Phonological abilities of Cantonese-speaking hearing-impaired children with cochlear implants or hearing aids.

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Abstract

This paper reports a detailed description of the phonological abilities of fourteen matched group of prelingual profound bilateral hearing impaired children (ages 5;01-6;04) with cochlear implants or hearing aids. The phonological abilities were described in terms of subjects' phonological units and phonological processes used. All except one subject had incomplete phonetic repertories and all subjects showed complete vowel and tone inventories. The phonological rules used include both developmental rules (e.g., stopping, fronting, deaspiration and cluster reduction) and non-developmental rules (e.g., backing and initial consonant deletion). Subjects' perception of single words was assessed by test of words that include tonal, segmental and semantic distracters. Subjects chose the target most often while the most frequent chosen distracters were the tonal distracters. Comparison of phonological abilities of cochlear implant users and hearing aid users was made and it was found that the percentage correct in consonant production of cochlear implant users was significantly higher than that of hearing aid users, although no significant difference was found for percentage correct in vowel and tone production.

Introduction

Historically, children who are born with profound hearing loss in the early stages of spoken language development find it difficult to hear and understand speech. The development and maintenance of intelligible speech have even been a considerable challenge for children with profound hearing loss, even with a powerful hearing aid. These children frequently have delayed or disordered speech production patterns and exhibit a broad range of deviant speech abilities with reduced phonetic repertories containing multiple errors and substitutions (Tobey, 1993). These findings have been well documented over a long period of time and in a wide variety of studies including those of Levitt, McGarr and Geffner (1987) and many others.

Speech ability acquired by children with hearing loss, especially with profound hearing-impairment, may not allow them to engage comfortably in ordinary communication. Their hearing loss adversely affects their perception of speech sounds and this, in turn, leads to problems in their acquisition of these speech sounds, resulting in errors in their speech. Lack of auditory feedback also has profound effects on the speech production characteristics of children with profound hearing loss, as they have difficulties in self-monitoring their own speech production. As a result, reduced speech intelligibility is often reported (Osberger & McGarr, 1982).

Conventional hearing aids enable most deaf children to hear and gain access to spoken language by amplification. Previous examinations of phonological abilities in profoundly hearing-impaired Cantonese-speaking children, who used conventional hearing aid, revealed articulatory error patterns incorporating both developmental (assimilation, stopping, cluster reduction, deaspiration, affrication and /h/-deletion) and non-developmental (frication and initial consonant deletion) phonological processes (So & Dodd, 1994).

Multichannel cochlear implants have been available to profoundly deaf children for over a decade. With the introduction of cochlear implantation, the management of profoundly hearing-impaired children has entered into a new era. One of the primary benefits intended for children receiving cochlear implant is an improvement in speech perception skills which appear to support their speech production (Young & Killen, 2002). The cochlear implant prostheses, which function as a sensory aid, convert mechanical sound energy into a coded electrical stimulus that directly stimulates the remaining auditory neural elements, bypassing damaged or missing hair cell of the cochlea. Such a stimulation of the auditory system by the mimic features of normal audition and speech perception has had a major impact on improving the speech perception as well as phonological abilities of children with profound hearing impairments, especially who are unable to acquire adequate speech despite amplification. In the study conducted by Au, Wong, Ho, Tsang, Kung & Chung (2000), the post-implant speech perception scores of Cantonese-speaking hearing-impaired children improves significantly by demonstrating better performance in identification of phoneme, vowels and consonants after cochlear implantation when compared with their performance using powerful hearing aid.

