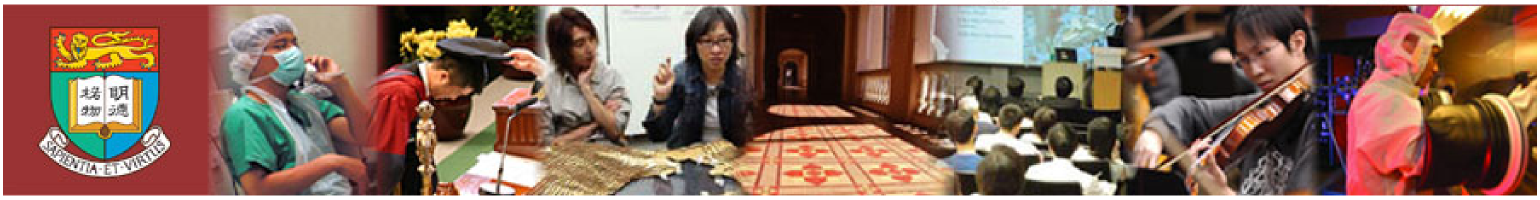

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Citation	
Issued Date	2008
URL	http://hdl.handle.net/10722/123888
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Production of Aspirated Phonemes in Cantonese-Speaking Children with Cochlear Implants or Hearing Aids

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A dissertation submitted in partial fulfilment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2008

Abstract

This paper investigated the ability of production of aspirated phonemes in Cantonese-speaking children with profound hearing loss who are users of cochlear implants or hearing aids. Participants were children aged between 3;00 to 6;03, and with profound hearing loss prelingually. The speech production of the participants in a picture naming task was analyzed perceptually and acoustically for voice onset time measurement. Results indicated that children with cochlear implants produced more errors in production of aspirated phoneme than the unaspirated cognates; while hearing aids users produced both aspirated phonemes and unaspirated cognates with similar accuracies. Mean VOTs produced by the participants were close to normal limits. Both cochlear implants and hearing aids were found to be beneficial for acquisition of aspiration. Early implantation before age 2;06 years old in children who had limited benefits from amplification was supported.

Introduction

The aim of this study is to investigate the production of aspirated phonemes in Cantonese-speaking children with profound hearing loss. In Hong Kong, children with profound hearing loss are managed by either cochlear implantation or fitting of hearing aids. The choice of the technology being used by each child depends on the availability of technologies, candidacy for cochlear implants and parents' decision. Parents of children with hearing impairment usually share a concern of whether their children can enter the mainstream education system at an early age (Geers, 2006). When making the decision of which technology to be used, parents rely a lot on information provided by professionals, other users and objective research results (Kluwin & Stewart, 2000). This study contributes to assist decision making of which technology to be used by 1) comparing the ability of production of aspirated phonemes of young cochlear implants users and hearing aids users; and 2) investigating the effect of age of cochlear implantation on the production of aspirated phonemes and VOT contrast in young children with profound hearing loss.

This study focused on production of aspirated phonemes. This is due to three major reasons. Firstly, missing of aspirated phonemes in phonological inventories of Cantonese-speaking children with profound hearing loss is common (Law & So, 2006; Dodd & So, 1994). Aspiration is important as ten consonants, including the five aspirated phonemes and their five unaspirated cognates, out of nineteen initial consonants in the Cantonese language system are being affected by aspiration. Hence, the error patterns of this population of children in production of aspirated phonemes were of interest of this study.

Secondly, children with hearing loss were known to depend on visual cue to learn production of speech (Blamey et al., 1995). Without visual contrast for production of aspirated and unaspirated pairs of phoneme, it is assumed that production of aspirated phonemes would be a sensitive indicator for the effectiveness of the technologies (cochlear implants and hearing aids) being used for detection of auditory information..

Thirdly, Osberger (1995) and Law & So (2006) suggested that cochlear implantation generally improves phonological development of children with hearing loss to a greater extent than hearing aid usage. On the other hand, residual hearing which would be lost in consequence of cochlear implantation was known to be extremely important for acquisition of aspiration (Dodd & So, 1994). It is worthwhile to compare the effect of cochlear implants and hearing aids in terms of acquisition of aspiration.

<u>Aspiration</u>

Aspiration is defined as a “noise produced at the glottis” (Johnson, 2004, p140) which passes through and is filtered by the vocal tract. Aspiration contrast was measured by voice onset time (VOT) according to Lisker & Abramson (1964). VOT is the time interval between a release of a closure of vocal tract and the onset of phonation (Clumeck, Barton, Macken & Huntington, 1981). According to Lisker & Abramson (1964), a value of VOT can be described as one of the three categories: 1) long lead which is ranged from about -75 to 125 milliseconds (ms), results in a voiced unaspirated consonant; 2) short lag which is ranged from 0 to 25 ms, results in a voiceless unaspirated consonant; and 3) long lag which is ranged from about 60 to 100 ms, results in a voiceless aspirated consonant.

In the phonological system of Cantonese, there is no voiceless and voiced contrast. Therefore, the only contrast of VOT involved in the Cantonese language is between unaspirated and aspirated consonants.

<u>Perception and production of VOT contrast by children with hearing loss</u>

Voice onset time is measured from waveforms of sound (Fourakis, Geers & Tobey, 1994). Perception of VOT contrast is highly dependent on auditory information (Kishon-Rabin et al., 2002). Previous studies including those of Lane, Wozniak, and Perkell (1994), Fourakis, Geers, & Tobey (1994) and many others suggested that speakers with prelingual hearing loss have difficulties in producing VOT contrast. Lane and Perkell (2005) suggested that this population have difficulties regulating their motor programming using the acoustic consequence of those programs.

Kishon-Rabin et al. (2002) studied the speech perception and production in Hebrew-speaking children with cochlear implants. They suggested that perception and production of voicing contrast is the last contrast to be developed by children with profound hearing loss after cochlear implantation. Without the restoration of some hearing ability by cochlear implantation, it is impossible for the prelingually deaf children to develop this contrast (Kishon-Rabin et al., 2002).

VOT contrast in Cantonese

VOT scale is a continuum of time (Catford, 1977) as seen in Figure 1. According to Catford (1977), the VOT contrast in voiced and voiceless stops is larger than that in aspirated and unaspirated stops.

