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Citation	
Issued Date	2007
URL	http://hdl.handle.net/10722/55482
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The effect of cochlear implant usage duration on the Cantonese phonological development of hearing impaired children

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A dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June, 30, 2007

Abstract

This study examined if longer cochlear implant (CI) experience could improve the phonological ability of the prelingually deafened Cantonese-speaking children. The phonological skills of 8 children with more than 3;06 years of CI experience, 8 children with less than 1;06 years of CI experience, and 8 hearing aid users were compared. All participants were ranged from 4;06 to 7;07 years. The participants were asked to name 31 photos and retell a story. The phonological units and the phonological processes exhibited were analyzed. The percentages of vowel correct, consonant correct and tone correct were compared statistically among 3 groups of participants. Children with long CI experience exhibited better consonants and vowels production than the children with short CI experience, whose phonological ability had no significant difference with that of hearing aid users. Therefore, longer CI experience was found to be beneficial to the phonological ability in young children.

Introduction

Multichannel cochlear implants (CI) have been available to provide auditory input to people with profound hearing loss in the recent decades. The cochlear implant prostheses convert mechanical sound energy into a coded electrical stimulus, which bypasses the damaged or missing hair cells of the cochlea and stimulates the auditory nerves directly. Auditory input is provided and therefore the cochlear implants greatly improve the speech perception of the children with profound hearing loss (Wei et al., 2000; Wu & Yang, 2003). For tone production, Mandarin-speaking CI children were found to have flat and irregular tone patterns (Xu et al., 2004). CI users had difficulties in extracting the pitch information to identify the Cantonese lexical tones, when comparing with the performance of moderately hearing-impaired control listeners (Ciocca, Francis, Aisha, & Wong, 2002). Overall, the phonological abilities of the cochlear implant users were significantly better than those of hearing aid users, provided that they have similar level of hearing loss (Law & So, 2006).

In recent years, multichannel cochlear implantation has become more prevalent among the population of prelingually profound bilateral hearing impaired children, who cannot acquire adequate speech with the help of powerful hearing aids. Moreover, the age of implantation has the trend of becoming earlier and earlier. There have been some cochlear implant surgeries conducted in children below one year old (Holt, Svirsky, Miyamoto, &

Neuburger, 2004). The main reason is the benefit of cochlear implantation. With the multichannel cochlear implantation, researches found that the auditory skills (McConkey Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004), speech perception (Gstoettner, Hamzavi, Egelierler, & Baumgartner, 2000; Wei et al., 2000; Wu & Yang, 2003), speech production (Dawson et al., 1995; Tobey et al., 1991) as well as speech intelligibility (Tobey & Hasenstab, 1991) of the CI users can be improved significantly. Moreover, it was found that when cochlear implant was fitted to a prelingually deafened child, the rate of language skills development is about the same as that of normal hearing children (Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). For the rate of speech development, it is expected that children fitted with cochlear implant can also catch up with their normal peers, as phonology and lexicon acquisition has bidirectional influences (Paul, 1998), which implies that the rate of speech development after cochlear implantation is related to language development. More importantly, it is commonly believed that longer duration of CI usage results in better speech and language development of the prelingually deafened children. This study is going to explore if longer CI experience can really improve the phonological ability of the prelingually deafened children more significantly. The phonological ability will be described in terms of the phonetic repertoire as well as the phonological processes.

The age of cochlear implantation does affect the language and speech proficiency of young children (Svirsky, Teoh, & Neuburger, 2004). The expressive language growth in children implanted as infants was found to be more rapid than those implanted as toddlers, some even demonstrated age-appropriate expressive language (Hammes et al., 2002; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005). Holt et al. (2004) studied the effect of age at implantation, and thus the duration of CI usage, on spoken word recognition. It was found that children implanted at earlier age and with longer CI experience, showed advantages in spoken word recognition. Besides, a study found that children with CI fitted between two and five years old have better speech perception than children who have CI fitted after age five (Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997). Another study also showed the benefits in speech perception and language brought by cochlear implantation before age two (Svirsky et al., 2004) . For Mardarin-speaking profoundly deafened children, there is also a negative correlation between the age at implantation and the improvement in speech perception after implantation (Wu & Yang, 2003). Thus, for children of the same age, the longer the CI experience, the more benefit is to speech perception. As speech perception is the prerequisite of speech production, the speech production of the children with earlier and longer CI experience is better than that of the children with later and shorter CI usage (Brackett & Zara, 1998; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003), with the additional benefits of a burst of growth in vocabularies (Connor, Craig, Raudenbush, Heavner, &

