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Longitudinal Study of the Acquisition of Taiwanese Initial Stops*

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Abstract: This study focuses on the Taiwanese stop system and is intended to provide information regarding the three-way voicing contrast of Taiwanese stops, as they are acquired by children. There are three voiceless unaspirated stops in Taiwanese, /p, t, k/, three voiceless aspirated stops /p^h, t^h, k^h/ and two voiced stops /b, g/. A longitudinal study of two Taiwanese-acquiring girls between the ages of 28 and 29 months to 33 and 40 months respectively, indicated that Taiwanese voiceless unaspirated stops were acquired first, voiceless aspirated stops secondly, and finally voiced stops. Even though the two girls acquired the three-way voicing contrast by the age of three years, their productions were not adult-like, especially for the voiced stops. There were many voiced stops produced with short lag VOTs as was found in the voiceless unaspirated stops.

Introduction

The acquisition of stop consonant systems has been studied in various languages. It has been determined that the voiceless unaspirated stops are the first to be acquired by children in English (Macken & Barton, 1979), Spanish (Macken & Barton, 1980), Thai (Gandour et al., 1986), and Hindi (Davis, in press; Srivastava, 1974). In general, these studies also found that if the language contrasts more than one other stop type with [b̥], [d̥], [g̊] children begin to acquire voiceless aspirated after acquiring the voiceless unaspirated stops(Gandour et al, 1986; Davis in press) and only later acquire voiced or breathy-voiced stops. The only exception is the study done by Srivastava with one Hindi-learning child, who acquired voiced stops before voiceless aspirated stops. In the study done by Gandour et al. (1986) on Thai, voiced stops were the last type to be acquired. Even after children developed the skill to produce voiced stops with lead VOT (voice onset time), their productions at the age of five were not as precise and well controlled as the adults'.

By comparing Taiwanese data with data of other languages, this study intends to determine what acquisition patterns Taiwanese shares with other languages. For example, by comparing the acquisition of Taiwanese voiceless stops and voiced stops, we will find out whether Taiwanese voiced stops take as long to be acquired, as Thai and Hindi voiced stops do; and also whether Taiwanese voiceless unaspirated stops are indeed first to be acquired, as are the voiceless unaspirated stops in Thai, Hindi, English, Spanish, and Cantonese.

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Macken (1980) proposed that in order to claim that some similar acquisition patterns are observed across languages, at least two things need to be coordinated: (1) the appropriate unit of instrumental analysis and (2) a language-independent means of comparing the acquisition process across languages. Follo2wing Macken's concerns, the phonetic unit of analysis used here is VOT. The language-independent criteria for claiming a child's production as adult-like are therefore (1) a consistent relationship between the different types of stops produced by the child, (e.g., the VOT of voiceless aspirated stops must always be longer than those of voiceless unaspirated stops); (2) the mean VOTs of the child's production must approximate the mean VOT values of the adults and (3) there must be no overlap between the VOT ranges of different stop types produced by the children.

A pilot longitudinal study was carried out to trace the acquisition processes of two children over an extended period of time. Unlike pooled data with a large number of children being recorded only once, by following the same children for a long time, a complete individual acquisitional process is documented.

Method

Subjects

Two girls, growing up in a Taiwanese speaking environment in the U.S.A. participated in the study. EC was 28 months old when the recording started, and SC was 29 months old. All of the parents come from the central and southern part of Taiwan. The production of EC's mother ES and SC's father TC were used as a control in the adult acoustic study.

Data Collection

Each child was recorded until were able to consistently produce the three-way voicing distinction between homorganic stops and produced VOT values comparable to those of adult speakers. In the beginning of the study when the development was rapid, both children were recorded once every two weeks. Once the child began to make a statistically significant distinction between the three different types of stops (voiceless unaspirated, voiceless aspirated, and prenasalized voiced stops), the data was collected once every month.
EC was recorded with a SONY WM-D6C walkman, and a SONY ECM-144 microphone. Recording of EC was usually done by the experimenter, and occasionally by her mother ES at her home in Columbus, Ohio. Starting at the fifth month, EC was sometimes recorded using an AIWA cassette deck in a sound treated booth in the Linguistics Laboratory at the Ohio State University. SC was recorded at home by her father TC using an AIWA walkman, with a SONY ECM-144 microphone. The recording of SC was done by her father TC at their home in Los Angeles about every 10 days for a one-year period.

In the longitudinal study the tokens were elicited by having children imitate adult production. In the beginning of the study children learned several lexical items that were not originally in their vocabulary. Later on, whenever possible, spontaneous utterances were elicited by showing objects, or pictures.

Corpus

Table 1. corpus for EC and SC. For EC the item /be˨/ 'horse' chosen to replace the original item /be˦/ 'gruel' from the 31 months, because EC did not produce the target stop at all.

labial				labial nasal	
/pe˦/	'crawl'	/pŋ˧/	'rice'	/mẽ˧/	'younger sister'
/pʰe˧/	'futon'	/pʰɔŋ˦/	'bath'		
/be˨/	'horse'	/bŋ˦/	'door'		
dental				dental nasal	
/te˦/	'tea'	/tŋ˦/	'long'	/nẽ˥/	'milk'
/tʰe˧/	'take'	/tʰŋ˥/	'soup'		
velar				velar nasal	
/ke˥/	'chicken'	/kŋ˥/	'light'	/ŋ˦/	'yellow'
/kʰe˨/	'guest'	/kʰŋ˨/	'put'		
/ge˧/	'moon'	/gɔŋ˦/	'dizzy'		

Data analysis

The child's productions were categorized according to the adult target words. Even if the child produced a [p] when imitating the adult target word with initial /pʰ/, the production was categorized as an instance of /pʰ/. A token was discarded when the child made a mistake in place of articulation. For example, tokens of /tʰe˧/ ' take' that were produced as /kʰe˨/ 'guest' were excluded from further analysis. The recordings were analyzed acoustically to obtain spectral and temporal measures, including VOT. The VOT was measured by using a KAY 5500 DSP sonograph, and the measurements were statistically analyzed.

Adult Norm VOT Values

According to the results of a study on Taiwanese adult VOT production, adult mean VOT values range from 0 to 30 ms for voiceless unaspirated stops, from 40 to 100 ms for voiceless aspirated stops, and from -100 to -30 ms for voiced stops.

Subject EC

Statistical Results

The target item /bŋ˦/ 'door' was eliminated from the statistical analysis because it was produced as /mŋ˦/ ([məŋ˦]), with an initial nasal rather than an initial voiced stop by the adults in EC's environment. Data produced in the same month were pooled together to form a data set. There were all together, six month's worth of data recorded, representing six separate data sets. ANOVAs were done to determine the effect of voicing category, place of articulation, and following segments on each month's data. A three-way ANOVA with factors *voicing category, place of articulation* and *following segments* was not possible because of the lack of any /b/ initial tokens from 28 to 30 months. Therefore, six two-way ANOVAs with the factors *voicing category* and *following segments*, and 15 one-way ANOVAs with the factor *place of articulation* were used to analyze the VOTs of stops produced at three different places of articulation for each month.

