45	3107.84	361.66	3116.02
	seat	362.43	2979.24	379.5	3088.4		
ɪ	fish	567.3	3118.64	473.74	3123.62	502.85	2992.18
	pig	502.51	2884.38	467.85	2842.08		
ɛ	bed	1071.44	2449.84	836.59	2341.39	934.39	2403.53
	head	815.27	2263.7	1014.24	2559.2		
æ	hat	1265.67	2209.33	1094.41	2365.35	1119.63	2251.79
	sad	1103.74	2230.42	1014.71	2202.04		
u	boot	545.99	1638.02	442.63	1746.14	496.22	1850.33
	soup	463.63	1941.37	532.62	1954.51		
ʊ	foot	483.4	1434.52	470.22	1720.91	487.76	1562.31
	good	518.35	1618.25	479.06	1475.55		
ɔ	fork	535.19	848.89	568.65	975.77	592.18	975.49
	short	596	963.66	668.87	1113.65		
ɒ	hot	935.06	1308.98	738.99	1189.83	746.09	1186.36
	dog	665.66	1119.03	644.64	1182.89		
ɑ	card	773.24	1137.09	859.67	1267.94	902.59	1325.36
	park	1042.61	1544.46	934.83	1351.95		
ʌ	bus	968.9	1668.94	941.38	1623.91	1015.48	1701.57
	duck	1097.58	1814.1	1054.07	1699.34		
ɜ	church	911.91	1315.11	825.01	1201.57	748.63	1523.57
	bird	559.39	1959.17	698.21	1618.42		

Table 8. Vowel formant frequencies (in Hz) for Female Japanese Child 1.

Vowels	Test words	Sample 1		Sample 2		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2
i	feet	630.5	3462.58	571.42	3600.31	611.87	3549.32
	seat	641.08	3593.28	604.47	3541.09		
ɪ	fish	722.44	3211.52	620	3050.99	652.10	3353.51
	pig	624.57	3731.24	641.38	3420.28		
ɛ	bed	1150.08	2835.93	1114.4	2729.12	1170.66	2723.91
	head	1245.37	2647.99	1172.79	2682.61		
æ	hat	1108.36	2659.88	1122.7	2568.35	1115.42	2640.77
	sad	1096.67	2752.43	1133.95	2582.4		
u	boot	623	1342.21	557.34	1615.41	583.44	1564.88
	soup	577.35	1783.01	576.07	1518.88		
ʊ	foot	649.07	1941.39	692.02	2040.21	645.35	2051.84
	good	686.27	1958.41	554.02	2267.36		
ɔ	fork	1034.98	1510.45	872.12	1314.01	963.13	1481.86
	short	937.08	1613.06	1008.33	1489.91		
ɒ	hot	1083.6	1680.25	1207.45	1746.88	1058.42	1605.2
	dog	971.25	1450.61	971.36	1543.06		
ɑ	card	1128.02	1878.15	1077.79	1749.44	1154.31	1875.72
	park	1246.01	1995.42	1165.42	1879.88		
ʌ	bus	1218.23	2326.56	1263.41	2186.99	1234.07	2292.59
	duck	1205.4	2369.27	1249.25	2287.53		
ɜ	church	875.38	2341.58	985.51	2198.62	938.81	2264.47
	bird	909.25	2439.85	985.09	2077.81		

Table 9. Vowel formant frequencies (in Hz) for Female Japanese Child 2.

Vowels	Test words	Sample 1		Sample 2		Mean	
		F_1	F_2	F_1	F_2	F_1	F_2
i	feet	509.95	3043.46	440.04	3338.35	513.49	3411.89
	seat	557.05	3681.21	546.9	3584.52		
ɪ	fish	842.71	2758.69	607.66	2712.48	641.45	3006.97
	pig	572.67	3274.73	542.77	3281.98		
ɛ	bed	927.37	2780.79	1000.17	2827.02	1007.63	2669.09
	head	1064.69	2586.77	1038.29	2481.76		
æ	hat	1364.91	2138.55	1184.2	2364.62	1268.76	2317.57
	sad	1346.04	2330.11	1179.9	2437.01		
u	boot	632.4	1001.5	589.01	956.38	567.57	1274.68
	soup	554.79	1236.97	494.07	1903.86		
ʊ	foot	680.42	1061.25	579.66	887.43	622.93	1343.91
	good	637.57	1664.78	594.05	1762.16		
ɔ	fork	634.29	1077.91	641.51	942.9	645.73	1007.58
	short	609.15	927.16	697.97	1082.35		
ɒ	hot	952.94	1322.74	907.61	1429.29	905.16	1399.38
	dog	822.36	1373.54	937.74	1471.95		
ɑ	card	1071.07	1410.55	1109.75	1631.55	1125.71	1498.93
	park	1260	1615.2	1062.03	1338.43		
ʌ	bus	1198.47	1594.53	1146.62	1699.51	1134.15	1655.66
	duck	1123.33	1622.49	1068.17	1706.09		
ɜ	church	886.14	1945.45	892.21	2346.67	733.45	2100.80
	bird	622.02	2202.02	533.41	1909.07		

Table 10. Mean values (in Hz) of the vowel formant frequencies for two male Cantonese children and two female Cantonese children.

Vowels	Male children		Female children	
	F_1	F_2	F_1	F_2
i	468.28	3330.37	505.39	3521.16
ɪ	650.60	2692.79	708.94	2794.87
ɛ	996.26	2587.03	1000.57	2812.78
æ	1013.71	2564.74	1096.30	2725.67
u	485.44	1065.11	513.35	1262.07
ʊ	485.37	1224.29	600.20	1381.19
ɔ	809.06	1241.03	958.11	1388.75
ɒ	901.77	1317.35	1022.46	1499.44
ɑ	1074.55	1556.69	1192.28	1661.00
ʌ	1012.81	1711.57	1140.87	1864.10
ɜ	682.08	1679.70	771.17	1945.04

Table 11. Mean values (in Hz) of the vowel formant frequencies for two male Japanese children and two female Japanese children.

Vowels	Male children		Female children	
	F_1	F_2	F_1	F_2
i	368.29	3254.76	562.68	3480.60
ɪ	578.70	2747.21	646.78	3180.24
ɛ	873.61	2520.78	1089.15	2696.50
æ	1208.20	2226.01	1192.09	2479.17
u	509.05	1764.97	575.50	1419.78
ʊ	532.59	1643.59	634.14	1697.87
ɔ	725.42	1208.72	804.43	1244.72
ɒ	834.59	1314.11	981.79	1502.29
ɑ	956.21	1390.59	1140.01	1687.33
ʌ	1030.30	1648.57	1184.11	1974.12
ɜ	721.31	1742.43	836.13	2182.63

Table 12. Mean values (in Hz) of the vowel formant frequencies for four Cantonese children and four Japanese children.

Vowels	Cantonese children		Japanese children	
	F_1	F_2	F_1	F_2
i	486.83	3425.76	465.48	3367.68
ɪ	679.77	2743.83	612.74	2963.73
ɛ	998.41	2699.91	981.38	2608.64
æ	1055.00	2645.20	1200.14	2352.59
u	499.40	1163.59	542.28	1592.37
ʊ	542.79	1302.74	583.36	1670.73
ɔ	883.58	1314.89	764.93	1226.72
ɒ	962.12	1408.39	908.19	1408.20
ɑ	1133.42	1608.85	1048.11	1538.96
ʌ	1076.84	1787.83	1107.21	1811.35
ɜ	726.62	1812.37	778.72	1962.53