Zwolan, 2006). Besides, the age and the duration of fitting CI were significantly related to the speech intelligibility on English speaking children (Niparko & Geers, 2004). This indicated that the conduction of CI surgery is time-sensitive. Niparko & Geers (2004) found that more hearing impaired children who received cochlear implantation at age two could catch up with the normal hearing age-matched peers in the aspects of speech and language skills than the children implanted at age four. Therefore, it is believed that the speech and language skills are affected by the age and the duration of using CI. In this study, we compared the phonological units and the phonological processes of children with CI experiences of two years and four years.

Furthermore, there is lack of literature concerning the effect of duration of CI usage on Cantonese phonological development. This area should be investigated because the phonological system of Cantonese is different from that of European languages, such as English. Moreover, Cantonese is one of the Chinese dialects and spoken by over 40 million people all over the world (Bauer & Benedict, 1997). Cantonese is a tonal language, which means that the word meaning can be changed by changing the tone of a syllable, and it is phonologically contrastive. The six contrastive tones are high level_{55}, high rise_{25}, midlevel_{33}, low fall_{21}, low rise_{23} and low level_{22}. The three entering tones are high entering_{5}, mid entering_{3} and low entering_{2},which are allotones of the three level tones and delivered with final stops, /-p/, /-t/ and /-k/. Cantonese has its own phonotactic structure, the number of contrastive consonants and aspiration contrasts. There are 19 initial consonants, 6 final consonants, as well as 11 monophthongs and 11 diphthongs in Cantonese. The syllable structures of Cantonese include V, CV, VC, CVC or syllabic nasals- /m/ and /ɴ/, in which a vowel is an obligatory segment. Appendix 1 summarizes all the characteristics and phonotactic structure of Cantonese. Appendix 2 shows the age of emergence of consonant phonemes for Cantonese-speaking children (So & Dodd, 1995).

This research will examine the benefits of longer CI experience in terms of phonological development. This will help clinicians and families realize more about the time-sensitive nature of the conduction of CI surgery (Niparko & Geers, 2004). For children of the same age, the longer CI experience means the younger age of implantation. Cochlear implantation at early ages carries great potential risk, due to the complexity of accurate determination of hearing levels and hearing aid benefit, as well as the anesthetic complication, which are the special consideration for the children under 12 months of age (Tomblin et al., 2005; Young, 2002). Given the potential benefits, is it worth taking the risks to receive early cochlear implantation? This study is going to give insight to this question.

Research questions/ Hypothesis:

1. It was hypothesized that children with longer CI experience would have better

phonological ability and fewer phonological processes than children with shorter CI experience. The speech production performance is influenced by the length of CI usage (Tobey et al., 2003). With longer duration of improved access to the environmental sounds, the Cantonese phonological development is supposed to be better.

2. The children with longer duration of CI usage have phonological abilities comparable to the age-matched normal hearing peers. While the children with shorter CI experience have phonological abilities better than the children using conventional hearing aids (Law & So, 2006), and both of them have not yet caught up with the age-matched normal peers in terms of phonological development.
3. It was hypothesized that the children with shorter CI experience would have higher percentage of unusual rules, such as initial consonant deletion and backing, than the children longer CI experience.

Method

Participants

There were three groups of participants, each with eight Cantonese-speaking children with congenital, bilateral profound hearing loss, in which the pure-tone average thresholds (PTA) in the better ear is greater then 90 dB HL at 0.5, 1.0, 2.0 kHz. The first two groups of the participants were fitted with cochlear implants (Nucleus 24 ESPrit 3G). The first group had at least 3;06 years of experience (CI group 1), while the second group had less than 18 months of CI experience (CI group 2). The third group of participants had conventional hearing aids (HA group). The age of the 14 boys and 10 girls ranged from 4;06 to 7;07 years. The three groups of participants were well matched in terms of chronological age and years of aided experience, including the duration of hearing aid and/or CI usage. The mean age of the CI group 1 (with longer CI experience) was 6;3 years(SD=0.53) and that of CI group 2 (with shorter CI experience) was 5;9 years (SD=0.87), while that of HA group was 5;10 years (SD=0.51). The mean number of years of aided experience (including CI and HA) of CI group 1 was 4;8 years (SD=0.89) and that of the CI group 2 (with shorter CI experience) was 4;4 years (SD=0.98). The mean aided experience of the HA group was 4;6 years (SD= 0.84). The range of years of aided experience were ranged from 2;11 to 6;00 years.