With the improvement shown in speech perception skills after implantation, improved speech production skills is inherently linked to it (Gstoettner, Hamzavi, Brigitte & Baumgartner, 2000). Indeed, researches on cochlear implantation in children in the last fifteen years or so does indicate that cochlear implants provide greater speech production benefit for profoundly deafened children than do other sensory aids (e.g., hearing aids, tactile aids). A number of recent researches do reveal that profoundly deaf children with cochlear implants demonstrate improved speech production skills by the increase of sound repertoire and/or the improvement in the accuracy of articulation. Improved segmental aspects of speech have also been noted in a few studies examining children with cochlear implant. They tend to increase their phonetic repertories and consonant features, and eventually improve overall speech intelligibility (Osberger, Maso & Sam, 1993; Tobey, Pancamo, Staller, Brimacobe & Beiter, 1991). Osberger (1998) observed more accurate sound pronunciation in cochlear implant users than in hearing-impaired subjects with hearing aids. The study of Tobey, Geers & Brenner (1994) also reported that children with cochlear implants imitate consonants, vowels and diphthongs better than children who use hearing aids. Examination of the spontaneous production of speech sounds with the Phonologic Level Speech Evaluation also revealed significant improvements for children with cochlear implants (Kirk & Hill Brown, 1985). The study by Gantz, Tyler, Woodworth, Tye-Murray and Fryauf-Bertschy (1994), in which the accuracy of consonant, vowel, and word production of fifty-four children with cochlear implant was examined, also indicated a steady improvement in the accuracy of word and phoneme production.

Observations in the aforementioned studies indicate that pediatric cochlear implant users have demonstrated enhanced phonological abilities after implantation and these improvements are significantly higher than those achieved by un-implanted peers with a similar degree of hearing loss. In other words, cochlear implants may represent a feasible prosthetic aid for improving the sound repertoire in profoundly hearing-impaired children, especially for those who are unable to benefit from conventional hearing aids. However, there appears to be no previous report to date investigating the phonological abilities of Cantonese-speaking cochlear implant children. Therefore, the phonological abilities of Cantonese-speaking cochlear implant children is of particular interest. Cantonese is a Chinese dialect spoken by over 40 million speakers worldwide (Bauer and Benedict, 1997). The Cantonese system differs from English on the dimensions of phonotactic structure, number of contrastive consonants and aspiration contrast. Moreover, Cantonese is a tone language where relative change in tone is lexically significant and therefore tone is phonologically contrastive. There are six contrastive tones: high level$_1$, high rising$_2$, midlevel$_3$, low fall$_4$, low rise$_5$, low level$_6$, and three glottalized tones which are level tones delivered with a final stop /-p/, /-t/ or /-k/ replacing the homorganic nasal coda, /-m/, /-n/ or /-ŋ/. It is generally accepted that Cantonese has nineteen initial consonants including three nasals, six stops, two clusters, two affricates, three fricatives, two glides and one lateral; eight final consonants; ten vowels and eleven diphthongs. The syllable structure of Cantonese is relatively simple that a syllable may take the structure of vowel (V), consonant-vowel (CV), vowel-consonant (VC), consonant-vowel-consonant (CVC), consonant-vowel-vowel (CVV) and nasal singleton (/m, ŋ/). With a vowel being an obligatory segment, the number of segments can vary from one to three.

Many prelingually deaf children have experienced significant improvements in speech perception (Au et al., 2000; Fryhauf-Bertschy, Tyler, Kelsay, Gantz & Woodworth, 1997), speech production (Tobey, Geers, & Brenner, 1994), and language skills (Tomblin, Spencer, Flock, Tyler & Ganz, 1999) following cochlear implantation. However, there is dearth of previous studies investigating the phonological production abilities of Cantonese-speaking cochlear implant users, let alone the comparison between cochlear implant users and hearing aid users' phonological abilities. Therefore, in order to enhance our understanding about the phonological production competence of Cantonese-speaking cochlear implant users and hearing aid users, in this study, the phonological abilities of two groups of children with prelingual profound bilateral deafness: one group of cochlear implant users and one group of conventional hearing aid users, were described and compared.

In this study, it was predicted that:

1. Cantonese-speaking cochlear implant users will have better phonological abilities than those of hearing aid users with similar degree of hearing loss, as found in the previous studies that English-speaking pediatric cochlear implant users demonstrate enhanced phonological

abilities after implantation. Technological advances of cochlear implant development permits children, who are profoundly hearing impaired and receive negligible benefit from conventional hearing aid, access to environmental sounds and information about spoken language. It was then hypothesized that children who use cochlear implant can be benefited from auditory speech input in speech perception, so that they can perform better in speech production.

2. Despite some additional unusual rules, the phonological processes and rules used by both groups of children will primarily be the same as those would be expected in normally hearing children acquiring Cantonese. Specifically, both groups of children will exhibit the following phonological rules: initial consonant deletion, fronting, stopping, deaspiration, affrication, /h/ deletion, deaffrication and final consonant deletion.

