# DEVELOPMENTAL CHANGES OF ACOUSTICAL VOWEL SPACE BEFORE 7 YEARS OF AGE

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## ABSTRACT

The present study is the seventh year of a longitudinal observation of vowel production in Mandarin-learning children. Major findings in the seventh year are: 1) Unlike the trend of decrease in formant values in the previous stages, decrease in F1 F2 values was not evident at this stage in the boy subject. Up to 7 years of age, no obvious change in formant values was found in the girl subject. In addition to gender difference, they seemed to experience a slow growth at this stage; 2) F1 values are more stable than F2 values in both subjects. They appeared to acquire jaw movement sooner than tongue movement; 3) Decline in variability of F2 can be found from 4 years on in girl subject; 4) Although they have acquired corner vowels at early childhood, F2 values of high front [i] and high back [u] vowels still displayed high variability up to 7 years of age; 5) The earlier trend of shrinkage in F1-F2 vowel area was not found at this stage; 6) No obvious decline in fundamental frequencies was found at this stage in both subjects. Longitudinal data of vowel formant values from the same group of subjects provides important references for assessment and treatment of articulation disorders in children.

**Keywords:** vowel development, vowel formant frequencies, vowel space area

## 1. INTRODUCTION

With both perceptual transcription and acoustic analysis, vocalic production in two Mandarin-learning children was investigated from birth to seven years old. This current study focuses on the development of the seventh year and the continuity in the process.

Many children may not receive speech therapy on vowels although there are obvious vowel errors because clinicians tend to treat consonants before vowels. This can be attributed to much more established guideline in assessment and treatment in the intervention for consonant errors than for vowel errors [11]. The acquisition of vowels is less studied than the acquisition of consonants because vowels are generally regarded to be learned earlier than consonants. Moreover, vowel errors are less frequent than consonant errors in children with phonological impairment [2, 11]. However, according to Pollock and Keiser's [8] study of 15 children with moderate-to-severe phonological impairment, vowel errors may occur in as many as 50% of children with phonological disorders. Vowel development thus deserves more attention for both research and clinical application. Studies on early vocalic production in both qualitative and quantitative changes can provide more accurate norms for evaluating and helping in the early identification of articulation disorders [3].

The growth of vocal tract and its relationship with the development of speech is a complicated process. The relationship between anatomical differences and the differences of speech production would be best studied in vowel production. It is expected that the vowel formant frequency will decrease as vocal tract length increases [4]. Moreover, because males and females differ in the length and shape of vocal tracts and boys have a larger vocal tract than girls, there are differences in formant frequencies between preadolescent boys and girls. Perry, Ohde, and Ashmead [7] and Whiteside and Hodgson [12] pointed out as early as four years old, boys are found to have lower formant frequencies than those of girls. The differences become more obvious by 7 or 8 years. Namely, gender differences in speech acoustics can be observed in early childhood well before puberty. Chronological age and gender difference are the two major independent variables for studies of maturation, including speech. Development does not proceed in a linear fashion, rather development involves several periods of growth spurts and periods of regular but slow growth [5]. This trend of development is best observed in a longitudinal study.

## 2. METHODOLOGY

Vocalizations of 2 Mandarin-learning children (Subject A, a boy; Subject B, a girl) were audio recorded during observations of their natural daily activities in their homes and picture naming tasks once every 3 months, from birth to 7 years old. An average of 45 minutes of recordings was made from each of the two-hour observation sessions for each child.

A wireless lapel microphone was linked to a Sony DAT recorder with a signal-to-noise ratio above 91 dB. The DAT recorder was used for playback in perceptual transcription and acoustical analysis. All spontaneous productions and elicitation data were then digitally recorded into a computer using Computerized Speech Lab (Kay CSL 4400). The sampling rate was 48,000 samples per second. The frequency values of the first and the second formants of the vowels were measured with reference to the four displays: narrowband spectrogram, broadband spectrogram, FFT, and LPC.

