Prelinguistic Vocalic Production in the First Year of Life: The acoustic-phonetic analysis

語言前期母音發音：語音及聲學分析

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摘要

本系列研究旨在探索語言前期母音長期的發展歷程，這篇研究報告是第一階段（即 12 個月大之前）的結果。本階段研究長期追蹤 2 位在中文環境中的嬰兒，在 12 個月大之前的母音學習過程，並探索母音共振峰頻率空間的形狀、範圍及變化方向。研究結果顯示：1)主要的母音類型為中低母音/ə, ɑ, ɛ/；2)屬於母語特色的低母音/ɑ/在 9 個月大後有明顯增加趨勢；3) F_1F_2空間範圍至 12 個月大之前，沒明顯的變化。F_1平均值約 860Hz，F_2平均值約 2400Hz；4)同一母音在F_1F_2空間有分散的幾個集中區。因為母音發展得早，而且母音F_1F_2空間的變化可顯示細微的長期發展型態，因此可以由觀察母音的發展來辨識聽語障和正常嬰幼兒最早期的喃喃語差異。這樣的研究結果在臨床上可協助在最早的階段，診斷有語言溝通障礙危險的嬰幼兒，在最早的時機介入治療。

Abstract

This is a longitudinal study of early vowel development by Mandarin-learning infants in the first 12 months of life. Data from two Mandarin-learning infants were collected from birth through 12 months and analyzed with both perceptual transcription and spectrographic analysis for the developmental changes on vowel space (F_1 F_2 charts). Major findings are: 1) Mid and low vowels /ə, ɑ, ɛ/ are prominent; 2) There is a remarkable increase in the frequency of occurrence of the language-specific vowel /ɑ/ after 9 months of age; 3) During these 12 months, there are no obvious changes in the vowel space with the average value of F_1 around 860 Hz and F_2 around 2400Hz; 4) Considerable variation of the formant frequencies of the same vowel was observed.

關鍵字：嬰兒語、母音習得、共振峰頻率
Keywords: Babbling, Vowel Development, Vowel Formant Frequencies

I. INTRODUCTION

This study is a continuation of the preliminary cross-sectional research

conducted from 2001 to 2002 and is designed to investigate the longitudinal developmental process of vocalic production from babbling to early speech in two Mandarin-learning children in the first 12 months of life with both perceptual transcription and acoustic analysis. Part of the findings from the first six months was reported in Chen (2003). The importance of this research is discussed in research methodology and its implication for speech disorders.

Vocalic development has been less extensively studied than consonant development, mainly due to vocalic utterances are very difficult to transcribe reliably and thus difficult to lead to a valid developmental profile. Therefore, recent studies on vowel development, especially in the first year, employ both perceptual transcription with high-quality recording and transcribing equipment and acoustic analysis. In addition to quantitative changes in children's vocalic production reported in most studies with perceptual transcription, acoustic analysis is crucial in identifying subtle qualitative changes in vocalic production over time. Since vocalic space is found to develop in a continuous and consistent way, a combination of perceptual and acoustic analyses is thus critical to characterize the process of vowel development in prelinguistic babbling and in the transition from babbling to early speech.

In addition, studies on both qualitative and quantitative changes in early vocalic development from babbling to early speech are critical in providing defining characteristics for early identification of developmentally abnormal patterns (Ertmer, 2001). These studies are particularly important in identifying subtle differences in vocalic utterances, which are not readily detectable by human ear, in phonological disordered children to establish definable guideline and to set up goals for speech therapy.

Acoustic analysis of early vocalic production usually focuses on the change of formant frequencies. Kent and Murray (1982) indicated that the range for F1 and F2 increased with age. However, the majority of the vocalizations across these three age levels displayed about the same formant patterns: Fl 0.9 - 1 .0 KHz, F2 about 3 KHz, and F3 about 5 KHz. This overwhelming type of utterance was like the neutral vowel /ə/ in adult model. This finding confirms Lieberman's study (1980) of one infant aged 16 to 64 weeks. These two studies suggested that there was no remarkable change in the average values of formant frequencies across various age levels.

In addition, according to Kent and Murray (1982) and Lieberman (1980), there were specific acoustic characteristics in infants' vocalic utterances. Comparing with adult model, infant vowels were displaced upward and to the right in the Fl and F2 chart. In addition, there was remarkable

overlapping among formant frequencies of different vowels. Moreover, considerable variation of the formant frequencies of the same vowel was observed in infants' vocalizations. According to Kent and Murray's (1982) study, infants' vocalizations contained a variety of changing patterns ranging from a stable and well-defined formant pattern to a rapidly changing formant pattern. It was also pointed out that during the process of development there was a gradual improvement in the consistency of the pattern of formant frequencies of various vowels.