There was a limited amount of data obtained from the voiced stop /b/ - due to the fact that EC's mother produced the word 'gruel' as [mua˧] instead of [be˧]. EC refused to produce any tokens of /be˧/ 'gruel', when asked to repeat the word. The item 'gruel' was changed to /be˨/ 'horse' in the 31st month. Since EC did not produce any voiced labial stops during the 28, 29, and 30 months, only three one-way ANOVAs with the factor *place of articulation* were used to analyze the VOT values of voiced stops at 31, 32, and 33 months. Since 24 ANOVAs were used to analyze EC's data, to avoid getting significant results by chances, the α was adjusted to 0.001 level.

Let us first consider the results of the two-way ANOVAs for each month. The results of these six ANOVAs indicated a significant main effect of voicing 2category for all six months: the 28th month ($F(2, 45) = 9.69$, $p<0.001$), the 29th month ($F(2, 83) = 14.86$, $p<0.001$), the 30th month ($F(2 ,114) = 37.52$, $p<0.001$), the 31st month ($F(2, 45) = 9.69$, $p= 0.003$), the 32nd month ($F(2, 44) = 79.35$, $p<0.001$), and the 33rd month ($F(2, 101) = 112.48$, $p<0.001$).

Six post-hoc Tukey tests were done on the data of each month to check the source of the significant main effect of voicing category. The Tukey test shows that at 28 months, there is already a statistically significant distinction between the mean VOTs of aspirated stops and unaspirated stops. However, there is no distinction between the mean VOTs of the voiced stops and the voiceless unaspirated stops, or between voiced and voiceless aspirated stops. From 29 to 31 months, the unaspirated stops are significantly different from aspirated stops, and the voiced stops are also different from aspirated stops. However, there is still no distinction between stops with voicing lead and stops with short lag VOT. Starting at 32 months, the difference between voiced stops and voiceless unaspirated stops is significant. EC continued to distinguish between the three types of voicing manner at 33 months.

Results of the six ANOVAs indicated no significant main effect of following segments for any of the six data sets: the 28th month ($F(1, 45) = 0.74$, $p = 0.394$), the 29th month ($F(1, 45) = 1.12$, $p = 0.348$), the 30th month ($F(1, 45) = 0.16$, $p = 0.688$), the 31st month ($F(1, 45) = 0.74$, $p = 0.394$), the 32nd month ($F(1, 45) = 0.89$, $p = 0.352$), and the 33rd month ($F(1, 45) = 2.73$, $p = 0.102$).

Six one-way ANOVAs with the factor place of articulation were also used to analyze the VOT values of voiceless unaspirated stops at each month. Result of the six ANOVAs indicated no significant effects of place of articulation for the VOT values of voiceless unaspirated stops for the six months: 28 months ($F(2, 25) = 1.51$, $p = 0.240$), 29 months ($F(2, 32) = 4.85$, $p = 0.014$), 30 months ($F(2, 48) = 1.1$, $p = 0.343$), 31 months ($F(2 , 18) = 1.68$, $p = 0.215$), 32 months, and at 33 months ($F(2 ,12) = 0.61$, $p = 0.561$). Table 2 shows the mean VOTs of voiceless unaspirated labial, dental, and velar stops for each of the six months.

Table 2 EC's monthly mean VOTs broken down by voicing category and place of articulation

28 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	20.315	17.19	--
S.D.	(2.21)	(--)	
N	2	1	
DENTAL			
VOT	15.107	66.01	--
S.D.	(5.92)	(33.55)	
N	3	8	
VELAR			
VOT	22.146	50.39	28.12
S.D.	(6.84)	(24.06)	(--)
N	23	12	1

29 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	-15.82	51.56	--
S.D.	(55.03)	(46.61)	
N	8	23	
DENTAL			
VOT	21.35	87.19	--
S.D.	(8.08)	(35.42)	
N	9	10	
VELAR			
VOT	34.95	79.58	24.33
S.D.	(38.67)	(35.83)	(7.32)
N	18	14	7

Table 2 (continued)

30 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	11.989	83.81	--
S.D.	(25.30)	(37.56)	
N	9	25	
DENTAL			
VOT	26.563	79.68	--
S.D.	(14.82)	(35.21)	
N	22	16	
VELAR			
VOT	19.218	68.47	18.75
S.D.	(34.50)	(50.90)	(30.48)
N	20	17	11

31 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	15.10	17.19	-14.06
S.D.	(16.08)	(--)	(64.08)
N	6	1	5
DENTAL			
VOT	25.69	66.01	--
S.D.	(23.98)	(33.55)	
N	9	8	
VELAR			
VOT	23.44	50.39	24.66
S.D.	(33.08)	(24.06)	(22.14)
N	9	12	10

Table 2 (continued)

32 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	27.502	68.43	-49.595
S.D.	(22.55)	(34.03)	(37.27)
N	5	5	5
D2ENTAL			
VOT	20.938	102.22	--
S.D.	(10.69)	(38.37)	--
N	5	7	
VELAR			
VOT	32.188	68.55	-39.843
S.D.	(12.91)	(34.14)	(19.34)
N	5	8	10

33 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	19.443	81.25	-25.347
S.D.	(9.85)	(59.33)	(28.65)
N	9	16	9
DENTAL			
VOT	27.213	64.95	--
S.D.	(11.87)	(22.49)	--
N	12	14	
VELAR			
VOT	30.468	100.61	-43.748
S.D.	(18.65)	(36.65)	(40.53)
N	14	15	18

Another set of six one-way ANOVAs with the factor place of articulation were used to analyze the VOT values of voiceless aspirated stops at each of the six months. Result of the six ANOVA also indicated no significant effect of place of articulation for the VOTs of voiceless aspirated stops for all six months: 28 months ($F(2, 18) = 1.68$, $p = 0.215$), 29 months ($F(2, 44) = 3.41$, $p = 0.042$), 30 months ($F(2, 55) = 0.71$, $p = 0.495$), 31 months ($F(2, 18) = 1.68$, $p = 0.215$), 32 months, and 33 months ($F(2, 17) = 2.03$, $p = 0.162$).

Result of the three ANOVAs indicated no significant effect of place of articulation for the VOTs of voiceless aspirated stops for 31 to 33 months: 31 months ($F(1, 19) = 1.68$, $p = 0.215$), 32 months ($F(1, 13) = 0.46$, $p = 0.509$), 33 months ($F(1, 25) = 1.47$, $p = 0.236$).

Three regressions were performed to determine if there was a significant relationship between *age* and *VOT development* of voiceless unaspirated stops, between *age* and *VOT development* of voiceless aspirated stops, and between *age* and *VOT development* of voiced stops. The regressions show significant linear relationships between age and VOT values of unaspirated stops, and aspirated stops (Table 3).

Table 3 EC summary table of ANCOVA analysis examining effect of age on VOT

	EFFECT OF AGE ON VOT	
	Linear Trend	Linear & Quadratic Trend
UNASPIRATED		
R-Square	0.438	
Sig. level	P<0.0001	
ASPIRATED		
R-Square	0.771	
Sig. level	P<0.0001	
VOICED		
R-Square	0.088	0.396
Sig. level	P=0.081	P<0.0001

As the age increases, the VOTs of /p, t, k, p^h/ increase, the VOTs of /t^h/ decrease, the VOTs of /k^h/ stay relatively the same (Figure 1). For voiced stops, there is no significant linear relationship between age and VOT values. By multiplying the age to the second order, a significant quadratic relationship was found. The curve fitted through the mean VOTs of /g/ in Figure 1 shows the relationships between age and VOT developments. At the 31 and 32 months, the /b/ tokens were sampled with mean VOT around -30 ms. At the 33 months the mean VOT value of /b/ increased toward -15 ms as shown in Figure 1. There was a quadratic trend type of VOT development through the three months. As for /g/ the mean VOTs stayed relatively the same around 30 ms from 28 to 30 months. At 31 months, the mean VOT value suddenly decreased to around 0 ms, and the mean VOT values continued to decrease during 32 months.