Aims of the Present Study

Better phonological abilities induce better competence in oral communication. A major goal of professionals working with Cantonese-speaking hearing-impaired children in Hong Kong is to improve children's oral communication. As more and more hearing-impaired children enters day-to-day client populations for practicing speech therapist and audiologist, the need for detailed and specific descriptions of phonological systems becomes more acute. To the fact that one of the objectives of this study is to describe the phonological abilities of Cantonese-speaking bilateral profoundly hearing-impaired children with cochlear implant or hearing aids, this study is of clinical interest because an understanding of error patterns across the population of hearing-impaired children can be helpful in exploring the implication of the results on assessment and intervention on speech of Cantonese-speaking hearing-impaired children. For example, it can provide guidance for speech and language professionals in ordering speech treatment curriculum for new cochlear implant users, phonemes that are shown to be produced relatively accurately might be targeted earlier while those which are produced relatively poorer might be targeted later.

On the other hand, as comparison of phonological abilities between cochlear implant users and hearing aid users is another concern of this study, the result of the study can also give an idea of whether Cantonese-speaking cochlear implant users do really have a better potential to develop good speech production skills, as advocated by other previous studies investigating English-speaking hearing-impaired children with cochlear implant or hearing aid. (Osberger, Maso & Sam, 1993; Tobey, Pancamo, Staller, Brimacobe & Beiter, 1991; Tobey et al., 1994). This can provide important information for counseling families and potential cochlear implant candidates and for developing habilitation programs.

Method

Subjects

The subjects were fourteen Cantonese-speaking children with bilateral profound hearing loss with seven subjects with cochlear implants (CI) and seven subjects with conventional hearing aids (HA). Table 1 shows their unaided and aided pure tone averages for left and right ears, as well as their degree of aided residual hearing at 250 Hz, the average fundamental frequency level for Cantonese tones (Ching, 1984). The seven boys and seven girls ranged in age from 5;01 – 6;04 years (mean = 5;07). The subjects were divided into two groups. CI group includes seven cochlear implant users and HA Group includes seven hearing aid users with well-fitted ear molds. These two groups were well matched in terms of chronological age and years of speech training. Mean age of CI group = 5;08 , SD = 0;03. Mean age of the HA group = 5;07, SD = 0;06. While the mean number of years of training of CI group and that of the HA group were both = 2;01.

All of the subjects were prelingually hearing impaired and presented no known anomalies other than deafness. None of the children were reported to be at risk of cognitive delay and none had any other sensory or neurological deficit. Oro-motor examinations were done and it was confirmed that all subjects had normal oral-motor functioning. All subjects attended Special Child Care Center of the Hong Kong Society for the Deaf, three hours per day, five days per week. The number of years of training of subjects of CI group ranged from 1;03 – 3;03 (Mean = 2;01) and the same is true for that of HA group. All children were monolingual Cantonese speakers and were using multiword utterances.

Table 1. Descriptive information for subjects.

			Unaided level dBHTL			Aided level dBHTL					
S*	CA**	Sex	PTA*** (R)	PTA (L)	PTA (R)	PTA (L)	250Hz	Category	Year of training	Time of onset	Mode *****
A	5;08	F	103	92	41	N/a	50	Profound	1.25	C****	CI
B	5;10	M	110	118	n/a	47	45	Profound	3.25	C	CI
C	6;00	M	97	113	53	52	55	Profound	2.25	C	CI
D	5;08	F	90	90	46	(Binaural)	50	Profound	2	C	CI
E	5;03	M	118	120	40	(Binaural)	50	Profound	1.5	C	CI
F	5;10	M	119	105	53	N/a	50	Profound	2.25	C	CI
G	5;06	F	90	90	40	(Binaural)	45	Profound	2.2	C	CI
H	5;03	M	92	90	58	(Binaural)	60	Profound	1.25	C	HA
I	5;00	F	90	90	52	(Binaural)	60	Profound	1.5	C	HA
J	6;01	M	102	97	58	(Binaural)	60	Profound	3	C	HA
K	5;02	M	90	92	52	(Binaural)	55	Profound	2	C	HA
L	6;04	F	90	93	58	(Binaural)	50	Profound	1.4	C	HA
M	5;03	F	90	93	48	(Binaural)	50	Profound	2.25	C	HA
N	5;10	F	107	107	55	60	60	Profound	3.25	C	HA