All participants had homogeneous language input (Cantonese dominant), multiword utterances and no known complications other than deafness, as reported by the parents and medical reports. All children were full-time hearing aid or cochlear implant users.

The participants attended mainstream kindergartens, three hours per day, for 5 days per week. All participants received speech training and auditory discrimination from teachers in the child care centers or kindergartens. Table 1 summarized the demographic information for the participants.

Table 1. Descriptive information for participants

P	CA	Sex	Unaided level dB HTL PTA (R)	Unaided level dB HTL PTA (L)	Aided level dB HTL PTA (R)	Aided level dB HTL PTA (L)	Years of training	Age of onset	Aided experience* HA+CI (CI)
CI group 1									
A	6;11	F	117	118	65	38	4;01	c	5;00 (3;11)
B	6;10	F	105	113	43	Binaural[a]	4;05	c	5;10 (4;11)
C	6;06	M	108	120	35	55	1;03	1;00	4;11 (4;05)
D	6;06	M	127	132	38	Binaural[a]	1;07	c	5;00 (5;00)
E	6;04	M	103	117	37	Binaural[a]	5;03	c	5;05 (4;11)
F	6;03	M	104	108	46	Binaural[a]	4;03	c	4;08 (4;05)
G	6;00	F	110	113	48	Binaural[a]	3;05	0;01	3;08 (3;06)
H	5;03	F	121	107	47	36	3;03	c	3;09 (3;06)
CI group 2									
I	7;01	M	108	101	50	50	3.2	c	6;00 (1;06)
J	6;07	M	90	115	38	43	3.3	0;08	5;05 (1;06)
K	6;05	M	106	117	48	53	0;09	1;05	4;08 (0;05)
L	5;04	F	112	105	43	Binaural[a]	3;06	1;01	3;05 (1;00)
M	5;08	F	103	92	41	Binaural[a]	1;04	1;05	4;05 (1;06)
N	5;03	M	118	120	40	N/A	1;05	1;00	3;05 (1;05)
O	5;01	F	111	113	60	58	4;00	c	4;03 (0;10)
P	4;07	F	122	Binaural	53	Binaural[a]	2;00	c	3;04 (1;09)
HA group									
Q	6;06	M	95	Binaural	53	Binaural[b]	3;09	1;10	5;07
R	6;03	M	85	123	47	Binaural[b]	3;03	c	5;00
S	6;03	M	120	120	45	Binaural[b]	3;09	c	5;03
T	5;08	F	105	102	35	Binaural[b]	3;09	0;08	4;09
U	5;07	M	90	100	40	43	4;02	1;05	4;05
V	5;05	M	108	101	50	50	2;05	c	4;02
W	5;02	M	105	110	43	47	2;00	1;05	4;00
X	4;10	M	99	104	38	42	1;09	c	2;11

Note: P=participants; CA=chronological age; M=male; F=female; PTA: pure tone average of thresholds at 500, 1k, and 2kHz; R=right; L=left; HTL=hearing threshold ; c=congenital; HA=hearing aid; CI=cochlear implant

*Aided experience: number of year using HA and/or CI; [a] CI+HA ; [b] 2HAs

Procedure

The phonological abilities of the participants were assessed in a quiet room. Cantonese Segmental Phonological Test (CSPT, (So, 1993) was administered in live voice to assess the phonological ability of the children. The participants were asked to name 31 photos and retell a story illustrated by five photographs. The 31 words in this test consisted of all initial and final consonants, vowels, diphthongs, tones as well as syllabic structures (Appendix 3). The photos used in this test were all color photographs of real objects with a dimension of 3x5 inches. Each session lasted for about 30 minutes. The speech samples obtained were recorded by MSC DM-HA128 MP3 digital player, which was placed at the children's chest level.

Data analysis

The speech samples of both single-word and spontaneous speech were transcribed. The phonemic repertoires and the phonological processes of the participants were found.

A phoneme, which is defined as the smallest distinctive unit that differentiates between words, was regarded as having been acquired by the child if it was used twice, correctly or consistently as a substitute for another phoneme.