II. METHODOLOGY

This study is longitudinal in nature to observe and analyze the spontaneous vocalic production in home environment in 2 Mandarin-learning infants spanning the period from birth to 12 months starting from birth in early phonation, cooing, expansion stage, or vocal play to canonical babbling and variegated babbling (Oller, 1980; Stark, 1980). The infants were full-term normal infants at birth with normal hearing and were free of any developmental delays.

Recordings were made in infant's (Infant A) or the caregiver's home (Infant B) once every 3 months. The spontaneous vocalizations were recorded in individual 45-minute sessions. To achieve good quality and flexible recording without distracting the subjects, a wireless lapel microphone was clipped to infants' apron, approximately six inches from the mouth. The microphone was linked to a Sony DAT recorder. A DAT recorder with a signal-to-noise ratio above 91 dB was used for playback for perceptual transcription and acoustical analysis. Utterances selected for measuring formant frequencies were then delivered to Kay CSL 4400. According to previous cross-sectional study, variable bandwidths were used with an attempt to acquire optimal appearance of the formants in a spectrogram. Narrow-band and wide-band spectrograms were displayed on the same screen for comparison. Central frequency in the temporal midpoint of the steady part (especially for utterances of changing formant patterns) of the first and the second formants were measured with reference to FFT and LPC analysis.

In this study, only speech-like utterances were included for both perceptual and spectrographic analysis. This definition thus excluded vegetative or reflexive sounds (e.g., cries, coughs, breathing noise, etc.). Moreover, this study included only fully resonant vowels with at least two measurable formants in addition to the resonance in the lower frequency range. For the reliability of spectrographic measurement, utterances that were clear in perception, but were difficult to measure for the formant frequencies (mostly the low vowel / ɑ /) were excluded from the data.

III. FINDINGS AND DISCUSSION

RANGE OF FORMANT FREQUENCY

The utterances in each age level for Infant A and Infant B ranged from 37 to 62 vowels. All of the vocalic productions which were clear in perception and clear for formant measurement were included in spectrographic analysis. The range of frequencies of the first and the second formants of these vowels are displayed in Table 1.

TABLE 1. Range and Average Values of Formant Frequencies (in Hz)

Age		3 Months		6 Months		9 Months		12 Months	
		Range	Average	Range	Average	Range	Average	Range	Average
Infant	F1	475-1198	960	473-1365	846	211-1683	694	519-1640	931
A	F2	1682-2981	2189	1766-3056	2384	1857-3400	2546	1450-3701	2642
Infant	F1	480-1162	795	385-1851	907	328-2017	816	328-1669	982
B	F2	1461-2984	2096	1771-3575	2504	1362-3513	2630	1911-3415	2457

As shown in this table, there was a big range in the distribution of formant frequencies in each age level for both of these 2 infants, and there was no obvious tendency of narrowing down the range before 12 months of age. The average formant value of F1 was around 860 Hz and 2400 Hz for F2 in both infants. In general, this was similar to the findings in previous cross-sectional study with 4 infants aged 0-6 months (Chen, 2002). However, the average values for F2 in this longitudinal study were lower than that in both Kent and Murray (1982) and Chen (2002). This is probably due to the procedure in selecting data. In this study, vowels with a F2 of extremely high frequencies (usually over 4000Hz) were excluded for the reliability and consistency of analysis. Most of the discarded data were the low vowels / ɑ /. Because of the closeness of F1 and F2 values of / ɑ / and the excessive nasal formant in the lower frequencies, it was difficult to identify F2 value for this vowel. In some of cases, the extremely high frequency of F2 for / ɑ / measured from spectrographic display might be F3. This is similar to Buhr's (1980) findings. According to Buhr (1980), the vowel-like utterances along the grave axis (back vowels) were less well identified often because individual formants could not be recognized due to the noise spectrogram introduced by the nasalization. In Buhr (1980), much of the longitudinal data of infants aged 16-64 weeks was excluded because of excessive formants introduced by nasal coupling that made it extremely difficult to measure the second and the third formants.