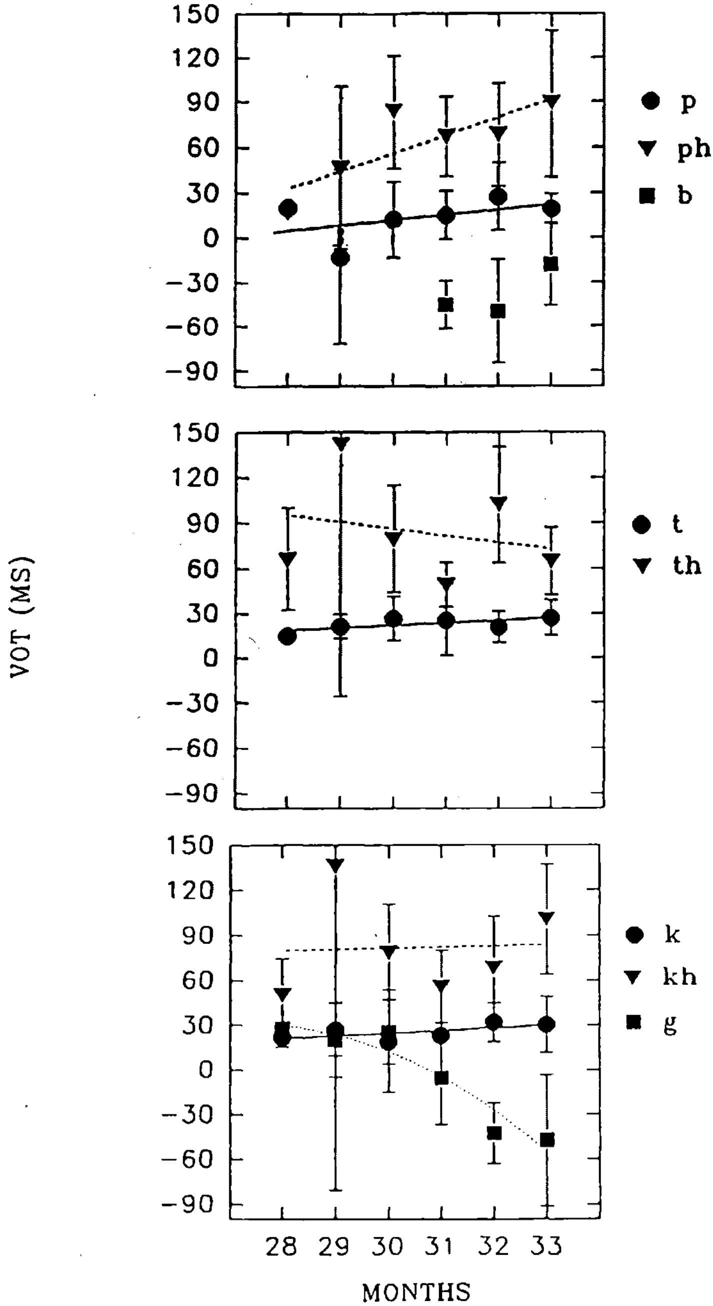

Figure 1 VOT development for EC, means and standard deviations

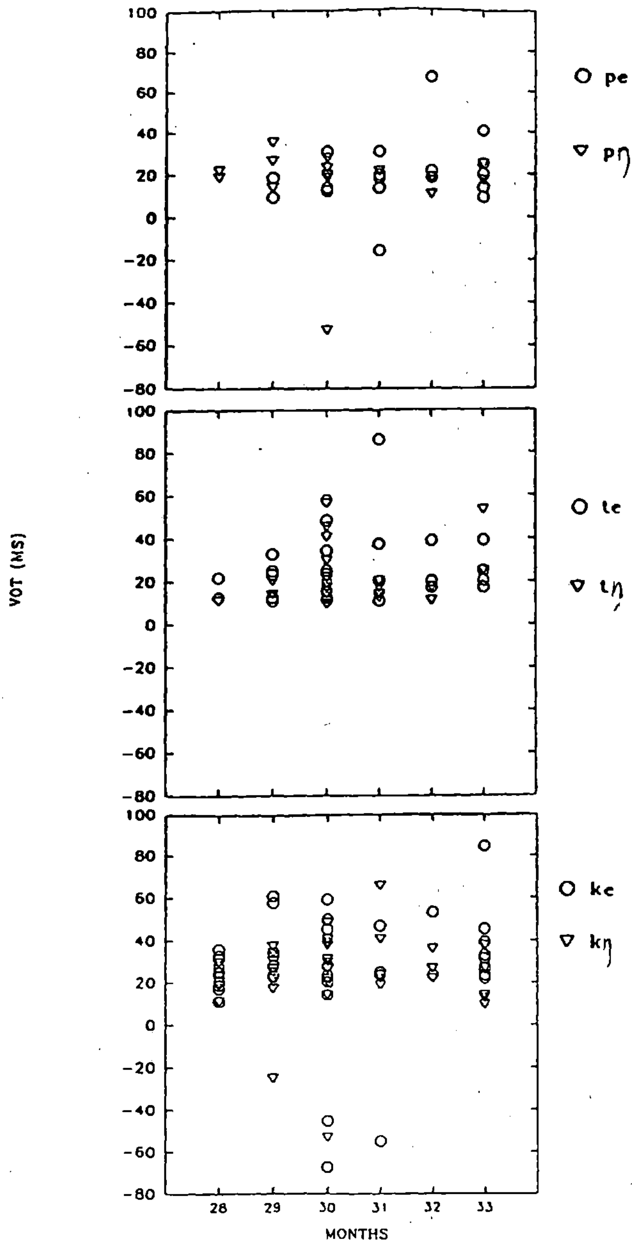

Figure 2 Scatter plots of /p, t, k/ VOTs produced by EC

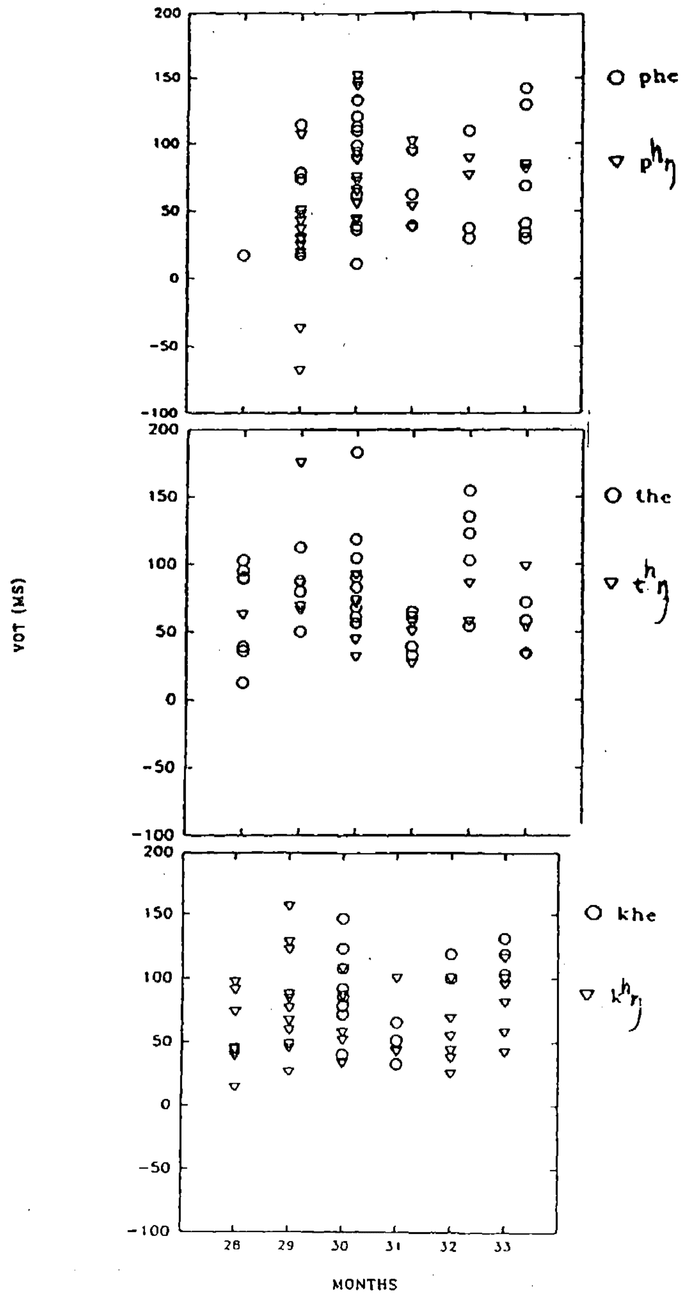

Figure 3 Scatter plots of /pʰ, tʰ, kʰ/ VOTs produced by EC

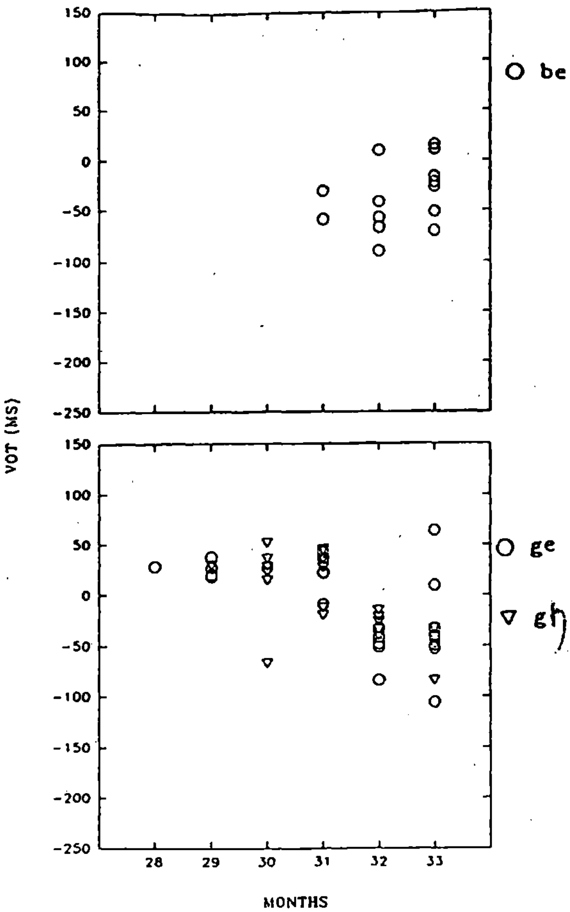

Figure 4 Scatter plots of /b, g/ VOTs produced by EC

General Tendencies of EC's Data

At the beginning of this study, EC's VOTs for unaspirated stops ranged between 0 to 40 ms. These were lengthened during the 30th and 31st month, when EC produced aspirated stops with VOTs exceeding the adult upper VOT limit for aspirated stops, which is 100 ms. The production of extra long aspiration will be referred to as hyperaspiration hereon. In the 32nd month, the VOTs were shortened. Some tokens of unaspirated stops were produced as nasals during 29 to 31 months.

As for the aspirated stops, in the 28th month, except for /pʰ/, the VOT values were within the adult norm. But in the 29th month, the individual VOT values exceeded the adult norm, which is 100 ms. EC kept on increasing the VOTs of aspirated stops from 28 through out 30 months. Depending on her familiarity with a word, the VOT peak was reached either in the 29th or the 30th month. In words that she was familiar with, e.g. /kʰŋ˩/ 'put' in Figure 3, the VOT peak was reached earlier than in unfamiliar words, like /pʰe/ 'futon'. By 31 months EC shortened the hyperaspiration for the aspirated stops.

EC started to produce /b/ with lead VOTs in the 31st month. At 33 months the VOT values of /b/ increased again. From 28 to 30 months most of the /g/ tokens were produced with short lag VOTs. During the 31 and 32 months, the VOTs of /g/ suddenly dropped. By the 33rd month, there was a clear distinction among the three voicing contrast of stops.