Besides, the error patterns of vowels, diphthongs, syllable-initial consonants, syllable-final consonants and tone were analyzed by linear approach (Oller & Kelly, 1974). An error pattern is considered to be adopted if there were at least two occurrences of the error in different lexical items and without opposing examples.

To determine the inter-rater transcription reliability, a sample of ten percent of the data was transcribed independently by the principal investigator and by another transcriber, a final year speech therapy student. The transcriptions were then compared. Also, intra-rater reliability was evaluated by re-transcribing ten percent of the data by the principal investigator about one week after the first transcription. The inter-rater and intra-rater reliabilities were 87% and 93% respectively. This was calculated by dividing the number of agreements of the transcriptions of the speech sounds by the total number of sounds produced and multiplying by 100.

The percentages of vowel, consonant and tone correctly produced by the three groups were analyzed statistically by using Analysis of Variance (ANOVA) to determine if there were any significant group differences.

Result

Phonological Units

Table 2 shows the syllable-initial and syllable-final consonants missing from the phonetic inventories of the three groups of participants. It indicates that the consonant repertoires of CI group 1, except participant F, were generally more complete than that of CI group 2, in which the participants had less CI experience. While the completeness of the consonant repertoires was similar in CI group 2 and HA group.

Table 2. Syllable-initial and syllable-final consonants missing from children's speech transcript.

P	Syllable-initial consonants	Syllable-final consonants
CI group 1[a]		
A	n, s	n
B	k^{h}, n, N, s, ts, ts^{h}, k^{w}	n
C	N	n, N
D	p^{h}, n, f, s	m, N, p, t
E	k^{wh}	
F	p, p^{h}, t^{h}, k, k^{h}, n, N, f, s, ts^{h}, k^{w}, k^{wh}	p
G	k, n, N, k^{wh}	m, n, N, p, t
H	n, N, s, l	
CI group 2[b]		
I	t, n, f, ts, ts^{h}, k^{w}, k^{wh}	
J	p^{h}, n, N, s, k^{wh}	m, p, t
K	p^{h}, t^{h}, k, k^{h}, n, N, s, l, ts, ts^{h}, k^{w}, k^{wh}	N
L	s, ts^{h}	
M	N, f, s, ts^{h}	n, t
N	f, s, ts^{h}, k^{w}, k^{wh}	
O	p^{h}, n, N, f, s, ts, ts^{h}	n
P	k^{h}, n, N, f, s, l, ts, ts^{h}, k^{wh}	m, n, N, p
HA group		
Q	t^{h}, ts, k^{wh}	m, N, p
R	p, p^{h}, t^{h}, k^{h}, n, N, s, ts, ts^{h}, k^{w}, k^{wh}	m
S	m, f, s, ts, ts^{h}	N
T	n. N, f, s, ts, k^{wh}	t
U	k^{h}, n, f, s, l, ts, ts^{h}	
V	p^{h}, f, s, l, ts, ts^{h}, k^{wh}	
W	t^{h}, f, s, l, ts, ts^{h}, k^{wh}	N, t
X	k^{h}, n, j, f, s, ts^{h}, k^{wh}	

a: Participants with cochlear implant experience more than 3;06 years.

b : Participants with cochlear implant experience less than 1;06 years.

There are total 1,608 occurrences of syllable-initial consonants in the transcripts of all the participants. The bands of percentage of errors of the initial consonants of each group were classified and are presented in table 3. Across all the groups, /s/ had the highest percentage of error, while /p/, /m/, /w/, /j/, /t/, /k/ and /h/ had the lowest percentage of error.

Table 3. The percentage of error for each initial consonant produced by the participants.

% error	Syllable-initial consonants		
	CI group 1	CI group 2	HA group
81-90			s
71-80			
61-70	s	s, ts, ts^h	ts, ts^h
51-60	n	k^{wh}	k^{wh}
41-50	N	n, N, f	t^h
31-40	ts^h	k^w	k^h, n, f
21-30	k^{wh}		
11-20	p^h, t^h, k, k^h, f, l, ts, k^w	p^h, t^h, k^h, h, l	k^w, N, l, k^w
1-10	p, m	t, k	p, w, j
0	t, w, j, h	p, m, w, j	t, k, m, h

For syllable final consonants, final /n/ and /N/ deletion were the most common errors among the three groups. Other final consonants /m/, /p/, /t/ and /k/ were acquired by most participants.