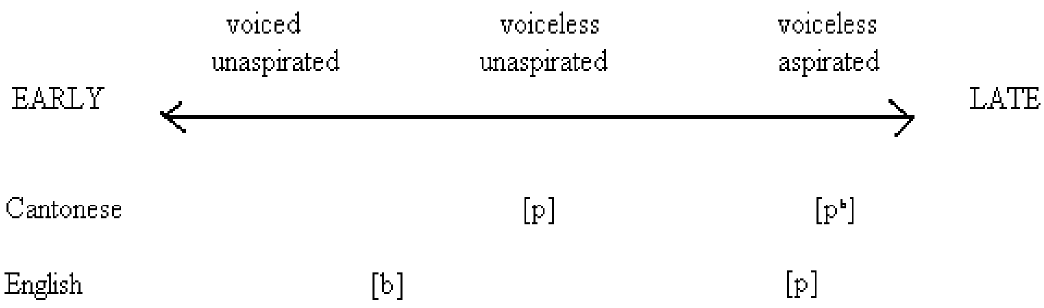

Figure 1 Voicing and aspiration on continuum of VOT scale (Li, 2003; Catford, 1977)

Previous studies about the production of VOT contrast in children with hearing loss mainly focused on voiced and voiceless stops (Lane & Perkell, 2005; Lane, Wozniak, & Perkell, 1994; Fourakis, Geers & Tobey, 1994) in English. There are no studies of the production of VOT contrast in Cantonese-speaking children with hearing loss. This study contributes to the investigation of the effectiveness of cochlear implants and hearing aids in the production of the smaller VOT contrast between voiceless unaspirated and voiceless aspirated cognates in Cantonese.

In the phonological system of Cantonese, there are five phonemes which are aspirated. All of these aspirated consonants occurred only in the initial position of the syllable. They include: aspirated bilabial stop /p^h/, alveolar stop /t^h/, velar stop /k^h/, labialized velar stop /k^{wh}/ and aspirated affricate /ts^h/. Each of these aspirated phonemes has one unaspirated cognate with the same place and manner of articulation. These unaspirated cognates are: /p/,/t/, /k/, /ts/ and /k^w/ respectively.

In this study, the following hypotheses were predicted:

a) children with cochlear implants would produce aspirated phonemes with higher accuracy than children with hearing aids since previous studies found that cochlear implant users produce initial consonants better than hearing aid users (Law & So, 2006);

b) VOT contrast in production of aspirated and unaspirated phonemes produced by children with cochlear implant will be more significant than that produced by children with hearing aids since cochlear implants were beneficial for perception and control of production of VOT contrast (Lane, Wozniak & Perkell, 1994);

c) children who received cochlear implantation at younger age rather than children who received cochlear implantation at older age produce aspirated phonemes with accuracy closer to their age-matched peers with normal hearing. This is expected as a lot of studies (Govaerts at al., 2002; Tye-Murray, Spencer & Woodworth, 1995) had suggested that implantation at younger age was more beneficial for acquisition of speech in children with profound hearing loss.

Method

Participants

The participants were twenty-three Cantonese-speaking children with prelingual profound hearing loss and no other concomitant problems (e.g. autism, ADHD, cerebral palsy, Down's syndrome). The subjects are users of oral language and aged between 3;00 and 6;03. This age range is chosen because according to So & Dodd (1995), aspiration should be acquired by 90% of children with normal hearing at the age of 3;06 to 4;00. Seventeen of the participants used cochlear implants and six of the participants used hearing aids. Table 1 provides information of the participants' unaided pure-tone average of both ears, age of fitting of technological devices (cochlear implants / hearing aids), year of experience with the devices, and year of speech and auditory training received.

Participants were recruited from education centres for children with hearing impairment. Parents reported that all children used Cantonese as their first language.

Table 1 Descriptive information for participants

P	CA	Sex	unaided PTA (R) (dBHL)	unaided PTA (L) (dBHL)	Technology (age of fitting)	Year of technology use	Year of training
A	4;07	F	>120	>120	CI (1;09)	2.75	1.5
B	3;07	M	108	>120	CI (1;00)	2.5	0
C	3;09	M	>100	>100	CI (1;10)	2	1.5
D	3;11	F	110	110	CI (1;05)	2.5	2.5
E	4;07	F	110	110	CI (1;07)	3	1.5
F	5;07	M	126	102	CI (1;06)	4	3.5
G	5;10	F	120	98	CI (3;00)	2.75	2.5
H	4;05	M	>125	>125	CI (1;05)	3	3
I	5;03	F	100	100	CI (1;11)	3.25	3.5
J	5;09	M	117	117	CI (2;05)	3.25	2.5
K	5;10	M	>125	>125	CI (2;07)	3.25	3.25
L	6;02	F	>125	>125	CI (1;09)	3.5	3.5
M	5;06	F	128	>125	CI (2;07)	3	3
N	5;00	F	115	117	CI (1;06)	3.5	4.5
O	5;04	M	121	>125	CI (4;10)	0.5	3
P	5;04	F	104	101	CI (4;07)	0.75	2.75
Q	3;11	F	>110	100	CI (1;05)	2.5	2.5
R	3;11	F	92	95	HA (1;08)	2.25	2.25
S	4;09	M	95	90	HA (2;11)	1.5	1.75
T	4;10	F	95	>100	HA (2;02)	2.5	2.5
U	4;11	F	120	95	HA (1;11)	3	2.25
V	5;10	M	94	109	HA (1;08)	4	3.5
W	4;01	F	120	95	HA (2;05)	1.5	1.5

Note: P = participant; CA = chronological age; PTA = pure-tone average of thresholds at 500, 1000, and 2000 Hz; R = right, L = left; M = male; F = female; CI = cochlear implants; HA = hearing aids.

All participants were receiving or had received auditory and speech training from the child care centres or the early education and training centre.

<u>Stimuli</u>

The test materials consisted of eighty-five colored pictures with size 12cm X 7cm. The pictures were put into five separated 3R-photo albums. Each picture illustrated an object, animal, or a motion representing the target word. The distribution of target words is illustrated in table 2.

