

嬰兒 0 至 6 個月母音空間分化的發展

The Development of Vowel Spacing in the First Six Months of Life: a longitudinal case study

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摘要

本研究以聽覺轉寫及聲學分析長期追蹤兩位在中文環境下的嬰兒，從出生至六個月大的母音學習歷程。這項研究藉著長期追蹤，觀察及分析在母音構音上細微的質量變化。檢驗研究者先前斷層研究（國科會研究計畫 NSC 90-2411-H-006-015）的結果。在本研究中，母音的發展由五個方向來探討：(1) 母音共振峰頻率範圍的長期變化，(2) 在 F1 及 F2 表上，母音空間分化及穩定的過程，(3) 各母音出現頻率，(4) 母語音系發音型態的發展。在前項斷層研究中，發現嬰兒在六個月大之前，就有受母語音系影響的發音型態（譬如，/ɯ/ 在不滿六個月大的嬰兒語中就可發現）。在本長期個案研究的兩位嬰兒的語料中，也有相同的發現。(5) 母音學習過程及學習策略上的個別差異。除了一些共同的发展歷程，本研究中兩位嬰兒的母音發展也有許多個別差異，尤其在個別母音出現頻率及共振峰頻率範圍上。本研究是接續前一項斷層研究的長期個案研究。同時，本研究的結果，將作為下一個階段臨床應用研究的基礎。在本研究及前項斷層研究中所發現的母音發展在各方面的特色，將可作為建立常模的初步參考，以確認母音發展的時間進程。這個重要的參考將可在臨床上協助早期偵測構音障礙（甚至在六個月大之前），及設定臨床治療上的合理及正確目標。

關鍵字：嬰兒語、母音習得、共振峰頻率

Abstract

This is one of the first longitudinal studies of early vowel development by Mandarin-learning infants in the first 6 months of life. This study verifies and supplements the prior cross-sectional research (NSC 90-2411-H-006-015). The early emergence of language-specific patterns, e.g., the low back vowel /ɯ/ found in the babbling of many infants in the cross-sectional study, were carefully examined in this longitudinal project to identify the onset of language-specific vowel production

Longitudinal data from 2 Mandarin-learning infants were collected from birth through 6 months of age and analyzed with both perceptual transcription and spectrographic analysis. Major aspects in vowel development investigated in this study were: 1) the change of the range of center frequency in vowel formant over time, 2) the stabilization process of the vowel spaces (the F1 and F2 chart), 3) the frequency of occurrence of vowels, 4) the emergence and development of language-specific pattern. In addition, 5) the individual differences in the developmental process of vocalic production and in the strategies employed in vowel acquisition were traced over time and analyzed.

Keywords: babbling, vowel acquisition, formant frequencies

I. INTRODUCTION

There are two different research methodologies commonly used in the study of phonetic and phonological development. In a cross-sectional research design, different children at different age levels are observed for their speech production to yield a composite profile about the developmental process. However, this approach fails to capture the variability throughout the developmental process of individual children's speech production. Nevertheless, this limitation in cross-sectional studies is a major accomplishment in longitudinal studies in which individual children are observed and the data are collected at different points in the development over a long period of time. However, in longitudinal studies, usually the data of only a relatively small number of children are collected, and thus it is difficult to lead to any valid generalizations about the pattern and process of development. Therefore, preliminary profile in vowel development drawn from large-scale cross-sectional study should be subsequently verified with close analysis on the vowel production of single children over time from longitudinal study.

Aiming at filling the gaps left by previous studies in early speech development, and with reference to research methodologies of relevant studies, this study is a continuation of the preliminary cross-sectional research (NSC 90-2411-H-006-015) and was designed to investigate the longitudinal developmental process of vocalic production in 2 Mandarin-learning children in the first 6 months of life with both perceptual transcription and acoustic analysis.

Acoustic analysis of early vocalic production usually focuses on the change of formant frequencies. As to the change of the range of F1 and F2 across different age levels, Kent and Murray (1982) indicated that the range for F1 and F2 increased with age as shown in the following table.