CI group 2 and the HA group exhibited higher percentage of vowel errors than the CI group 1, in which most participants' vowel inventories were complete. Errors exhibited by the CI group 2 were mainly simplification and substitution of diphthongs; while that of HA group were predominated by substitution of single vowel.

When it comes to tone production, all subjects in CI group 1 except participant F showed complete inventories. Generally, CI group 1 exhibited less tone errors than CI group 2, while CI group 2 had less tone errors than HA group.

Phonological processes

The phonological processes made by all the three groups of participants are shown in Table 4. The first five rules in Table 4 were adopted by more than 10% of a normative sample of normal hearing Cantonese-speaking children (So & Dodd, 1995). They were fronting (e.g. /k^{h}6m$_{21}$/→ [t^{h}6m$_{21}$]), stopping (e.g. /s6i$_{25}$/→[t6i$_{25}$]), deaspiration (e.g. /p^{h}iN$_{21}$/→ [piN$_{21}$]), affrication (e.g. /s6i$_{25}$/→ [ts6i$_{25}$]), and delabilization (/k^{w}O$_{25}$/→[kO$_{25}$]). The next six phonological processes were seldom used by the children with normal phonological development. The unusual rules were initial consonant deletion (e.g. /si$_{25}$/→[i$_{25}$]) , frication (e.g. /ŋan$_{23}$/→[han$_{23}$]) , gliding (e.g. /lei$_{22}$/→[jei$_{22}$]), aspiration (e.g. /k6i$_{55}$/→[k^{h}6i$_{55}$]), nasalization (e.g. /lei$_{22}$/→[nei$_{22}$]) and backing (e.g. /tou$_{55}$/→[kou$_{55}$]).

For syllable-final consonants, there were one developmental rule: Final consonant deletion, and two unusual rules: backing and stopping.

Table 4. Phonological processes applicable to all participants.

Phonological	CI group 1								CI group 2								HA group							
processes	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Initial consonants																								
Developmental rules																								
Fronting						*	*					*		*		*		*						
Stopping		*		*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Deaspiration						*				*				*		*		*	*	*			*	*
Affrication				*		*		*			*		*											*
Labialization		*				*	*		*					*				*						
Unusual rules																								
ICD[++]														*	*									
Frication										*								*						
Gliding						*		*		*						*								
Aspiration									*															
Nasalization							*																	
Backing						*	*																	
Final consonants																								
Developmental rules																								
FCD[+++]			*	*		*	*										*							
Unusual rules																								
Backing						*												*						
Stopping										*														

Note: * means the presence of rules; [++] ICD=Initial consonant deletion; [+++] FCD=inal consonant deletion

Quantitative Error Analyses

Comparison of groups' percentage correct for consonants, vowels, and tones. Table 5 shows the percentage of words containing correct consonants, vowels, and tones made by the three groups. Repeated measures analysis of variance (Group X PCC, PVC, PTC) showed a statistically significant main effect of the group, $F (2, 21) = 10.405$, $p<0.05$. While the main effect of the three conditions (PCC, PVC and PTC) was also found to be statistically significant, $F (2, 69) = 80.68$, $p<0.05$. Post hoc testing found that that the vowel and tone production of the participant was significantly better than their consonant production.

For interaction effect, the simple main effects of group at each of the three levels (PCC, PVC and PTC) of the condition were analyzed. The simple main effect of group was statistically significant for consonant production, $F(2,21)=9.954$, $p<.05$, but not significant for PVC and PTC. This revealed that only the development of consonant production was affected by the duration of using CI and the instrument fitted (CI and HA). The post hoc testing found that the PCC of CI group 1 and CI group 2 and that of CI group 1 and HA group exhibited statistically significant differences, but not that between CI group 2 and HA group. For PVC, only CI group 1 and CI group 2 showed significant difference. That means the consonant and vowel acquisition was benefited by the longer CI experience (>3;06), the short CI experience (<1;06) did not ensure a better consonant development than HA users. The tone acquisition was not affected by either the duration of CI usage or the instrument fitted.

Table 5. Percentage of correct consonants, vowels, and tones.