Macken (1980) proposed three categories for VOT development. During category I, there is no distinction between the aspirated and unaspirated stops. In category II, there is a distinction, but the VOT for both the aspirated and unaspirated stops fall within the adult norm for unaspirated stops (1;7 to 1;9 Tom; 1;5 to 1;9, Tessa; 1;7 to 1;10, Jane). In category IIIA, the children hyperaspirated the stops with long lag VOT (1;9, Tom, 1;9 to 2;0 Tessa, 1;10 to 2;0, Jane), They began to shorten the VOT back to the adult norm (category IIIB) (1;11 to 2;1, Tom). Generally speaking the data for EC agree with the category III pattern defined by Macken.

Subject SC

Statistical Results

Data produced in the same month were pooled. Two-way ANOVAs with the factors voicing category and following segments, and one-way ANOVAs with the factor place of articulation were used to analyze the VOTs of each of the 12 months data. Results of twelve two-way ANOVAs (voicing category * following segments) indicated significant main effects of voicing category for the data of the 12 months, as shown in Table 4.

Table 4 Significant main effects of voicing category for each months' data

Months	Effects of voicing category
29 months	(F (2 , 58) = 4.32, P = 0.018)
30 months	(F (2, 183) = 75.47, P< 0.001)
31 months	(F (2, 105) = 62.30, P< 0.001)
32 months	(F (2, 107) = 108.91, P< 0.001)
33 months	(F (2, 119) = 50.73, P< 0.001)
34 months	(F (2, 95) = 48.27, P< 0.001)
35 months	(F (2, 94) = 55.85, P< 0.001)
36 months	(F (2, 42) = 20.63, P< 0.001)
37 months	(F (2, 175) = 59.64, P< 0.001)
38 months	(F (2, 178) = 90.64, P< 0.001)
39 months	(F (2, 173) = 36.85, P< 0.001)
40 months	(F (2, 64) = 57.47, P< 0.001)

For data of every month, post-hoc tests were used to check if there are significant differences between VOTs of stops with different voicing categories. The post-hoc Tukey tests showed a significant difference between voiceless aspirated and unaspirated stops from the 29th to the 40th month. There were significant differences between the VOTs of voiceless aspirated stops and voiced stops. A significant difference between mean VOTs of voiceless unaspirated stops and voiced stops did not show up until the 34th month. However, at 39 and 40 months there were again no longer any significant differences between the mean VOTs of voiced stops and voiceless unaspirated stops.