Table 2 Distribution of target words elicited using picture naming task

	Monosyllabic words	**Disyllabic words (SIWI)[a]**	**Disyllabic words (SIWW)[b]**	**Disyllabic words (both)[c]**	**total**
/p/	2	2	2		**6**
/t/	2	2	2		**6**
/k/	2	2	2		**6**
/kw/	1	1	1		**3**
/ts/	2	2	2		**6**
/p^h/	3	2	3	1	**9**
/t^h/	5	5	5		**15**
/k^h/	5	4	3	1	**13**
/kw^h/	1	1	2		**4**
/ts^h/	5	5	4	1	**15**
total	**28**	**26**	**26**	**3**	**83**

Note a = targeted phoneme is located at syllable initial word initial position
b = targeted phoneme is located at syllable initial within word position
c = targeted phoneme is located at syllable initial position of both syllables

The first two pictures of the first photo album were samples which function were to make sure the participants understand the procedure of the task. Twenty-seven of the target words were consisted of unaspirated cognates (/p/, /t/, /k/, /k^w/ and /ts/) of the five Cantonese aspirated phonemes (/p^h/, /t^h/, /k^h/, /k^{wh}/, and /ts^h/). These unaspirated cognates were included in order to evaluate the children's ability to produce the unaspirated cognates of the aspirated phonemes and the VOT contrast.

Procedures

The participants were assessed in a quiet room by the researcher. The first 10 minutes were spent on collecting language sample and establishing rapport with the children through conversation and free play. Then, the children were required to name all the 85 pictures from five separated photo albums. There were times that the children could not name the particular pictures. Modeling was provided and the children were asked to say the target word after the researcher. A short game time was assigned after naming all pictures in each album to maintain the children's attention and motivation. The speech samples were audio-recorded by the built-in voice recorder and microphone of a Samsung MP3 player of model YP-U3Q which was clipped to the children's clothing at chest level.

Data analysis

The speech samples collected were phonologically and acoustically analyzed.

1. Phonological analysis

Perception of production was online transcribed by the author. The phonological analysis of speech samples were done by the researcher using the phonological process analysis method. The phonological processes used by each participant were later recorded based on the online transcription using a phonological process analysis form. A phonological process was judged to be used by a participant if the participant has demonstrated use of it at least twice in different target words.

Ten percent of the data were retranscribed by the same researcher by listening to the sound tracks about one week after the first transcription. Intra-rater reliability was 93%. Ten percent of the participants' production was transcribed by the author and another data collector separately at the same time in the same room. Inter-rater reliability across online transcription was 91 %.

2. Acoustic analysis

Twenty percent of the target words produced by each participant were extracted using free software PRAAT for analysis of VOT. The extracted samples tracks were low-pass filtered at 5 kHz and sampled at 22.05 kHz. VOT of each production of targeted phonemes was measured by marking the starting point at the onset of the release burst and the ending point at the onset of phonation. The release burst was illustrated by an abrupt onset of energy in the wide band spectrogram, while the onset of phonation which was represented by the onset of vertical striations in the spectrogram. Figures 2a and 2b illustrated how the VOT was obtained from spectrogram of production of Cantonese words 筆 /pɐt$_5$/ and 跑 /p^{h}au$_{25}$/ by participant L respectively. The two vertical white dotted lines indicate the starting point and the ending point of VOT measurement.

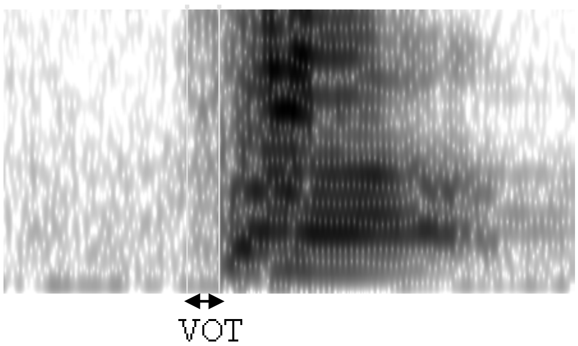

Figure 2a Spectrogram of production of /pɐt$_5$/ by L.

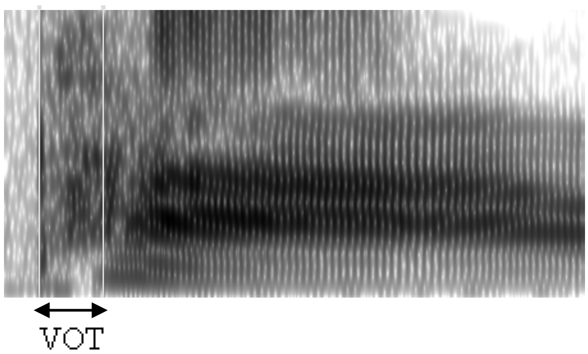

Figure 2b Spectrogram of production of /p^{h}au$_{25}$/ by L.

Results

<u>Phonological processes</u>

The participants of both technology groups have used both developmental and non-developmental phonological processes which were identified from speech of normal hearing children (So & Dodd, 1995) in production of aspirated phonemes. The developmental rules observed included: fronting (used by 76.5% of participants of the CI group; and 66.7% of the HA group), stopping (used by 64.7% of the CI group; and 66.7% of the HA group), and deaspiration (used by 52.9% of the CI group; and 66.7% of the HA group). The non-developmental processes used by both groups were: backing (used by 52.9% of the CI group; and 50% of the HA group), gliding (used by 47.1% of the CI group; and 66.7% of the HA group), and frication (used by 58.8% of the CI group and 50% of the HA group).

1. Comparison of effect of different technologies

Six CI participants including B, C, D, E, F and Q were matched with six HA participants including R, S, T, U, V and W respectively according to their years of technology use and years of training received. The percentages of correct production of the four aspirated stops: /p^h/, /t^h/, /k^h/, /k^{wh}/ and the aspirated affricate /ts^h/ by each technology group were summarized in table 3. Effect of group on the percentage of correct production of the five aspirated phonemes was measured using the t-tests. There was no statistically significant difference between the groups' performances in production of the five aspirated phonemes. One-way ANOVA indicated significant effects of different phonemes produced by the HA group, $F (4, 25) = 2.826$, $p<.05$, and the CI group, $F (4, 25) = 2.886$, $p<.05$.

A t-test was used to measure the effect of aspiration by comparing the difference between percentage of correct production of aspirated phonemes and their unaspirated cognates. For the CI group, the production of the unaspirated cognates was significantly better than the production of the aspirated phonemes, t = 2.79, p< .05. There was no significant effect of aspiration in the HA group, t =1.23, p = .273.