* S: Subject
** CA: Chronological Age
*** PTA: Pure tone average of thresholds at 500, 1000 and 2000 Hz
**** C: Congenital
***** Mode: Mode of hearing aid

Procedure

Children were assessed in a quiet room in the Special Child Care Center by the researcher. The first five minutes were spent establishing rapport with the children through conversation and free play. Once the researcher had built up rapport with the child, the Cantonese Segmental Phonology Test (CSPT) (So, 1992, Research version) was administered so as to investigate the phonological errors in the speech of the two groups in the study. The subjects were asked to name the fifty-seven photos in the test. The fifty-seven words included in this photo-naming test comprised all initial and final Cantonese consonants, vowels, diphthongs and tones. The photos used in this test, with dimension three by five inch, are all colour photographs of real objects. In order to sample pronunciation of words in continuous speech, children were also be asked to retell two stories illustrated by five photographs, each with dimension five by seven inch. Speech samples obtained in the CSPT were recorded on Sony minidisks using a Sharp portable minidisk recorder MD-MT66 and a Sony Type ECM-717 electret condenser microphone, which was clipped on the subject's clothing at the chest level.

The Cantonese Lexical Comprehension Test (So & Varley, 1991) was also administered to assess the children's ability to distinguish between words that differed in tone only or consonant segment only in the presence of a semantic distracter. This test consists of two parts. In part one, children were asked to name twenty-nine photos that are included in Part two in order to ensure that the children knew the names of the stimulus photos. If the child was unable to name a photo, despite semantic cues, then any errors involving that item were deleted from the scoring procedure for Part two. In Part two, it was a closed-set test in which thirty-one sets of four photos were presented consecutively in a situation where the children were able to use lipreading and hearing together and asked to point to the named photo. Such an audio-visual condition was chosen as being the most representative of the children's usual communication mode. Each set of four photos consisted of the target photo (e.g., /pau_1/ [bread]), a tonal distracter (e.g., /pau_2/ [full]), a segmental distracter (e.g., /mau_1/ [cat]) and a semantic distracter (e.g., /$p\varepsilon\eta_2$/ [biscuit]).

Data Analysis

The speech samples of the two groups were phonologically analyzed. Phonetic transcriptions on the audiotapes were done and a form which presents the subjects' phonological error pattern was completed. The phonological measures were therefore derived from both single-word and spontaneous continuous speech (the number of word for each child ranged from 120-166, mean = 141). Although variation in the speech of users of Cantonese, like many languages, are many and wide, like there is a merger of [ŋ-] with [ϕ-] (Cheung, 1986), there is little information on the prevalence of these variations in the speech of hearing-impaired children. Therefore for the purpose of this study, the standard form is chosen to avoid introducing factors that might make this study more complicated than necessary.

A phoneme (the smallest distinctive unit that differentiates between words) was judged to be part of the child's inventory if it was used twice, correctly or as a consistent substitute for another phoneme. A phonological rule was judged to be used if there were at least two examples of its application in different lexical terms and no counter examples of another error type. A sample of ten percent of the data was transcribed independently by another transcriber, who is a speech therapy student, to evaluate inter-rater transcription reliability. Another ten percent of the data were re-transcribed by the same transcriber about one week after the first transcription to determine the intra-rater reliability. The intra-rater reliability and inter-rater point-to-point reliability across transcriptions was 89% and 87% respectively calculated by dividing the percent of the number of agreements about the occurrence of speech sounds by the total number of sounds produced. Percentage of consonant, vowel and tonal correct produced by the two groups were analyzed statistically to check any significant group difference. Children's performance on the Cantonese Lexical Comprehension Test (So & Varley, 1991) was analyzed statistically to compare scores on target and error types by group to provide a measure of receptive phonology.

Results

Phonological Units

The syllable-initial and syllable-final consonants missing from children's speech transcript in both groups are shown in Table 2. Only one child (Subject B) had complete phonetic inventory of syllabic-initial consonant phones. Inspection of Table 2 indicates that the consonant repertoires of subjects in CI Group were relatively more complete. The phonemes most likely to be missing from their repertoire were fricatives /f/, /s/ and none of the children in HA group could produce clusters /kw/ and its aspirated counterparts /kw^h/.