Results of the 12 two-way ANOVAs (voicing categories * following segment) indicated no significant main effects of the following segment for VOTs for any months except for the 33rd month. There was a significant effect of following segments on VOTs at 33 months (F(1, 119) = 11.07, p = 0.0012).

Results of 12 one-way ANOVAs indicated that there were no significant main effects of place of articulation for the VOTs of voiceless unaspirated stops for any months except for the 32nd and 38th month. There were significant main effects of place of articulation for the VOTs of voiceless unaspirated stops for the 32nd month (F (2, 52) = 7.00, p = 0.002). and for the 38th month (F (2, 77) = 10.09, p < 0.001). Table 5 shows the monthly mean VOTs of voiceless unaspirated labial stops, dental stops, and velar stops.

A post-hoc test showed that at 32 and 38 months, the VOTs of voiceless unaspirated velar stops, were significantly different from those of voiceless unaspirated alveolar and labial stops.

Results of the 12 one-way ANOVA indicated that there were no significant main effects of place of articulation for the VOTs of voiceless aspirated stops for any months except for the 31st and the 39th month. There were significant main effects of place of articulation for the VOTs of voiceless aspirated stops produced at the 31st month (F (2, 32) = 12.29, p< 0.001), and the 39th month (F (2, 64) = 12.8, p< 0.001).

Table 5 SC's monthly mean VOTs broken down by voicing category and place of articulation effect of places of articulation

29 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	16.620	60.594	--
S.D.	(5.24)	(40.98)	
N	11	9	
DENTAL			
VOT	23.213	47.851	--
S.D.	(11.25)	(22.18)	
N	7	8	
VELAR			
VOT	25.293	58.854	--
S.D.	(11.61)	(20.85)	
N	16	9	

30 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	24.672	71.420	13.907
S.D.	(11.99)	(34.31)	(5.77)
N	19	28	10
DENTAL			
VOT	22.823	65.381	--
S.D.	(12.82)	(31.30)	
N	29	26	
VELAR			
VOT	30.834	67.463	33.306
S.D.	(13.50)	(26.03)	(23.21)
N	30	23	19

Table 5 (continued)

31 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	25.915	111.36	21.615
S.D.	(25.64)	(28.87)	(13.97)
N	12	11	12
DENTAL			
VOT	15.075	56.76	--
S.D.	(6.20)	(21.73)	
N	17	13	
VELAR			
VOT	28.312	73.865	25.954
S.D.	(22.10)	(31.21)	(9.88)
N	17	11	18

32 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	17.450	89.316	13.869
S.D.	(6.53)	(25.63)	(3.58)
N	12	12	8
DENTAL			
VOT	17.118	63.635	--
S.D.	(6.58)	(18.02)	
N	22	11	
VELAR			
VOT	26.935	69.923	26.249
S.D.	(12.83)	(30.80)	(17.43)
N	21	12	15

Table 5 (continued)

33 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	18.751	66.586	7.618
S.D.	(15.19)	(36.08)	(16.50)
N	17	13	16
DENTAL			
VOT	24.541	66.184	--
S.D.	(22.13)	(36.24)	
N	17	14	
VELAR			
VOT	21.604	78.280	11.167
S.D.	(6.17)	(38.12)	(33.01)
N	23	10	15

34 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	24.689	67.883	-7.924
S.D.	(17.46)	(27.60)	(30.40)
N	10	9	14
DENTAL			
VOT	14.510	48.924	--
S.D.	(4.65)	(26.73)	
N	14	16	
VELAR			
VOT	20.899	66.875	-4.296
S.D.	(10.35)	(28.89)	(22.46)
N	16	10	12

Table 5 (continued)

35 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	11.831	61.062	0.976
S.D.	(4.85)	(28.62)	(17.08)
N	7	17	8
DENTAL			
VOT	19.401	52.675	--
S.D.	(8.77)	(29.93)	
N	19	14	
VELAR			
VOT	21.87	61.408	-3.282
S.D.	(7.73)	(16.47)	(30.43)
N	21	15	10

36 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	15.623	62.480	-14.304
S.D.	(4.13)	(68.48)	(22.72)
N	3	2	13
DENTAL			
VOT	13.802	51.560	--
S.D.	(9.24)	(35.36)	
N	6	2	
VELAR			
VOT	15.108	62.498	-3.023
S.D.	(7.05)	(38.93)	(25.07)
N	3	4	15

Table 5 (continued)

37 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	9.233	60.750	-3.571
S.D.	(17.78)	(44.01)	(27.67)
N	22	19	35
DENTAL			
VOT	17.313	51.485	--
S.D.	(9.06)	(31.91)	
N	25	20	
VELAR			
VOT	21.237	67.018	3.173
S.D.	(20.24)	(29.72)	(27.26)
N	22	19	32

38 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	12.579	64.835	0.500
S.D.	(6.073)	(27.20)	(15.07)
N	20	15	25
DENTAL			
VOT	16.965	74.217	--
S.D.	(16.56)	(33.32)	
N	28	24	
VELAR			
VOT	27.392	91.407	10.623
S.D.	(11.00)	(42.21)	(46.08)
N	32	20	20

Table 5 (continued)

39 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	13.750	78.219	5.981
S.D.	(11.61)	(43.00)	(22.39)
N	15	17	29
DENTAL			
VOT	10.119	31.581	--
S.D.	(18.75)	(25.38)	
N	21	27	
VELAR			
VOT	22.498	67.121	17.559
S.D.	(18.61)	(31.59)	(31.85)
N	26	23	21

40 months

PLACE	Voicing Categories		
	Unaspirated	Aspirated	Voiced
LABIAL			
VOT	15.626	97.034	9.374
S.D.	(11.40)	(36.62)	(2.61)
N	6	10	6
DENTAL			
VOT	17.709	71.309	--
S.D.	(7.93)	(42.55)	
N	9	11	
VELAR			
VOT	18.404	86.875	-4.786
S.D.	(12.30)	(35.97)	(19.70)
N	9	10	9

Post-hoc tests indicated that the VOTs of voiceless unaspirated labial, dental, and velar stops are different from each other at the 31st month. The VOTs of voiceless unaspirated dental stops are significantly different from those of voiceless unaspirated labial and velar stops at the 39 months.

SC did not produce any voiced stops at 29 months. Eleven one-way ANOVAs were used to check the main effect of place of articulation for the VOTs of voiced stops produced from 30 to 40 months. Results of these 11 one-way ANOVAs indicated that there were no significant main effects of place of articulation for the VOTs of voiced unaspirated stops from the 31st month on. There was a significant effect of place of articulation on voiced stops produced at the 30th month ($F(1, 27) = 6.66$, $p = 0.016$). Table 5 shows the monthly mean VOTs of voiced labial and velar stops.

For each of the three data sets a regression was used to check if there is a significant relationship between age and the VOT developments. The regressions found significant linear relationships between age and the VOTs of voiceless unaspirated, voiceless aspirated, and voiced stops. There were gradual decreases of VOTs for /p, b, t, k, g/. There were gradual increase of VOTs for /p^h, t^h, k^h/. Table 6 shows the result of regression analyses.