Measurement	P	Total no. of words	PCC %	PVC%	PTC%
CI experience > 3;06	A	67	89.60	100.00	100.00
(CI group 1)	B	67	82.10	100.00	98.50
	C	67	92.50	94.00	100.00
	D	67	71.60	97.00	98.50
	E	67	98.50	100.00	100.00
	F	67	42.00	98.50	100.00
	G	68	70.60	97.50	83.80
	H	68	75.00	100.00	98.50
Mean			77.74	98.38	97.41
SD			17.66	2.15	5.55
CI experience < 1;06	I	67	55.10	97.00	98.50
(CI group 2)	G	67	42.10	92.50	95.50
	K	67	61.20	94.00	100.00
	L	67	77.80	98.60	90.30
	M	67	50.60	95.50	100.00
	N	67	58.40	100.00	75.00
	O	67	54.60	94.00	100.00
	P	67	52.70	91.00	91.00
Mean			56.56	95.33	93.79
SD			10.29	3.06	8.01
HA group	Q	67	43.20	98.50	83.60
	R	67	52.50	100.00	100.00
	S	67	43.10	98.5	100.00
	T	67	48.70	89.60	98.50
	U	67	63.20	100.00	97.00
	V	67	48.40	98.50	88.10
	W	67	63.20	97.00	92.50
	X	67	33.10	100.00	100.00
Mean			49.43	97.76	94.96
SD			10.25	3.46	6.27

Discussion

The phonological abilities of the 24 Cantonese-speaking children with bilateral profound hearing loss with cochlear implants or conventional hearing aids were described in terms of the productions of consonants, vowels and tones and phonological processes. Besides, the percentages of correct consonants, vowels and tones were also compared statistically to analyze the phonological abilities of the participants. Results showed that the children with longer duration of cochlear implant usage had a better phonological development than the children with shorter duration of cochlear implant usage and the conventional hearing aids users.

Phonological Units

It was found that the consonant repertoire of CI group 1 (with longer duration of cochlear implant usage) was generally more complete than that of CI group 2 as well as that of HA group, while that of CI group 2 and HA group was similar. When investigating the percentage of error for the initial consonants, CI group 1 only exhibited maximum 63% of error for the initial /s/, while other phonemes had less percentage of errors. For CI group 2, there were more phonemes having 41-70% of errors than group 1. This revealed that the children with longer duration of cochlear implant usage exhibited less phonological errors. Moreover, only the /s/ of the HA group showed 81-90% of errors, which was the highest among three groups.

CI group 2 and HA group did show some similar phonological patterns. The /ts/, /ts^{h}/ as well as /k^{wh}/ of both groups also fell into the same bands of percentages, which were much higher than the corresponding percentages of CI group 1. This indicated that there is not much difference in the phonological production abilities between the children with short duration of cochlear implant usage and those using conventional hearing aids. While the CI group 1 showed the most outstanding phonological abilities among three groups.

Across all the groups, /s/ was most likely to be missing from the children's consonant repertoire. While /ts/ and /ts^{h}/ were more likely to be missing in CI group 2 and HA group but not CI group1. This corresponds to the fact that /s/, /ts/ and /ts^{h}/ are acquired after 4 years old in 90% of the children (So & Dodd, 1995). /t/, /p/, /j/, /w/ and /m/ were present in the consonant repertoire of most participants. These sounds are acquired by age 3;0 in normal hearing Cantonese-speaking children (So & Dodd, 1995). Therefore, the order of phonological acquisition of the profoundly hearing impaired children is similar to the trend of typical phonological development. Besides, another reason for the higher accuracy of /t/, /p/, m/ is that they are more visible and have more anterior place of articulation than back consonants, such as /k/ and /k^{w}/. As the hearing impaired children can use the visual cues to learn the front consonants, the front consonants should be produced with higher percentage of accuracy than the consonants occurring in the middle or posterior regions of the mouth (Dawson et al., 1995).

On the other hand, there were fewer errors in unaspirated stops (/t/, /p/, /k/) than their aspirated counterparts (/t^h/, /p^h/, /k^h/). This phenomenon followed the order of normal phonological development, in which the aspirated counterparts were acquired at the later stage than the unaspirated counterparts (So & Dodd, 1995). Another reason for this phenomenon is that the abnormal timing relations of aspiration distinction in speech production is a significant problem in the profoundly deafened children (Tobey et al., 1991).

The vowel and tone production was significantly better than consonant production in all the three groups. This supports the view that hearing impaired children generally had more consonants error than vowel and tone errors (Khouw, 1994).