Table 1. F1–F2 range for 3-, 6-, and 9-month-olds (from Kent and Murray, 1982)

	3 months	6 months	9 months
F1	0.5 - 1.5	0.5 - 1.7	0.5 - 1.8
F2	1.8 - 3.8	1.6 - 3.8	1.4 - 4.1

(in KHz)

Although the frequency range increased from 3 to 6 and from 6 to 9 months of age, the majority of the vocalizations across these three age levels displayed about the same formant patterns, i.e., around the position of mid-front vowels or central vowels. The average values of formant frequencies for all of the three age levels were: F1 0.9 - 1.0 KHz, F2 about 3 KHz, and F3 about 5 KHz. Their data showed that the center points of the first three formants (across three age levels) remained about 1, 3, and 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 (at 3, 6, and 9 months of age in Kent and Murray; 16-64 weeks of age in Lieberman).

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 F1 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. Lieberman (1980) indicated that a greater range of variation in the formant frequency could be found in the vocalization of younger infants than in older ones. 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. Nasal quality is another remarkable characteristic in infants' speech. Kent and Murray (1982) suggested that the approximation of soft palate and epiglottis in infants' vocal tract resulted in a greater degree of nasal resonance. They also pointed out that by 4-6 months, when the separation of the velum and epiglottis occurred, non-nasal vowel sounds were produced. 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. 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.

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 6 months of age starting from birth in early phonation, cooing, expansion stage, or vocal play before 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 done in the caregiver's home once every 2 months. A 45-minute audio recording was made for each two-hour observation session. To achieve good quality and flexible recording without distracting the subjects, a wireless lapel microphone were clipped to infants' apron, approximately six inches from the mouth. The microphone were 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.

Only speech-like utterances were included in this study, and thus this definition excluded vegetative or reflexive sounds (e.g., cries, coughs, breathing noise, etc.). Also, this study included only fully resonant vowels with at least two measurable formants in addition to the resonance in the lower frequency range. Utterances that were clear in perception, but were difficult to measure for the formant frequencies were excluded from the data for the reliability of spectrographic measurement. Some / \square /token were discarded because of the difficulty in measurement due to nasal coupling although they could be rather clear in perception. It is thus very critical to use recording and analysis equipments and software with reasonably good quality for accurately recording, transcribing and measuring infants' vocalizations, especially vowels.

III. FINDINGS AND DISCUSSION

RANGE OF FORMANT FREQUENCY

The utterances in each age level for Infant A and Infant B ranged from 22 to 44 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 2.

Table 2 Range and Average Values of Formant Frequencies

Age in Months		2 Months		4 Months		6 Months	
		Range	Average	Range	Average	Range	Average
Infant A	F1	641-1162	900	473-2111	1061	385-989	734
	F2	1427-3234	2221	1590-3579	2438	1592-2714	2120
Infant B	F1	344-1247	763	290-1722	1015	554-1762	790
	F2	930-3060	1887	1161-4900	2086	1242-5289	2147

(Frequency in Hz)

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 6 months of age. Regarding the average values of formant frequencies across these three age levels, the average formant value of F1 was around 700-1000 Hz and 1800-2400 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 were excluded for the reliability and consistency of analysis. Therefore, concluded from the previous cross-sectional study and this longitudinal study, for infants younger than 6 months of age, the average values of vowel formant frequencies were about 1000 Hz for F1 and 2000-2500 Hz for F2.

Table 3 Average Values of Formant Frequencies

Age in Months			2 Months	4 Months	6 Months
			Average	Average	Average
Infant A	/ɪ/	F1	900	904	733
		F2	2125	2196	2540
	/ε/	F1	928	1163	821
		F2	2320	2481	2178
	/ə/	F1	878	1063	690
		F2	2209	2497	2038
Infant B	/ɪ/	F1	710	1249	1029
		F2	1980	1995	2576
	/ε/	F1	693	755	1204
		F2	1909	2339	3610
	/ə/	F1	790	793	689
		F2	1867	2057	1893

With regard to the formant frequencies of each vowel category, as illustrated in Table 3, among those three frequently occurring vowels, the vowel /ε/ displayed the highest F1 and showed high frequencies in F2 across the three age levels consistently and there seemed to be a gradual separation of vowel space for the vowel /ε/ from the other two vowels /ɪ, ə/ in Infant A. In Infant B, there was a similar tendency that the vowel /ε/ consistently showed the highest F2 in all the three age levels starting from 4 months of age and thus a gradual separation of vowel space for the vowel /ε/ was also found.