Table 6 SC summary table of ANCOVA analysis examining effect of age on VOT

EFFECT OF AGE ON VOT	
	Linear Trend
UNASPIRATED	
R-Square	0.648
Sig. level	P<0.001
ASPIRATED	
R-Square	0.781
Sig. level	P<0.001
VOI	
R-Square	0.060
Sig. level	P<0.001

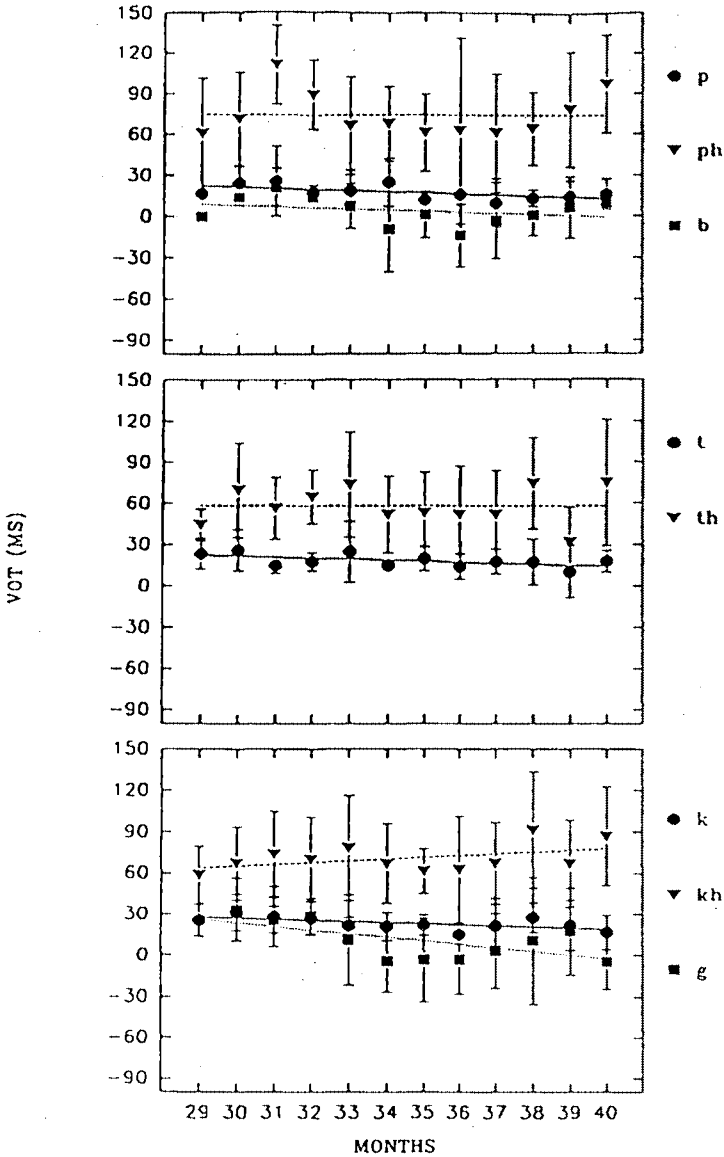

Figure 5 VOT development for SC, means and standard deviations

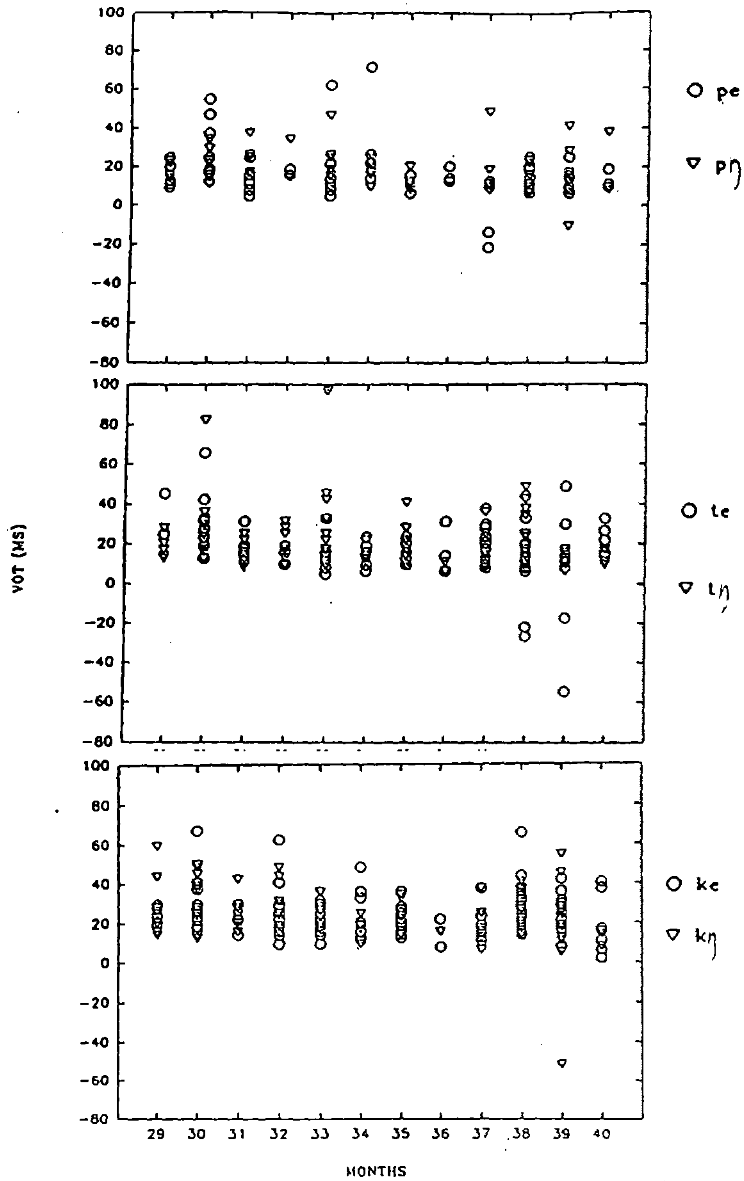

Figure 6 Scatter plots of /p, t, k/ VOTs produced by SC

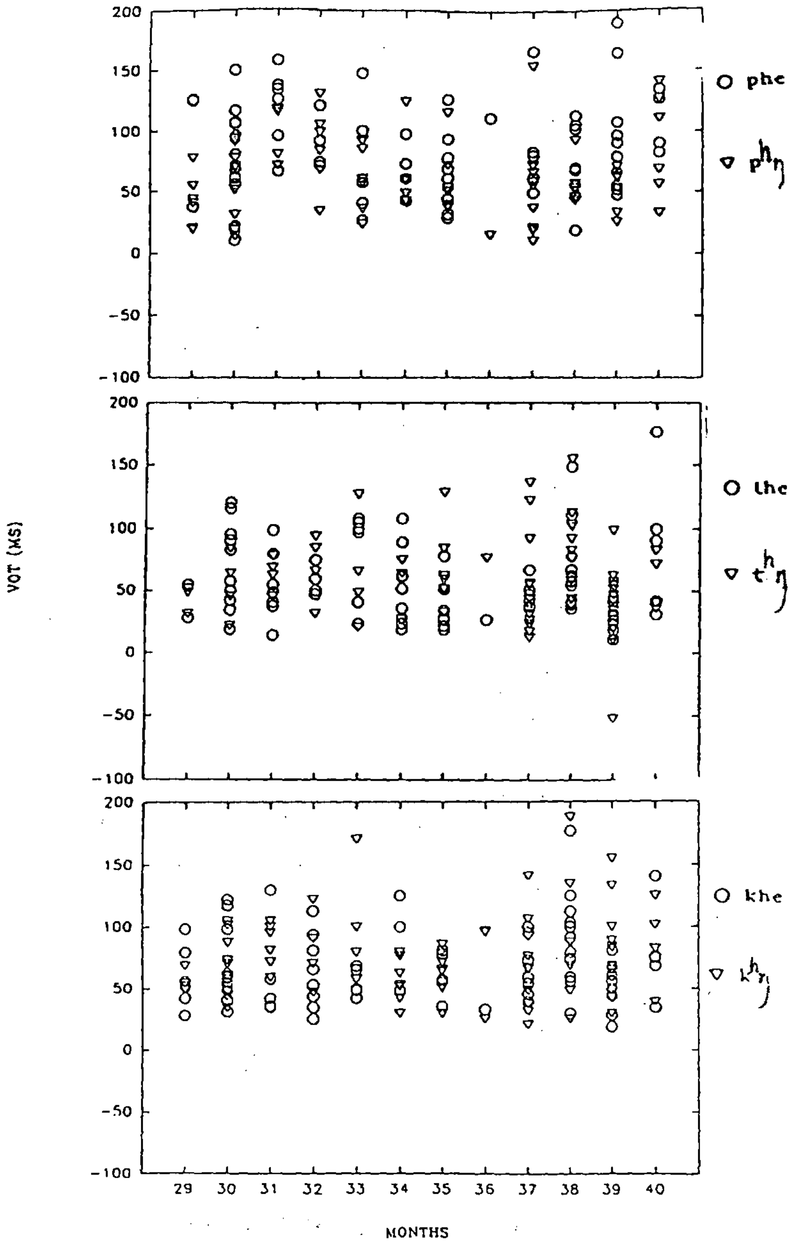

Figure 7 Scatter plots of /pʰ, tʰ, kʰ/ VOTs produced by SC

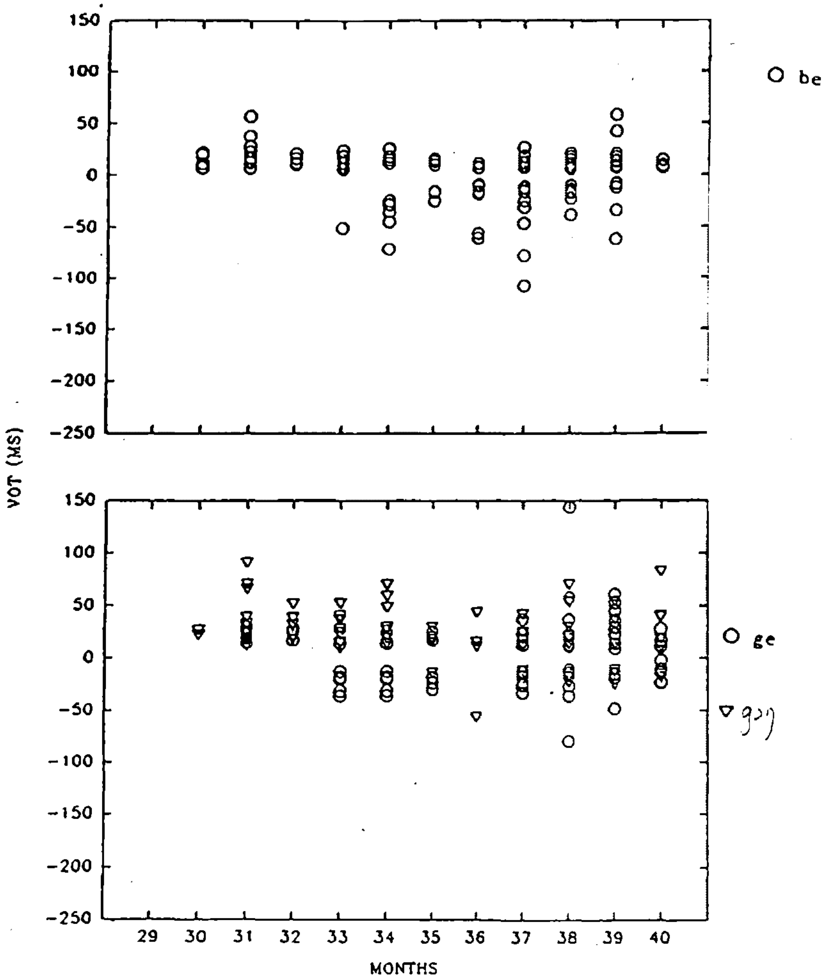

Figure 8 Scatter plots of /b, g/ VOTs produced by SC

General Tendencies of SC's Data

Figure 5 shows the means and standard deviations of SC's VOTs during the twelve months of data collection. Figure 6 shows the individual tokens of SC production for voiceless unaspirated stops. Figure 7 shows the tokens for voiceless aspirated stops, and Figure 8 shows the data for voiced stops.

As shown in Figure 5, the data from the 29th month showed that SC had already learned to make a distinction between voiceless stops with short lag and long lag VOT. At 30 and 31 months SC prolonged the VOT of the voiceless aspirated stops. As the VOTs of aspirated stops were hyperaspirated, the VOTs of voiceless unaspirated stops were also increased. Later SC gradually shortened the VOTs of aspirated stops to the range similar to the adults'. At 34 months, as SC began to produce voiced stops with lead VOTs, the VOTs of aspirated stops were also shortened. The means were separated by less than the sum of the two standard deviations of homorganic aspirated and unaspirated stops, from the 35 to 38 months. At the 38th month, SC hyperaspirated aspirated stops again, and the means were separated by more than the sum of the two standard deviations of voiceless aspirated and unaspirated stop at the 40th month. However, as SC hyperaspirated her aspirated stops, the VOTs of her voiced stops also increased toward the lag VOT direction. At 39 and 40 months, a post-hoc test indicated no distinction between VOTs of voiceless unaspirated stops and voiced stops.