Table 3. Percentage of correct production of aspirated stops and aspirated affricate by the matched technology groups

Measurement		**Percentage of Correct production**				
		/p^h/	/t^h/	/k^h/	/k^{wh}/	/ts^h/
CI group						
	Mean	94.5	87.8	76.2	41.7	65.6
	Range	88.9-100	53.3-100	57.1-92.8	0-100	6-100
	SD	6.08	17.60	16.06	49.16	38.23
HA group						
	Mean	90.8	67.8	59.5	37.5	34.3
	Range	55.6-100	6.7-93.3	14.3-92.9	0-100	0-100
	SD	17.78	31.93	34.61	37.91	41.68
		Significance of difference between groups				
	t-test	0.42	1.30	1.07	0.17	1.45
	p value	0.692	0.250	0.334	0.872	0.207

2. Comparison of effect of age of cochlear implantation

According to So & Dodd (1995), developmental phonological rules were used by less than 10 % of children with normal hearing at age five. Within the seventeen children who were users of cochlear implants, ten of them were over age five. In order to compare the performance of children with profound hearing loss who were implanted at different ages, the ten children were divided into two groups according to their age of implantation: implanted before age 2;06 group (early implantation group), implanted after age 2;06 group (late implantation group). The percentages of correct production of the four aspirated stops: /p^h/, /t^h/, /k^h/, /k^{wh}/ and the aspirated affricate /ts^h/ by each group were summarized in table 4.

Table 4. Percentage of correct production of aspirated stops and aspirated affricate of the early of implantation group (implanted before 2;06 years old) and the late implantation group (implanted after 2;06 years old)

Measurement	**Participants**	**Percentage of Correct production**				
		/p^h/	/t^h/	/k^h/	/k^{wh}/	/ts^h/
Early implantation group	F, I, J, L, N					
	Mean	86.7	93.3	74.3	70.0	92.6
	Range	66.7-100	73.3-100	35.7-100	25-100	75-100
	SD	14.47	11.56	25.05	41.08	10.29
Late implantation group	G, K, M, O, P					
	Mean	91.1	69.3	34.3	30.0	75.8
	Range	77.8-100	26.6-100	7.1-71.4	0-100	60-94
	SD	9.29	31.49	23.36	44.72	12.07
		Significance of difference between groups				
	t-test	0.58	1.6	2.61	1.47	2.37
	p value	0.578	0.148	0.031	0.80	0.045

T-tests revealed the early implantation group performed significant better than the late implantation in production of aspirated velar stop /k^h/ and aspirated alveolar affricate /ts^h/. No statistically significant effects of group were found in production of bilabial stop /p^h/, alveolar stop /t^h/ and labialized velar stop /k^{wh}/. The overall percentage of correct production of aspirated phonemes of the early implantation group was significantly higher than that of the late implantation group, t = 2.76, p<.05.

The effects of aspiration on the percentage of correct production of aspirated phonemes and their unaspirated cognates were insignificant for both the early implantation group and the late implantation group.

<u>Acoustic analysis of VOT</u>

1. Comparison of effect of different technologies

Figures 3a to 3e illustrated the mean VOT in millisecond produced by the matched CI group and HA group when producing unaspirated stops and affricate and aspirated stops and affricate respectively.

The VOT contrasts produced by the CI group and the HA group in production of the five pairs of phonemes were compared by t-tests. The results shown that there were no significant difference in the two groups' VOT contrast production of /p/ and /p^h/, t = 0.06, p = 0.953; /t/ and /t^h/, t = 2.18, p = 0.052; /k/ and /k^h/, t = 0.61, p = 0.554;

$/k^w/$ and $/k^{wh}/$, t = 0.40, p = 0.697; and /ts/ and $/ts^h/$, t = 0.56, p = 0.587.

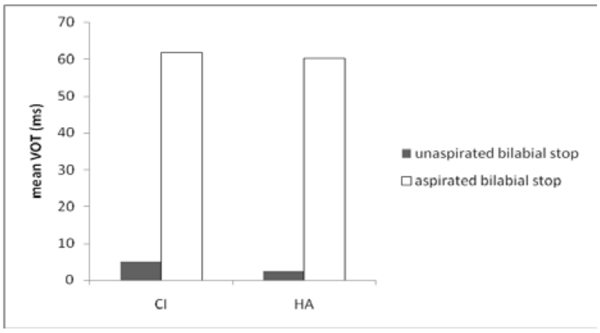

Figure 3a. Mean VOT of /p/ and $/p^h/$ produced by the CI group and the HA group.

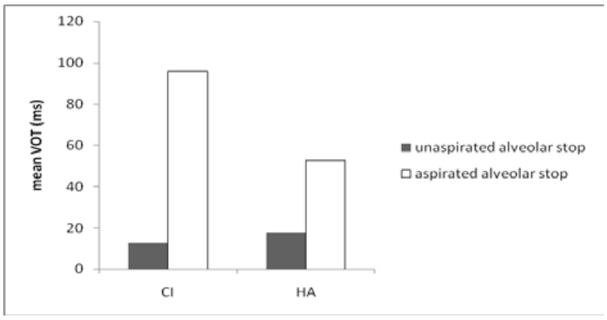

Figure 3b. Mean VOT of /t/ and $/t^h/$ produced by the CI group and the HA group.

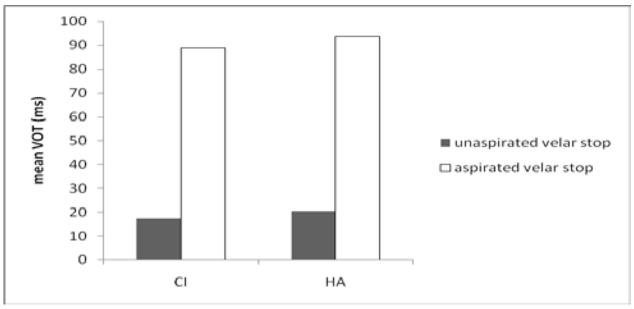

Figure 3c. Mean VOT of /k/ and $/k^h/$ produced by the CI group and the HA group.

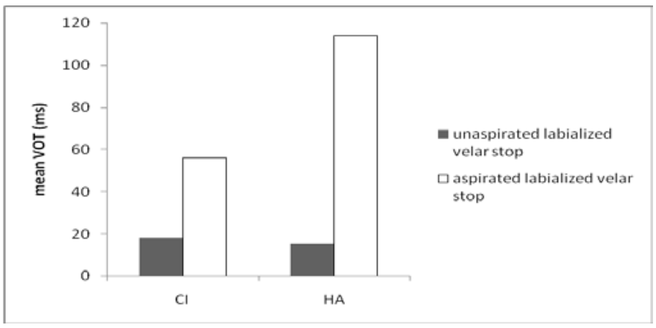

Figure 3d. Mean VOT of $/k^w/$ and $/k^{wh}/$ produced by the CI group and the HA group.