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

	Ss	Syllable-initial consonants	Syllabic-final consonants
CI Group	A	s ts^h	
	B		
	C	p^h t^h k^h s ts ts^h kw kw^h	n
	D	l f s	
	E	f s ts^h kw kw^h	
	F	p^h f s ts^h	
	G	s kw kw^h	
HA Group	H	j n p^h k^h f s ts^h kw kw^h	n
	I	p^h t^h k^h h f s ts ts^h kw kw^h	n
	J	f s ts^h kw kw^h	
	K	s ts ts^h kw kw^h	
	L	ŋ ts^h kw kw^h	n
	M	p^h k^h s ts ts^h kw kw^h	ŋ
	N	p^h k^h h s ts ts^h kw kw^h	n, ŋ

Of the 1979 occurrence of syllable initial consonant in the transcripts of children of both groups, 60.8% of syllable initial consonant were produced correctly, and 39.2% were in error. Frequency of error for each initial consonant ranged from the highest of 86.4% for /s/ to the lowest of 0% of /p/, /m/, /w/. All initials were grouped together in bands of percentage and they are presented in table 3. On the other hand, most subjects' syllable-final consonants, vowels and tone inventories were complete. Diphthong reduction was the predominant type of error made by both groups of children's vowel production.

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

Percentage of error (%)	Syllable-initial consonants
80-90	s
70-80	f kw kw^h
60-70	ts^h
50-60	ts p^h k^h
20-30	t^h k l
10-20	h t n
0-10	ŋ j
0	p m w

Phonological Process

The phonological processes used to account for all errors made by both groups of children are shown in Table 4. The first six rules were those used by more than 10% of the normative sample of children with normal hearing ability (So & Dodd, 1995). They were fronting (e.g., /$k^h ei_{33}$/ → [$t^h ei_{33}$]), stopping (e.g., /si_{55}/ → [ti_{55}]), deaspiration (e.g., /$p^h iŋ_{21}$/ → [$piŋ_{21}$]), affrication (e.g., /sy_{55}/ → [tsy_{55}]), /h/-deletion (e.g., /hai_{21}/ → [ai_{21}]) and cluster reduction (/kwa_{55}/ → [wa_{55}]). Across both groups of subjects, stopping was the most frequent rule used by the children that all children, except subject B, J and L, had used this rule. Apart from stopping, cluster reduction was also a frequent rule used by all children, except subject A, B, D and F.

The following two rules were unusual non-developmental rules including initial consonant deletion (e.g., /$tsiu_{55}$/ → [iu_{55}]) and backing (e.g., /tou_{55}/ → [kou_{55}]). Concerning the final consonant production of the subjects in both groups, the two rules used by children in both groups were final consonant deletion and backing.

Table 4. Phonological processes applicable to children in CI and HA group

	CI Group							HA Group						
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Initial Consonants:														
Developmental rules														
Fronting			+		+			+	+	+	+	+	+	+
Stopping	+		+	+	+	+	+	+	+		+		+	+
Deaspiration			+			+		+	+		+		+	
Affrication				+				+						
/h/-deletion									+					+
Cluster reduction			+		+		+	+	+	+	+	+	+	+
Unusual rules														
Initial consonant deletion			+	+				+	+			+		+
Backing								+	+					
Final Consonants:														
Developmental rules														
Unusual			+					+	+			+	+	+
Backing										+			+	

Quantitative Error Analyses

Comparison of groups' percentage correct in consonants, vowels and tones.

The total number of words included in each subject's transcript and the percentage of words that contained correct consonant, vowel and tone are shown in table 5. The percentage correct of consonant, vowel and tone made by the CI group and HA group was compared. A two-factor repeated measures analysis of variance (group X consonants, vowels, tones) showed a statistically significant main effect of group term [$F(1, 12) = 11.555$, $p < 0.05$]. Concerning the condition term, the result of the repeated measures analysis of variance also revealed a statistically significant main effect of condition term [$F(2, 24) = 66.458$, $p < 0.05$]. Post-hoc F testing was done and it was found that subjects' performance in vowel and tone productions were significantly better than that of consonant production, while subject' performance in vowel production was significantly better than that of tone production. Interaction term between the two independent variables (i.e., group term and condition term) was also found statistically significant [$F(2, 24) = 6.568$, $p < 0.05$].