During the one year over which SC was recorded, the VOTs of her unaspirated stops increased, when she hyperaspirated her aspirated stops. At 30, 38 and 39 months, there were many tokens of unaspirated stops with VOT over 40 ms (Figure 6). It was also observed in English (Macken & Barton, 1979), Cantonese (Clumeck et al., 1981), and EC's data that as the VOTs of aspirated stops increase the VOTs of unaspirated stops also increase. It is as if children were so involved in increasing the VOTs for aspirated stops, that they overgeneralize the task to unaspirated stops. More studies are necessary to test the hypothesis.

Four tokens of /t/ and one token of /k/ were found to be prevoiced during the 38 and 39 months, as SC learned to produce voiced stops with lead VOT. Before children can produce voiced stops with lead VOTs, all the voiced stops were produced with short lag VOTs. It is very likely that as children learn to apply the voicing lead skill to items that were originally produced with short lag VOTs, they overgeneralize the skill. Thus some /t, k/ tokens were also produced with lead VOTs. Further studies are necessary to test this hypothesis.

When the recording started at the 29th month, SC had already begun to distinguish between voiceless aspirated and unaspirated stops. She continued to increase the VOTs of aspirated stops until the 31st month the VOTs are shortened back. During the 35th month to 37th month the lower limit of the VOTs for /k^h/ and /p^h/ began to decrease. There was more overlap between voiceless aspirated and unaspirated stops. In the 38th month SC hyperaspirated the aspirated stops again to distinguish between voiceless aspirated and unaspirated stops.