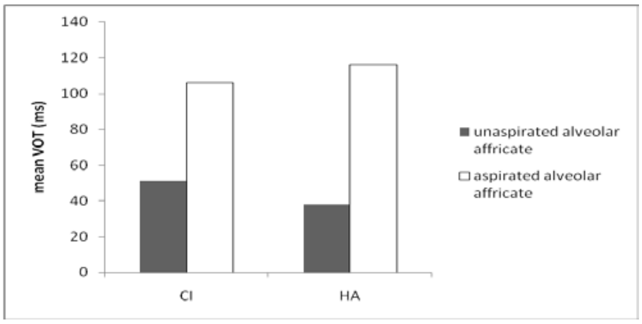

Figure 3e. Mean VOT in milliseconds of /ts/ and /ts^h/ produced by the CI group and the HA group.

2. Comparison of effect of age of cochlear implantation

Figures 4a and 4b show the average VOT in millisecond produced by the early implantation group (implanted before age 2;06) and the late implantation group (implanted after age 2;06) when producing unaspirated stops and affricate and aspirated stops and affricate respectively.

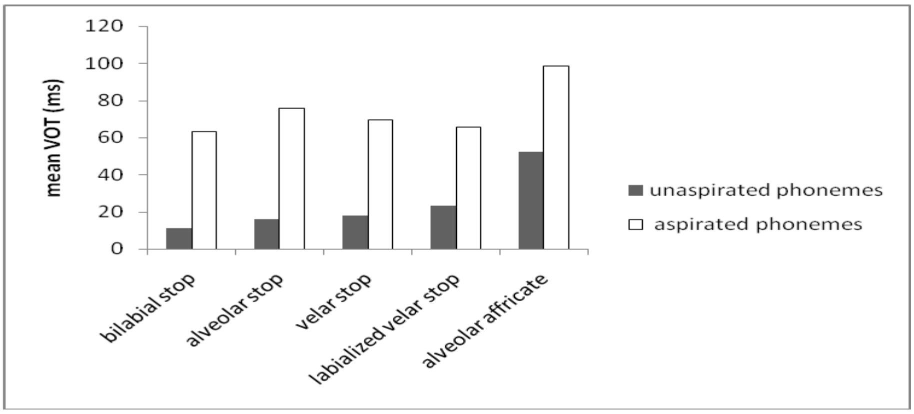

Figure 4a. Average VOTs produced by the early implantation group in production the five Cantonese aspirated phonemes and their unaspirated cognates.

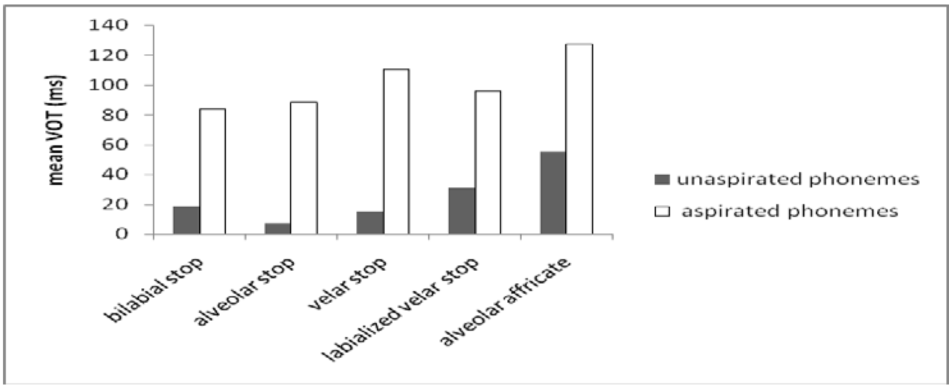

Figure 4b. Average VOTs produced by the late implantation group in production the five Cantonese aspirated phonemes and their unaspirated cognates.

The VOT contrasts produced by the early implantation group and the late implantation group in production of the five pairs of phonemes were compaired using t-tests. There were no statistically significant differences in the production of VOT contrast of all five pairs of phonemes between the two groups.

Discussion

Phonological processes

Both developmental and non-developmental phonological processes were observed in participants of this study. This confirmed with the findings of many previous studies about children with hearing loss (Law & So, 2006; Dodd & So, 1994; Flipsen & Parker (in press). For the developmental phonological processes, 13 participants of this study used deaspiration, 15 participants used stopping in production of affricates, and 17 participants used fronting in production of velar stops. Non-developmental phonological processes were also observed. Thirteen participants demonstrated use of the backing process, 12 participants used the gliding process, and 13 participants also used the frication process.

More usages of phonological processes involving error in place of articulation such as fronting and backing were seen in the production of aspirated phonemes than of the unaspirated cognates in this study. This result agrees with previous studies of speech production of children with hearing loss (Law & So, 2006). This may be due to the difficulties in coordination of tongue and laryngeal glottis simultaneously (Stokes and Ciocca, 1999).

So & Dodd (1995) found that less than 10% of the normal hearing children would use deaspiration after age three. In the current study, 56.5% of the participants with profound hearing loss still demonstrated use of deaspiration. Law & So (2006) also found children with profound hearing loss use the deaspiration process more than normal hearing children. This discrepancy revealed that hearing ability is important for acquisition of aspiration.

Aspiration and voicing are both measured by voice onset time (Lisker & Abramson, 1967; Clumeck et al., 1981). In languages other than Cantonese, production of voicing contrast by children with hearing impairment was studied (Kishon-Rabin et al., 2002; Tobey, Pancamo, Staller, Brimacombe, & Beiter, 1991). Kishon-Rabin et al. (2002) identified voicing as the most difficult feature to be acquired by hearing impaired children who use Hebrew as first language because voicing contrast is "highly dependent on auditory information". Tobey et al. (1991) also found that voicing errors are common in English-speakers with profound hearing loss. Though more than half of the participants in the current study used deaspiration, none of the participants deaspirated all five aspirated phonemes. The most commonly deaspirated phoneme was the labialized velar stop /k^{wh}/. This is comparable with the performances of normal hearing children as studies in So & Dodd (1995), which revealed that /k^{wh}/ is generally the last consonant to be acquired and mismatch of /k^{w}/ with /k^{wh}/ is common.

Frication was used by 56.5% of participants in the current study though it is an unusual rule in normal hearing children. In this study, the most commonly produced fricative in substitution of aspirated phonemes was the glottal fricative /h/. Johnson (2004) defined aspiration noise as noise produced at the glottis, implying that aspiration noise is actually a glottal fricative noise. The participants' production of aspirated phonemes as glottal fricative may indicate their awareness of the fricative noise in aspiration.