For vowel production, except participant P in CI group 2, who had one missing diphthong /ai/, it was found that all participants had complete vowel inventories. The better production of vowels may be due to the fact that vowels last longer in production and are more intense than consonants and thus can be more easily perceived and acquired by the hearing impaired children.

Although the tone inventory was completed in all the participants, it should be noted that there were some tone substitutions. The performance of tone production was generally poorer than that of the vowel production, but there is no significant difference between the percentages of tone and vowel errors. There is no predominant substitution of tones. The completeness of the tone inventory was due to the tonal nature of Cantonese and the heavy functional load of tones. It is important to produce the Cantonese words with correct tones in order to produce the target word correctly. Since all participants had complete tone inventory, the analysis of tone errors was not emphasized much here.

Phonological Processes

All participants, except participants A and E in CI group 1, showed phonological processes in syllable initial and syllable final consonants. All three groups also adopted stopping as the most common rule. /s/→[t] was exhibited in all participants exhibiting stopping. This corresponds to the result that the percentage of errors of /s/ was the highest. Other common errors in stopping was /f/→[p], /ts/→[t] and /ts^h/→[t^h]. This reveals that the acquisition of high frequency sounds is particularly difficult for hearing impaired children (Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004). The predominance of stopping is due to the reason that it is the most frequent developmental rules adopted by Cantonese-speaking hearing impaired children (Dodd & So, 1994). The second most predominant rule exhibited was deaspiration. This corresponds to the findings that the aspirated phonemes found to have less errors than their unaspirated counterparts, because the aspirated sounds tended to be substituted, e.g. $/p^h/ \rightarrow [p]$.

Unusual rules, which were atypical in the normal phonological development of hearing Cantonese-speaking children, were also found to be present in the participants' speech transcripts. However, the developmental rules were more predominate than the unusual rules in all three groups. The most common abnormal rules adopted was gliding (e.g. $/lei_{22}/ \rightarrow [jei_{22}]$). Other rules (i.e. initial consonant deletion, aspiration, nasalization, backing, final consonant stopping and final consonant backing) were adopted by one to two participants only. The developmental rules was dominant, because the phonological processes and rules used by Cantonese-speaking hearing impaired children are similar to those of normally hearing children (Law & So, 2006).

The number and types of phonological processes used by the participants was more or less the same among the three groups of participants. However, CI group 1 had the highest percentage of accuracy in consonant production, since the rules were applied to limited phonemes only. On the other hand, CI group 2 and HA group had lower percentage consonant correct, as the rules were exhibited by a wider range of phonemes. This is the reason that the PCC of CI group 1 is significantly different to HA group, while that of CI group 2 is not.

For vowel and tone errors, participants in CI group 2 and HA groups exhibited more vowel and tone errors than CI group 1. The most common pattern of vowel error of CI group

2 was the substitution of single vowel, e.g. /wun$_{25}$/→ [wan$_{25}$]. While the participants in HA group exhibited simplification of diphthong (e.g. /tsau$_{55}$/→[tsa$_{55}$]), substitution of diphthong (e.g. /tou$_{55}$/→ [tai$_{55}$]) as well as the substitution of single vowel with similar percentages. The indicated that conventional hearing aid users had more vowel errors than cochlear implant users. And longer duration of CI usage does also facilitate the acquisition of vowels. In terms of tone production, it was generally performed poorer than the vowel production, when comparing the means of percentage of correct productions. Some hearing impaired participants showed certain degree of tone production errors, no matter in which group. Therefore, tone production is poorly affected by the profound hearing loss.

The CI group 1 children still could not catch up the phonological abilities with the normal peers, who should have acquired a complete phonetic inventory at age five (So & Dodd, 1995). The result indicated that even the children with more than 3;06 years of CI experience showed certain degree of consonant, vowel and tone errors.

Conclusion

This study analyzed the phonological abilities of the Cantonese-speaking children with profound hearing loss in terms of the phonological units and the phonological processes adopted. It was hypothesized that the longer duration of CI usage would benefit the phonological development of the Cantonese-speaking children with hearing impairment. For children with more than three and a half years of CI usage, better phonological abilities including the consonants and vowels production were exhibited, when comparing with the children having less than one and a half years of CI usage.