## 3. FINDINGS AND DISCUSSION

### 3.1. Main vowel categories

There is no obvious change in the distribution pattern of main vowel categories at this stage in both subjects. Diphthongs show the highest frequency at this stage in both subjects as in the previous stage (see Figures 1 and 2). The frequency of vowels with nasal endings shows prominent increase at 5 years old, and continues to increase from 6 to 7 years of age. After prominent use of vowels with nasal endings, Subject B (girl) continues to use this vowel category more frequently than Subject A (boy). In girl subject, vowels with nasal endings show similar frequency as diphthongs at this stage. However, up to 7 years old, in boy subject vowels with nasal endings still show much lower frequency than diphthongs.

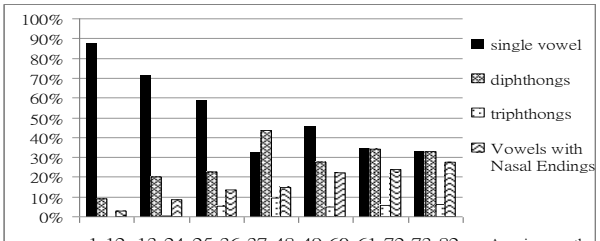


Figure 1 Main vowel categories in Subject A

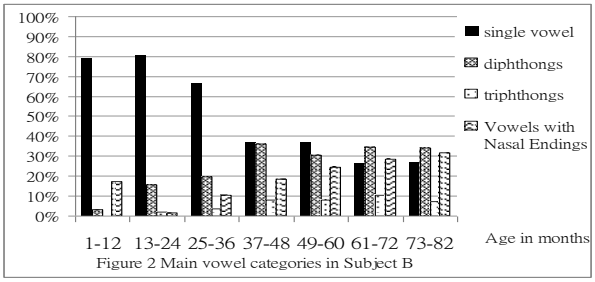


Figure 2 Main vowel categories in Subject B

### 3.2. Vowel formant frequencies

In the previous report, we found that, like what was found in [7] and [12], from 3 years and 6 months, the boy subject shows relatively lower vowel formant values than girl subject, reflecting gender differences in the development of vocal tract. This trend was continuously observed till 6 years of age. However, unlike the trend of decrease in formant values in the previous stages, decrease in F1 F2 values was not evident at 7 years of age in the boy subject. As to girl subject, up to 7 years of age, no obvious change in formant values was found. In addition to gender difference, they seemed to experience a slow growth at this stage.

In measuring articulatory variability, standard deviations of F1 and F2 values across ages are calculated. As seen in Figures 3 and 4, in the course of development, F1 values are more stable than F2 values in both subjects. They appeared to acquire jaw movement sooner than tongue movement. Moreover, a general trend of decrease in F2 variability can be found from 4 years on in both subjects, with more steady decrease in girl subject. However, there seems to be more fluctuation of F2 values at 7 years of age in both subjects.

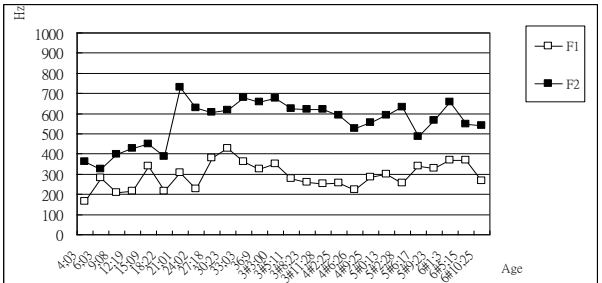


Figure 3 Standard deviation of F1 and F2 in Subject A

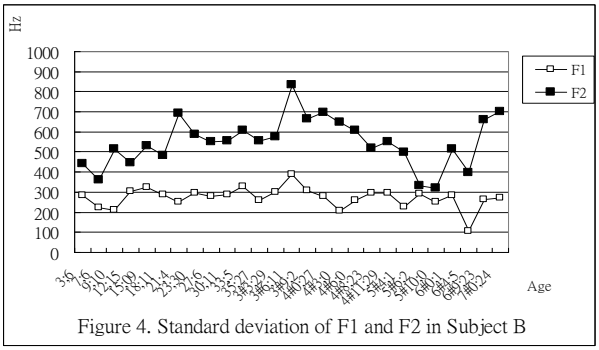


Figure 4. Standard deviation of F1 and F2 in Subject B

Although they have acquired corner vowels at early childhood, F2 values of high front [i] and high back [u] vowels still displayed high variability up to 7 years of age, especially in boy subject as seen in Figures 5-8.