In addition to these general developmental process, in Infant B, there were at least two obvious shifts of formant patterns which were not observed in Infant A. There were an obvious increase of formant values of F1 for the vowel /ɪ/ (from 710 Hz in 2 months to 1249 Hz in 4 months) and a increase of formant values of F2 for the vowel /ε/ (from 1909 Hz in 2 months to 2339 in 4 months). This is the earliest indication (at 4 months of age) of approaching adult models in vowel production.

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 2 months to 6 months of age as illustrated in Table 4 and Table 5.

Table 4 Frequency of Occurrence of Vowels (Infant A)

		Infant A					
		2 Months		4 Months		6 Months	
		Token	Frequency	Token	Frequenc y	Token	Frequency
Front Vowels	/ε/	8	24%	7	20%	6	27%
Central Vowels	/ə/	15	44%	17	49%	13	59%
Back Vowels	/ɪ/	11	32%	11	31%	3	14%
Total		34	100%	35	100%	22	100%

Table 5 Frequency of Occurrence of Vowels (Infant B)

		Infant B					
		2 Months		4 Months		6 Months	
		Token	Frequency	Token	Frequency	Token	Frequency
Front Vowels	/ε/	6	20%	8	18%	2	6%
	/ɪ/			2	5%		
Central Vowels	/ə/	19	63%	12	27%	23	75%
Back Vowels	/ɪ/	3	10%	21	48%	5	16%
	/U/	2	7%	1	2%	1	3%
Total		30	100%	44	100%	31	100%

In addition to this central vowel, early emergence of the low back vowel /ɔ/ was noted in both infants at 2 months of age. In Infant A, the frequency of occurrence of /ɔ/ was just next to the central vowel /ə/. In addition to confirm the findings in previous cross-sectional study (Chen, 2002) concerning language-specific characteristics of early emergence and the high frequency of occurrence in back vowels, this longitudinal study provided the evidence of the earliest occurrence of the back vowel /ɔ/ at 2 months of age in Mandarin-learning infants. As to the front vowel, although the vowel /e/ was the only vowel which showed a tendency in forming a separate vowel space as discussed in the previous section, /e/ was not the vowel which had the highest frequency of occurrence in Infant A and Infant B across the three age levels. The distribution patterns of the three commonly found vowels /ə, ɔ, ə/ in this longitudinal study is different from the findings in the previous cross-sectional study with 4 infants aged 0-6 months. The discrepancy might be due to the difficulty in the distinction between /e/ and /ə/ in perceptual transcription.

Apart from the general pattern, there were individual differences between these 2 infants in the frequency of occurrence of the various vowel categories. In Infant B, there was obvious increase in the production of low back vowel /ɔ/ at 4 months of age (from 10% in 2 months to 48% in 4 months) and the frequency of occurrence of the vowel /ɔ/ was even the highest among all vowel categories at this age level. Moreover, Infant B produced more vowel categories than Infant A over the course of these 6 months. There were even some occurrence of vowels /I/ and /U/ although these were not stable production patterns. This early evidence of approaching adult model in Infant B is parallel to the findings in spectrographic analysis discussed in the previous section.

IV. CONCLUSION

Longitudinal study of early vowel production by 2 Mandarin-learning infants at 2, 4, and 6 months of age indicated that: (1) The average formant value of F1 was around 700-1000 Hz and 1800-2400 Hz for F2; (2) There seemed to be a gradual separation of vowel space for the vowel /e/ from the other vowels; (3) The central vowel /ə/ had the highest frequency of occurrence; (4) Early emergence of the low back vowel /ɔ/ was noted at 2 months of age; and (5) Infants differed in the pace of approaching adult models. Individual differences are especially obvious in early stages of development. It is thus critical to collect and analyze 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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