SC did not produce voiced stops with lead VOTs until the 33rd month. Before then all the voiced stops had been produced with short lag VOTs. Even though there was a statistically significant three way distinction during the 34th to 38th month, SC started again to produce most voiced stops with lag VOTs at the 39th and 40th month, and so that the difference between VOTs of voiced stops and voiceless unaspirated stops was no longer significant. The difference is probably lost because of SC's exposure to English. During 39 and 40 months, SC began to speak English, and occasionally addressed in English, too.

Conclusion

The developmental patterns of voicing distinction in stop consonants were very different in SC and EC. When the recording started neither EC nor SC produced stops with lead VOTs. It took EC 6 months to acquire the three-way voicing contrast. Even at 31 months, when EC had learned to produce voiced stops with lead VOTs, the mean VOTs for voiced stops continued to decrease. There was less and less overlap between the standard deviations of homorganic stops. She seemed to go through a new "stage" every month. By the 33rd month, a clear three way voicing distinction of stops was achieved. As for SC, even after she learned to produce voiced stops with lead VOTs, the mean VOTs of voiced stops remained relatively the same and did not decrease very much. There was always overlap between the standard deviation bars for the homorganic stops of different types. Even though post-hoc Tukey comparison showed significant differences between the mean VOTs of voiceless unaspirated stops and voiced stops during the 34th to 38th month, the two stops were indistinguishable again in the 39th and 40th month. This loss of a three-way voicing distinction is very likely attributed to the exposure of English. Even though for EC a clear three-way voicing distinction was maintained at 33 months. It is very likely that the distinction could have been lost had the study continued for a longer period, because like SC, EC also began to learn English at 37 months.

The data of both SC and EC are consistent with the description of category III proposed by Macken & Barton (1980). In category III the VOTs of voiceless aspirated and unaspirated stops produced by children are similar to adult norms. In category IIIA, the VOT mean of aspirated stops are considerably longer. In category IIIB the means of aspirated stops are shorten back towards adult means. The same phenomenon was also observed here. Both SC and EC hyperaspirated their aspirated stops before the VOT was shortened again. It is hypothesized that hyperaspiration might be the general strategy that children use when they try to develop a distinction between voiceless aspirated and unaspirated stops.

It was noted that EC and SC produced some unaspirated stops with lead VOTs. This was also observed in English data. It was found that some English initial /b, d, g/ [b̥, d̥, g̊] tokens were produced with lead VOTs (Macken & Barton, 1979). In English, however, this is compatible with the adult target; although we do not understand the pattern of variability completely, it is clear that both voiced [b, d, g] and voiceless unaspirated [p, t, k] (or /b, d, g/) are possible variants of the English stop type (Lisker & Abramson, 1964). In Taiwanese, by contrast [b, d, g] are not acceptable productions of the voiceless unaspirated stops [p, t, k], since these two series contrast with each other.

There was another phenomenon that was noted not only in SC and EC's data, but also in acquisitional studies of English (Macken & Barton, 1979) and Cantonese data (Clumeck et al., 1981). Whenever aspirated stops were hyperaspirated, the VOTs of unaspirated stops also increased.

One thing noted from EC's data, and not reported in other languages was that word familiarity may influence a child's production of that word. Before using the word /be˧/ 'horse', which is a word that EC was familiar with, no tokens of /b/ were elicited. As soon as the item was used, many tokens of /b/ were elicited. Since she did not refuse to say the word any more. Also when hyperaspiration started, familiar words were first hyperaspirated before unfamiliar words. However, Macken (1980) did suggest that children's acquisition of voicing contrast appears first in the place of articulation that was used most in the children's lexicon. In other words, if children are more familiar with words starting with /b/, they learn the voicing contrast first for the bilabial sounds. In the current study, the more familiar place of articulation is confounded with the more familiar words. In any case the two studies agree that familiarity could influence children's production and acquisition of a sound. It was proposed in Gerken's (1994) speech production model that there is a limited pool of resources that the speaker can assign at each level of representation, such as the syntax, morphology, phonology, and phonetic levels. An utterance that requires more resources at one level will have less resources remaining at other levels. Therefore when asked to imitate after an unfamiliar word, there will be more resources assigned in order to perceive the word correctly, and to sort out the necessary motor controls to produce the word. Thus, less resources remain for producing the unfamiliar word.

Generally speaking, as proposed by Macken (1980) children learned to produce voiceless aspirated stops by hyperaspirating the aspirated stops. After the distinction between voiceless aspirated and unaspirated stops is established, the VOT of aspirated stops is shortened to be within the adult norm. Then children learn to produce voiced stops with lead VOT. Even though a child has acquired the skill to prevoice stops, it takes a long time for the production to become completely adult like. Gandour et al. (1986) found that even five-year-olds do not produce voiced stops in an adult like manner.

In sum, the data presented here show patterns that are similar to acquisition patterns observed in other languages. As in other languages with voiceless unaspirated stops, Taiwanese voiceless unaspirated stops are the first stops to be acquired by children. Just as English-learning and Cantonese-learning children do, when Taiwanese children first try to distinguish voiceless aspirated stops from unaspirated stops, they hyperaspirate voiceless aspirated stops. As in the Clumeck et al.'s (1981) Cantonese and Macken & Barton's (1979) English data, when the VOTs of these Taiwanese aspirated stops are lengthened, the VOTs of unaspirated stops also increase. As in Gandour et al's (1986) Thai data, Taiwanese voiced stops are the last to be acquired by children.

According to Gandour et al. (1986), Thai-learning five-year-olds still do not produce voiced stops in a completely adult-like manner. In order to trace the process of how children's production of voiced stops gradually became adult-like, a cross-sectional study sampling from a large number of children from various ages is necessary.

References

Allen, G. D. (1985). "How the young French child avoids the pre-voicing Problem for word-initial voiced stops," *Journal of Child Language*. **12**, 37--46.

Clumeck, H., Barton C., Macken M., & Huntington D. (1981) "The aspiration contrast in Cantonese word-initial stops: Data from children and adults," *Journal of Chinese Linguistics* **9**, 210-224.

Davis, K. (in press). "Phonetic and phonological contrasts in the acquisition of voicing: Voice onset time production in Hindi and English," *Journal of child Language.*

Gandour, L., Petty, S. H., Dardarananda, R., Dechongkit, L., & Mukngoen S., (1986) "The acquisition of the voicing contrast in Thai: a study of voice onset time in word-initial stop consonants," *Journal of child Language*, **13**, 561-572.

Gerken (1994) "Sentential processes in early child language: Evidence from the perception and production of function mophemes," in J.C. Goodman & H.C. Nussbaum (eds.), *The development of speech perception,* Cambridge, MA: The MIT Press, 271-338.

Lisker, L., & Abramson A. S. (1964) "A cross-language study of voicing in initial stops: acoustical measurements," *Word,* 20, 384-422.

Macken, M. A., & Barton D. (1979) "The acquisition of the voicing contrast in English: A study of voiced onset time in word-initial stop consonants," *Journal of Child Language,* **7**, 41-74.

Macken, M. A., & Barton D. (1980) "The acquisition of the voicing contrast in Spanish: Phonetic an phonological study of word initial stop consonants," *Journal of Child Language,* **7**, 433-458.

Macken. M. A. (1980). "Aspects of the acquisition of stop systems: A cross-linguistic perspective," in G.H. Yeni-Komshian, J.F. Kavanagh, & C.A. Ferguson (eds), *Child phonology,* **Vol.1**, 143-167.

Srivastava, G. P. (1974) "A child's acquisition of Hindi consonants," *India Linguistics*, **35**, 112-118.