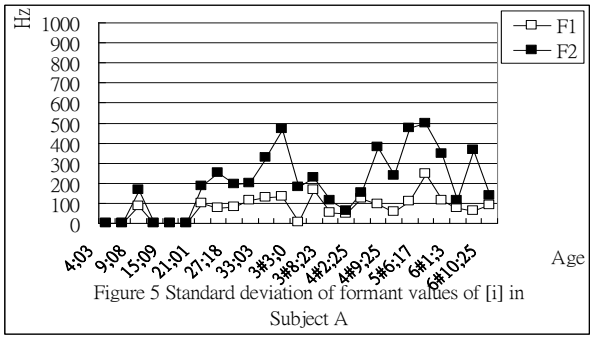


Figure 5 Standard deviation of formant values of [i] in Subject A

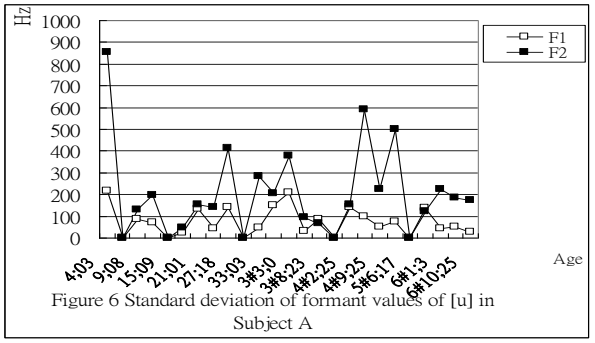


Figure 6 Standard deviation of formant values of [u] in Subject A

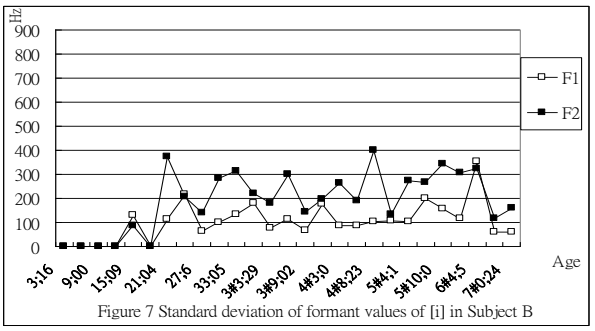


Figure 7 Standard deviation of formant values of [i] in Subject B

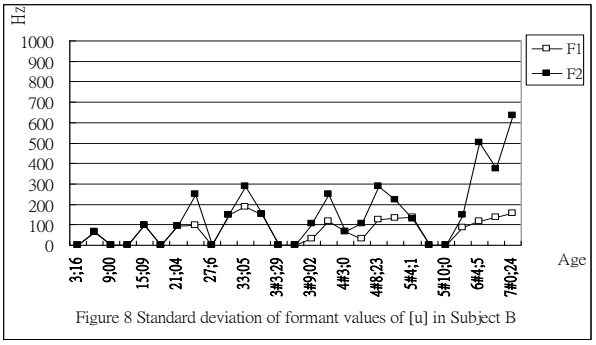


Figure 8 Standard deviation of formant values of [u] in Subject B

### 3.3. Vowel areas

Vowel areas are calculated for vowel triangles with three corner vowels. In boy subject, F1-F2 vowel areas reduce at 4 years, at the similar age when abrupt decrease of formant frequency was found. In girl subject, F1-F2 vowel areas decrease from 424268 $Hz^2$ at 5 years old to 254299 $Hz^2$ at 6 years old. Expand of vowel areas can be found at the early stage of development, followed by reduce of vowel areas at the later stage (5 years old for boy and 6 years old for girl) (see Figures 9 and 10). The broader vowel space at early stages corresponds to the increased variability of vowel formants which might be due to immature motor control [6, 9]. After acquiring more mature motor control for vowel production, the decreased variability of vowel formants leads to