Gliding was observed in production of both unaspirated and aspirated labialized velar stops, with most common error being substitution of /k^{w}/ or /k^{wh}/ by labial glide /w/. Forty-three percents of participants produced an aspirated labial glide /w^{h}/ in substitution of /k^{wh}/ at least once. This phenomenon was unexpected as /w^{h}/ does not exist in the Cantonese language system. The retention of the aspiration feature in these cases may imply that the speakers were conscious about the aspiration in the /k^{wh}/ phoneme. They failed to produce the targeted phoneme may be due to the difficulties in coordination of three articulators including the glottis, the tongue and the lips simultaneously (Stokes & Ciocca, 1999).

Percentages of correct production are higher for bilabial stops and alveolar stops, both unaspirated and aspirated, than velar stops. This result confirmed with the studies of Tobey et al. (1991), and Blamey et al. (1995). Phonemes articulated at the more anterior part of the mouth are generally more accurate since they are more visible (Blamey et al., 1995).

<u>Production of VOT contrast</u>

Comparing the mean VOTs of stops produced by participants in this study with the data of normal hearing children presented by Clumeck et al. (1981) and Lee (1997), the mean VOTs produced by children with profound hearing loss of both the CI group and the HA group is generally similar to that of normal hearing children. The mean VOTs of affricate produced by participants in this study are also similar to those produced by the normal group of children studied by Yu (1996).

The results of this study agree with the founding of Uchanski & Geers (2003), who studied the acoustic characteristics of speech of English-speaking young cochlear implant users. In their study, over 73% of the cochlear implant users produced VOT contrast of /t/ and /d/ within normal limits. Uchanski & Geers (2003) suggest the close to normal limits performance reflect that use of technology is generally beneficial for the perception of VOT contrast which is not visible.

Effect of different technologies

The difference between the percentages of correct production of the CI group and the HA group was insignificant in this study. Blamey et al. (2001) also found insignificant differences in the performances between CI users and HA users. Chin & Kirk (2002) found similar performances in CI users and HA users whose unaided hearing threshold were between 90dB and 100dB. This may be due to the fact that in all the three studies, participants who were users of hearing aids generally had unaided hearing threshold lower than the participants who were users of cochlear implants. The effectiveness of cochlear implants and hearing aids cannot be compared in this study as the degrees of hearing loss between the two groups were not balanced. The unbalance of the sampling group may be unavoidable because the world wide accepted criteria for cochlear implantation is strict for minimal benefit from amplification (Waltzman & Shapiro, 1999). As a result, the residual hearing levels to a certain degree determine the type of technology use for assistance of hearing.

Effect of age of implantation

Tye-Murray, Spencer, & Woodworth (1995) suggest children implanted before age 5 may perform better in speech production than children implanted after age 5. The current study investigates the effect of age of implantation within a younger group of children. The results of this study indicated that children who received implantation before age 2;06 had higher percentage of correct production of aspirated phonemes than children who received implantation after age 2;06. This suggested early implantation is beneficial for children with profound hearing loss in learning the production of both aspirated consonants and their unaspirated cognates. The result confirmed with Govaerts et al. (2002) who studied effect of age of implantation on language development of pediatric users of cochlear implants. Govaerts et al. concluded that implantation before 2 years of age is most favorable for implant candidates in terms of reaching normal auditory performance and entering mainstream educational system. Geers (2004) also found implantation before age 2 achieved speech and language skills comparable with their normal hearing age-matched peers.

Geers and Tobey (1992), Fourakis, Geers, & Tobey (1994), Chin & Kirk (2002) and Kishon-Rabin et al. (2002) found improved production of voicing contrast for children after two years of implantation, implying that acquisition of VOT contrast requires about two years of exposure to the contrast. Early implantation is more beneficial for children's phonological development in terms of being comparable with their age-matched peers with normal hearing at the age for entering schools.

Clinical implications

This study brought light to two aspects which worth awareness.

Firstly, Cantonese-speaking children with profound hearing loss respond differently to amplification of speech sounds in terms of acquisition of aspiration, depending highly on the amount of residual hearing ability. As a result, it is important to determine the candidacy for cochlear implants carefully because the implantation procedure sacrifices residual hearing ability.

Secondly, when a child is defined as an appropriate implant candidate, early implantation before 2;06 years old is more favorable for the child's phonological development in relation to reaching close to normal phonological ability by approaching school age.

Limitation and suggestion for further studies

The population of children with profound hearing loss in Hong Kong is small. Individual variation was quite large in the profound hearing loss population. There was a lot of confounding factors which were too difficult to be controlled.

The design of this study was not appropriate for comparing effectiveness of cochlear implants and hearing aids as hearing abilities of participants between the technology groups have unavoidable difference due to the criteria for cochlear implantation candidacy.

Single case longitudinal studies will be worthwhile to bring insight into developmental pattern of phonological ability, especially production of VOT contrast in individual children with hearing loss.

Acknowledgments

The author would like to thank Dr. Lydia So for her supervision on this dissertation; Dr. Anita Wong for her helpful suggestions on this project; Dr. Estella Ma, Dr. Lawrence Ng, Dr. Sam Leung and Dr. Sam Po Law for their guidance in carrying out research projects and writing a dissertation; Miss Carol Fung for checking the inter-rater reliability; Principals, speech therapists, teachers, staffs, parents and children from the Bradbury Special Child Care Centre, the Hong Kong Cochlear Implant Association, the Jockey Club Sign Bilingualism and Co-enrolment in Deaf Education Programme of the Chinese University of Hong Kong, the Sheung Tak Special Child Care Centre, and the Suen Mei Speech and Hearing Centre for their support and participation in this study.