TABLE 2. Average Values of Formant Frequencies (in Hz)

Age in Months			3 Months	6 Months	9 Months	12 Months
			Average	Average	Average	Average
	/ ɛ /	F1	924	903	817	918
		F2	2885	2926	2922	3018

Infant A	/ ə /	F1	824	740	643	857
		F2	2107	2141	2178	1909
	/ ɑ /	F1	1022	1009	976	1099
		F2	2179	2278	2250	2411
Infant B	/ ɛ /	F1	798	861	816	815
		F2	2719	2785	2968	2610
	/ ə /	F1	790	704	686	712
		F2	2082	2200	2257	2198
	/ ɑ /	F1	814	1152	1047	1213
		F2	1993	2707	2573	2471

With regard to the formant frequencies of each vowel category, as illustrated in Table 2, among those three frequently occurring vowels, the vowel / ɛ / displayed the highest F2 across the four age levels consistently starting from 3 months of age and there seemed to be a gradual separation of vowel space for the vowel / ɛ / from the other two vowels / ə, ɑ / in Infant A and Infant B. Moreover, the low vowel / ɑ / has the highest F1 throughout the 12 months in both infants. These two early-developed patterns reflect the vowel formant patterns in adult system. However, there seems to be two distinct distribution patterns for the low vowel / ɑ /. One is with F1 700-1000 Hz and F2 2000-2300Hz. The other is with F1 1000-1600Hz and F2 2400-2700Hz. This was also found in previous studies. According to Kent and Murray (1982) and Lieberman (1980), there was remarkable overlapping among formant frequencies of different vowels and considerable variation of the formant frequencies of the same vowel in infants' vocalizations. Moreover, a greater range of variation in the formant frequency could be found in the vocalization of younger infants than in older ones.

FREQUENCY OF OCCURRENCE

Basing on the phonetic transcriptions of all of the perceptually identifiable vowels in each of the 45-minute recordings, the central vowel / ə / had the highest frequency of occurrence in both Infant A and Infant B over the course of development from 3 months to 6 months of age as illustrated in Table 3 and Table 4. However, at the second half of the first year, the low vowel / ɑ / show the highest frequency of occurrence in both infants.

TABLE 3. Frequency of Occurrence of Vowels (Infant A)

	Infant A			
Age in Months	3 Months	6 Months	9 Months	12 Months

		Token	%	Token	%	Token	%	Token	%
Front Vowel	/ ɛ /	14	24	4	11	18	29	10	21
	/i/								
Central Vowel	/ ə /	26	44	25	68	20	32	12	26
Back Vowel	/ ɑ /	18	31	7	19	21	34	21	45
	/u/			1	2	1	2		
	/o/	1	1						
Total		59	100	37	100	62	100	47	100

TABLE 4. Frequency of Occurrence of Vowels (Infant B)

		Infant B							
Age in Months		3 Months		6 Months		9 Months		12 Months	
		Token	%	Token	%	Token	%	Token	%
Front Vowel	/ ɛ /	4	7	6	14	17	29	6	10
	/e/			1	2				
	/i/					4	7	2	3
Central Vowel	/ ə /	26	46	19	44	18	31	10	17
Back Vowel	/ ɑ /	24	43	17	40	18	31	37	64
	/u/	1	2			1	1	2	3
	/o/	1	2			1	1	1	1
Total		56	100	43	100	59	100	58	100

The early emergence of the low vowel / ɑ / was noted in both infants at 3 months of age. In both infants, the frequency of occurrence of / ɑ / was just next to the central vowel / ə / before 6 months of age. In addition to confirming the findings in previous cross-sectional study (Chen, 2002) concerning language-specific characteristics of early emergence and the high frequency of occurrence in low vowels, this longitudinal study provided the evidence of the earliest occurrence of the low vowel / ɑ / at 3 months of age in Mandarin-learning infants. As to the front vowel, although the vowel / ɛ / was the only vowel which showed a tendency in forming a separate vowel space as discussed in the previous section, / ɛ / was not the vowel which had the highest frequency of occurrence in Infant A and Infant B across the four age levels.

IV. CONCLUSION

Longitudinal study of early vowel production by 2 Mandarin-learning infants at 3, 6, 9 and 12 months of age indicated that: (1) The average formant value of F1 was around 860 Hz and 2400 Hz for F2; (2) There seemed to be a gradual separation of vowel space for the vowel / ɛ / from the other vowels;

(3) The central vowel /ə/ had the highest frequency of occurrence before 6 months of age; (4) Early emergence of the low vowel /ɑ/ was noted at 3 months of age. Moreover, /ɑ/ has the highest frequency of occurrence at the second half of the first year. It is critical to verify these findings by collecting and analyzing longitudinal data from more infants over a longer period of time in order to yield a valid generalization in developmental pattern and to trace the idiosyncratic developmental process.

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