the reduction of F1-F2 space at later stage. At 7 years of age, slow development was found. The earlier trend of shrinkage in F1-F2 vowel area was not found at this stage, and extension of vowel space was even found in both subjects at this stage.

**Figure 9:** Changes of vowel space from birth to 7 years of age in Subject A.

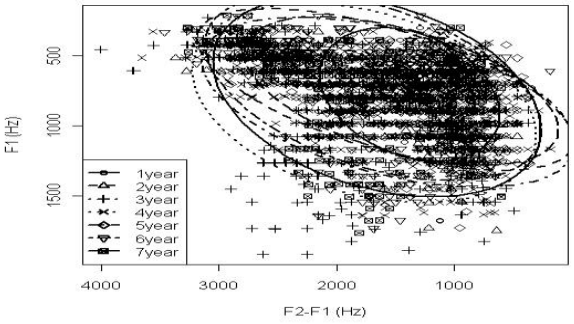
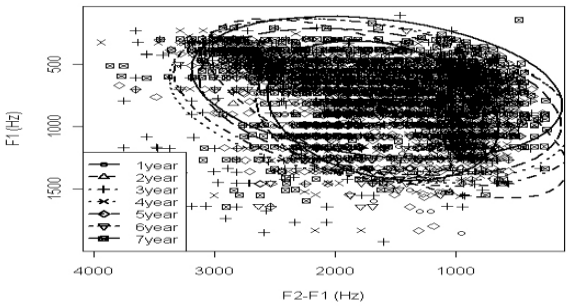


**Figure 10:** Changes of vowel space from birth to 7 years of age in Subject B.




### 3.4. Fundamental frequencies

Regarding vocal fundamental frequency of vowel production in different age levels and in both genders, decline of f0 is found in both subjects, especially for boy subject from about 5 years old. However, at 7 years of age, there is no obvious trend of f0 decline in both subjects (see Figures 11 and 12). Gender differences can be better identified in formant frequencies (vocal tract resonator), especially F2, rather than f0 (vocal tract length) [1].

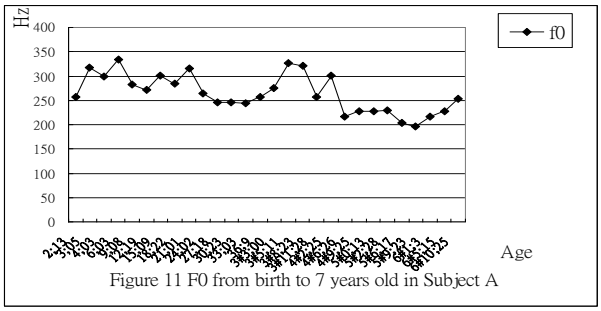



Figure 11 F0 from birth to 7 years old in Subject A

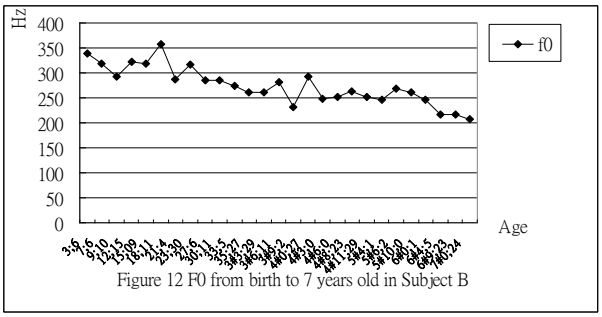



Figure 12 F0 from birth to 7 years old in Subject B

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