Besides, it was predicted that even the hearing-impaired children with short duration of CI usage would show better performance in phonology than the conventional hearing aids users. However, it was found that the short CI experience does not ensure the hearing impaired children to have better phonological abilities than conventional hearing aids users, even though some of the participants with only one year of CI usage achieved consonant production skills commensurate with the children with longer CI usage. Furthermore, all the three groups exhibited developmental and unusual phonological processes.

Finally, further research focusing on the effect of the age and duration of cochlear implantation in terms of language and reading skills of the Cantonese-speaking children will help the professionals and the families of hearing-impaired children to realize more about the benefit of cochlear implantation, and thus deciding at what time the children should receive cochlear implant surgery.

Limitation of study

First, the small number of subjects limits the generalization of the results. A larger number of subjects should be recruited in an ideal study. Moreover, the centers of training attended by the subjects were not controlled, so the frequency and the quality of the speech training were not under controlled.

This study focused on the speech production skills of the participants instead of speech perception ability. Therefore, further study should also put emphasis on the speech perception skills of the cochlear implant users and hearing aid users, so more complete pictures of the phonological abilities of the hearing impaired children and the relationship between the speech perception and production can be investigated.

Acknowledgements

I would like to express my grateful thanks to my dissertation supervisor Dr. Lydia So for her support, precious advice, comment and guidance for this study.

Besides, I would like to give my deepest appreciation to the principals and staffs in Bradbury Special Child Care Centre, Sheung Tak Special Child Care Centre and Suen Mei Speech and Hearing Centre and Ms. Kathy Lee from the Chinese University for their arrangements in helping me to collect the data needed.

Moreover, I have to thank all the subjects and their families for their participation. Finally, I would like to show my sincere thanks to Ms. Isabella Fung, Ms Charlotte Yuen and Ms Angela Lee for their care and support throughout the whole process.

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Appendix

Appendix 1. Cantonese Phonology

Structure	Cantonese
Tones	6 contrasting and 3 entering
Initial consonants	p p^h t t^h k k^h
	m n N
	f s h
	w j
	l
	ts ts^h
	k^w k^{wh}
Final consonants	p t k
	m n N
Vowels- Monophthongs	i y I e 9 8 a 6 O u U
- Diphthongs	ai 6i au ei 8y Oi ui iu ou eu 6u
Syllable structure	(C)V(C)

Appendix 2. Age of emergence of consonant phonemes for Cantonese-speaking children

Age	Consonant phonemes (90% Criterion)
2;0-2;5	n p t j
2;6-3;0	m w N
3;0-3;5	h k
3;5-4;0	l p^h t^h k^h k^w
4;0-4;5	f s ts
4;6-5;0	ts^h k^{wh}

Note: All vowels and tones are acquired by 90% of children by age two (So & Dodd, 1995).

Appendix 3. Items in Cantonese Segmental Phonology test (So, 1993).

1. /Nan$_{23}$/	eye	17. /mau$_{55}$/	cat
2. /m6t$_{2}$/	sock	18. /jy$_{25}$/	fish
3. /lei$_{22}$/	tongue	19. /ts^{h}ON$_{21}$/	bed
4. /n6u$_{25}$/	button	20. /pa$_{55}$ si$_{25}$/	bus
5. /pE$_{25}$/	biscuit	21. /ap$_{3}$/	duck
6. /s2I$_{25}$/	water	22. /k^{w}6i$_{55}$/	tortoise
7. /k^{h}6m$_{21}$/	piano	23. /fai$_{33}$ tsi$_{25}$/	chopsticks
8. /wun$_{25}$/	bowl	24. /hai$_{21}$/	shoe
9. /tsiu$_{55}$/	banana	25. /tin$_{22}$ wa$_{25}$/	telephone
10. /k6i$_{55}$/	hen	26. /t^{h}ON$_{25}$/	candy
11. /t^{h}Oi$_{25}$/	table	27. /k9k$_{3}$ pan$_{25}$/	sole
12. /k^{wh}6n$_{21}$/	skirt	28. /pui$_{25}$/	cup
13. /fa$_{55}$/	flower	29. /s6i$_{25}$ min$_{22}$/	wash face
14. /p^{h}IN$_{21}$ k^{w}O$_{25}$/	apple	30. /tsUk$_{5}$/	porridge
15. /s6i$_{55}$ k^{w}a$_{55}$/	watermelon	31. /ji$_{23}$/	ear
16. /tou$_{55}$/	knife		