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Appendix A (p.1 of 3)

Word list for the two sample words and 83 target words in the order of presentation

Picture No.	Traditional Chinese words (Targeted syllable)	Phonetic transcription	Word meaning
Sample 1	鎖匙	/sɔ$_{25}$ si$_{21}$/	key
Sample 2	喊	/ham$_{33}$/	cry
1	錶	/biu$_{55}$/	watch
2	狗	/gɐu$_{25}$/	dog
3	咳	/k^{h}ɐt$_{5}$/	cough
4	報紙	/pou$_{33}$ tsi$_{25}$/	newspaper
5	提子	/tɐi21 tsi$_{25}$/	grape
6	花盆	/fa$_{55}$ pun$_{21}$/	flower pot
7	西瓜	/sɐi$_{55}$ k^{w}a$_{55}$/	water melon
8	糖	/t^{h}ɔŋ$_{25}$/	candy
9	被	/p^{h}ei$_{23}$/	blanket
10	蝴蝶	/wu$_{21}$ tip$_{2}$/	butterfly
11	彈琴	/t^{h}an$_{21}$ k^{h}ɐm$_{21}$/	play piano
12	叉	/ts^{h}a$_{55}$/	fork
13	排隊	/p^{h}ai$_{21}$ tœy$_{25}$/	queue up
14	跳	/t^{h}iu$_{33}$/	jump
15	扣針	/k^{h}ɐu$_{33}$ tsɐm$_{55}$/	buckle pin
16	豬肉	/tsy$_{55}$ juk$_{2}$/	pork
17	毛巾	/mou$_{21}$ kɐn$_{55}$/	towel
18	噴	/p^{h}ɐn$_{33}$/	spray
19	皮帶	/p^{h}ei$_{21}$ tai$_{25}$/	belt
20	韆鞦	/ts^{h}in$_{55}$ ts^{h}ɐu$_{55}$/	swing
21	凉亭	/lœŋ$_{21}$ t^{h}iŋ$_{25}$/	pavilion
22	鉗	/k^{h}im$_{25}$/	pincers
23	頭髮	/t^{h}ɐu$_{21}$ fat$_{3}$/	hair
24	巴士	/pa$_{55}$ si$_{25}$/	bus
25	櫈	/tɐŋ$_{33}$/	chair
26	鉸剪	/kau$_{33}$ tsin$_{25}$/	scissors
27	鐘	/tsuŋ$_{55}$/	clock
28	琴	/k^{h}ɐm$_{21}$/	piano
29	樓梯	/lɐu$_{21}$ t^{h}ɐi$_{55}$/	ladder
30	腳	/kœk$_{3}$/	leg

cont. Appendix A (p.2 of 3)

Word list for the two sample words and 83 target words in the order of presentation

Picture No.	Traditional Chinese words (Targeted syllable)	**Phonetic transcription**	Word meaning
31	骨頭	/kwɐt$_{55}$ t^{h}ɐu$_{21}$/	bone
32	間尺	/kan$_{33}$ ts^{h}ɛk$_{3}$/	ruler
33	麵包	/min$_{22}$ pau$_{55}$/	bread
34	刀	/tou$_{55}$/	knife
35	警察	/kiŋ$_{25}$ ts^{h}at$_{3}$/	police
36	鉸剪	/kau33 tsin25/	scissors
37	烏龜	/wu$_{55}$ kwɐi$_{55}$/	turtle
38	跑步	/p^{h}au$_{25}$ pou$_{33}$/	run
39	企鵝	/k^{h}ei$_{23}$ ŋɔ$_{25}$/	penguin
40	天	/t^{h}in$_{55}$/	sky
41	車	/ts^{h}ɛ$_{55}$/	car
42	蛋糕	/tan$_{22}$ kou$_{55}$/	cake
43	裙	/k^{wh}ɐn$_{21}$/	skirt
44	遮	/tsɛ$_{55}$/	umbrella
45	鉛筆	/jyn$_{21}$ pɐt$_{5}$/	pencil
46	白兔	/pak$_{2}$ t^{h}ou$_{33}$/	rabbit
47	橋	/k^{h}iu$_{21}$/	bridge
48	橙汁	/ts^{h}aŋ$_{25}$ tsɐp$_{5}$/	orange juice
49	飛機	/fei$_{55}$ kei$_{55}$/	plane
50	蘋果	/p^{h}iŋ$_{21}$ k^{w}ɔ$_{25}$/	apple
51	紙巾	/tsi$_{25}$ kɐn$_{55}$/	tissue
52	的士	/tik$_{5}$ si$_{25}$/	taxi
53	菜	/ts^{h}ɔi$_{33}$/	vegetable
54	枱	/t^{h}ɔi$_{25}$/	table
55	旗	/k^{h}ei$_{21}$/	flag
56	金牌	/kɐm$_{55}$ p^{h}ai$_{21}$/	gold medal
57	湯	/t^{h}ɔŋ$_{55}$/	soup
58	草	/ts^{h}ou$_{25}$/	grass
59	鯨魚	/k^{h}iŋ$_{21}$ jy$_{21}$/	whale
60	細菌	/sɐi$_{33}$ k^{wh}ɐn$_{25}$/	germs
61	膝頭	/sɐt$_{5}$ tɐu$_{21}$/	knee
62	蕃茄	/fan$_{55}$ k^{h}ɛ$_{25}$/	tomato

cont. Appendix A (p.3 of 3)

Word list for the two sample words and 83 target words in the order of presentation

Picture No.	Traditional Chinese words (Targeted syllable)	**Phonetic transcription**	Word meaning
63	刷牙	/ts^{h}at$_{3}$ ŋa$_{21}$/	brushing teeth
64	曲奇	/k^{h}uk$_{5}$ k^{h}ei$_{21}$/	cookies
65	地拖	/tei$_{22}$ t^{h}ɔ$_{55}$/	Mop
66	鎚仔	/ts^{h}ɵy$_{21}$ tsɐi$_{25}$/	hammer
67	太陽	/t^{h}ai$_{33}$ jœŋ$_{21}$/	sun
68	機場	/kei$_{55}$ ts^{h}œŋ$_{21}$/	airport
69	鬚刨	/sou$_{55}$ p^{h}au$_{25}$/	shaver
70	熨斗	/t^{h}ɔŋ$_{33}$ tɐu$_{25}$/	iron
71	橙	/ts^{h}aŋ$_{25}$/	orange
72	喇叭	/la$_{33}$ pa$_{55}$/	horn
73	拳頭	/k^{h}yn$_{21}$ t^{h}ɐu$_{21}$/	fist
74	叉燒	/ts^{h}a$_{55}$ siu$_{55}$/	Chinese pork
75	兔仔	/t^{h}ou$_{33}$ tsɐi$_{25}$/	rabbit
76	彈琴	/t^{h}an$_{21}$ k^{h}ɐm$_{21}$/	play piano
77	甲蟲	/kap$_{3}$ ts^{h}uŋ$_{21}$/	ladybird
78	頭盔	/t^{h}ɐu$_{21}$ k^{wh}ɐi$_{55}$/	helmet
79	匙羹	/ts^{h}i$_{21}$ kɐ ŋ $_{55}$/	spoon
80	足球	/tsuk$_{5}$ kɐu$_{21}$/	football
81	火柴	/fɔ$_{25}$ ts^{h}ai$_{21}$/	match
82	跨欄	/k^{wh}a$_{55}$ lan$_{21}$/	hurdle
83	婆婆	/p^{h}ɔ$_{21}$ p^{h}ɔ$_{25}$/	old lady

Appendix B

Phonological process analysis form

	p	t	k	ts	kw	p^h	t^h	k^h	ts^h	kw^h
Deletion										
Fronting										
Backing (unusual)										
Labiolization										
Stopping										
delabilization										
Affrication										
Deaspiration										
Aspiration										
Gliding										
Frication										
Others:										

The **Bold** items are the phonological processes demonstrated by over 40% of subjects with hearing loss in the study of Dodd & So (1994).

Appendix Ca Parent Consent Form (English Version)

Parent/Guardian Consent Form

Date__________________

Dear Parents,

I am Year 4 student of Division of Speech and Hearing Sciences at the University of Hong Kong. I am conducting a research project on comparing hearing aid and cochlear implant on phonological development. Your child is invited to participate in the research project.

The title of the research project is "**Production of Aspirated Phonemes in Cantonese-Speaking Children with Cochlear Implants or Hearing Aids.**" The study is to investigate and compare the production ability of aspirated phonemes in hearing-impaired children with cochlear implant or hearing aids. Children who participate in this research would be invited to name 90 pictures to the researcher in a single testing session (20 minutes).

The testing session would be audio-taped. The recording could be reviewed by you at any time and erased entirely upon request. Your child may withdraw from the study at any time without any consequences and the respective audio-record(s) would be erased. Your child will receive a small gift for participation. Please complete the reply slip below to indicate whether you would allow your child to participate in the above research projects soon. Participation is entirely voluntary, and all information obtained will be used for research purposes only. If you have any questions about the research, please feel free to contact **Iris Pang (96355512; cattle@hkusua.hku.hk)**. If you want to know more about the rights as a research participant, please contact the Human Research Ethics Committee for Non-Clinical Faculties, the University of Hong Kong (2241-5267).

Your help is very much appreciated.

Yours sincerely,

____

Pang Cheuk Wing, Iris
Division of Speech and Hearing Sciences
The University of Hong Kong

Reply Slip

Student Name: ________________________ Class: ______ Class No.:_____

I ** will / will not give permission for my child to participate in the above research project.
(** Please delete if inappropriate.)

Parent Name: ______________________

Parent Signature:__________________

Date:____________________________

Appendix Cb　Parent Consent Form (Chinese Version)

家長/監護人同意信

日期:______________

致家長

本人是香港大學言語及聽覺科學系四年級學生彭卓穎。 本人正進行有關人工耳蝸與助聽器對於語音發展之比較的學術研究。　現邀請　貴子弟參與此項研究計劃：

研究計劃標題為： 以廣東話為母語並佩戴人工耳蝸或助聽器的小朋友的送氣聲發音能力。 這項研究旨在調查和比較聽力障礙並佩戴人工耳蝸或助聽器的小朋友的送氣聲發音能力。 參與是次研究的小朋友需要向研究人員說出不同圖畫的名稱 (大約需時 20 分鐘)。

研究過程會被錄音。　閣下可於任何時候要求檢閱或完全地刪除錄音聲帶。 貴子弟可於任何時候退出是次研究並不會附帶任何後果，而相關的錄音帶亦會被刪除。　貴子弟會於完成研究過程後收到小禮物一份。　是次研究計劃屬自願性參與，而所有資料只會用作研究用途。 希望　閣下能對此研究給予支持，讓　貴子弟參與其中。 請填妥以下回條以表示　閣下容許　貴子弟參與上述的研究計劃。 如有對是次研究的任何查詢， 歡迎聯絡**彭卓穎(96355512; cattle@hkusua.hku.hk)** 。 如　閣下想知道更多有關研究參與者的權益，請聯絡香港大學非臨床研究操守委員會(2241-5267)。
感謝 閣下及 貴子弟的參與

此致

____

彭卓穎
香港大學
言語及聽覺科學系

回條

學生姓名：______________________　　班級：______　　學號：_______

本人　** 同意 / 不同意　子弟參與是項研究。

(**請刪去不適用者)

家長姓名：__________________________

家長簽署：__________________________

日　期：__________________________

Appendix D   Case History Form

Name 姓名: Date of birth 出生日期: / / 日 月 年 Gender 性別: 男 / 女 Phone No.聯絡電話:	Centre attending 中心名稱: Date of admission 入學日期: / / 日 月 年
Address 住址:	

PTA(unmasked) air conduction first response level 純音氣導最低反應程度

		500Hz	1000Hz	2000Hz	4000Hz
Unaided	Right ear 右耳				
	Left ear 左耳				
Aided	Right ear 右耳				
	Left ear 左耳				

助聽設備類型: (右耳)人工耳蝸 / 助聽器 (類型:)/ 不適用
(左耳) 人工耳蝸 / 助聽器 (類型:)/ 不適用

如果孩子配帶人工耳蝸，請回答下以第 1-5 題。如果孩子配帶助聽器，請跳答第 6-9 題。

1. 孩子何時植入人工耳蝸? / /
日 月 年

2.植入人工耳蝸前，有沒有配帶助聽器? 有 / 沒有
如果有，何時開始配帶助聽器?

3. 孩子在一日中什麼時候帶上人工耳蝸的接收器?
全日□ 大半日 □ 少半日□ 間中□ 只在上課時 □ 甚少□

4. 植入人工耳蝸後，孩子有沒有接受聽覺訓練? 有 / 沒有
如果有，訓練維持了多久? 年/ 月 現在有沒有訓練? 有 / 沒有

5. 植入人工耳蝸後，孩子有沒有接受發音訓練? 有 / 沒有
如果有，訓練維持了多久? 年/ 月 現在有沒有訓練? 有 / 沒有

6. 孩子何時開始配帶助聽器? / /
日 月 年

7. 孩子在一日中什麼時候帶上並開啟助聽器?
全日□ 大半日 □ 少半日□ 間中□ 只在上課時 □ 甚少□

8. 配帶助聽器後，孩子有沒有接受聽覺訓練? 有 / 沒有
如果有，訓練維持了多久? 年/ 月 現在有沒有訓練? 有 / 沒有

9. 配帶助聽器後，孩子有沒有接受發音訓練? 有 / 沒有
如果有，訓練維持了多久? 年/ 月 現在有沒有訓練? 有 / 沒有