In order to examine the interaction effect, the simple main effects of group term at each of the three levels of condition terms were then analyzed. It was found that the simple main effect of group term was statistically significant for consonant production [$F(1, 12) = 17.3296$ ($p < 0.05$)], but the simple main effect of group term for vowel production [$F(1, 12) = 0.2181$ ($p > 0.05$)] and tone production [$F(1, 12) = 2.805$ ($p > 0.05$)] was not statistically significant. This revealed that cochlear implant users in this present study do demonstrate significantly better consonant production skills than that of hearing aid users. On the other hand, the simple main effects of condition term at each of the two levels of group terms were also analyzed. It was found that the simple main effects of condition term for both CI group [$F(2, 12) = 13.634$ ($p < 0.05$)] and HA group [$F(2, 12) = 67.1966$ ($p < 0.05$)], were statistically significant. Post-hoc F testing was then done to analyze the simple main effects of condition term more fully so as to determine the nature of the differences among the levels. For HA group, it was found that HA users' performance in vowel and tone productions were significantly better than that of consonant production, while their performance in vowel production was significantly better than that of tone production. However, for the performance of subjects in CI group, it was found that only vowel production was significantly better than consonant production.

Table 5. Percentage of words with correct consonant, vowel and tone

	Ss	Total number of words	PCC* (%)	PVC** (%)	PTC*** (%)
CI Group	A	158	77.8	98.6	90.3
	B	166	97.3	100	83.3
	C	137	72.2	91.7	90.3
	D	129	75	97.3	72.2
	E	120	58.4	100	75.0
	F	163	63.9	99.98	99.8
	G	166	69.3	100	99.9
	Mean		73.4	98.2	86.6
	SD		12.4	3.1	10.4
HA Group	H	124	36.1	79.2	72.2
	I	130	40	99.99	66.2
	J	149	53	99.99	72.5
	K	152	57.3	99.99	99.94
	L	137	57.7	100	73
	M	125	36.8	100	89.6
	N	123	48	100	77.3
	Mean		47.0	97.0	78.1
	SD		9.4	7.9	11.8

*PCC = Percentage of consonant correct
**PVC = Percentage of vowel correct
***PTC = Percentage of tone correct

Comparison of the group's receptive phonology

Table 6 presented the group means' for Part one and Part two of the Cantonese Lexical Comprehension Test (So & Varley, 1991). The two group's ability in naming the 29 pictures in Part 1 was compared by Mann-Whitney U test. Children in CI group failed to name a mean of 5.3 items while the children in HA group failed to name a mean of 6.6 items. There was no statistically significant difference between the group performances.

Concerning Part two of the test, a two-factor repeated measures analysis of variance (groups X target, tonal distracters, segmental distracters and semantic distracters) was done. It was found that the main effect of group term was not statistically significant [$F(1, 12) = 0.1894$ ($p > 0.05$)]. Concerning the condition term, the result of the repeated measures analysis of variance revealed a statistically significant main effect of condition term [$F(3, 36) = 92.6872$, $p < 0.05$]. Post-hoc F testing was done and it was found that subjects were most likely to choose the target picture than the most frequently chosen tonal distracter, while segmental and semantic distracters were chosen equally often. The interaction term between the two independent variables was not significant [F (3, 36) = 3.8059, (p > 0.05)]. On the other hand, the simple main effects of condition term at each of the two levels of group terms were also analyzed. It was found that the simple main effects of condition term for both CI group [F (3, 18) = 67.4734, p < 0.05] and HA group [F (3, 18) = 10.6443, p < 0.05] were statistically significant. Post-hoc F testing was then done to determine the nature of the differences among the levels. It was found that for CI group, subjects were more likely to choose the target photo, while the tonal, segmental and semantic distracters were chosen equally. For HA group, similar to that of CI group, subjects choosing target photos was significantly more, while the choosing of semantic distracters were significantly fewer than that of tonal and segmental distracters.

Table 6. Means and standard errors for the Cantonese Lexical Comprehension Test (So & Varley, 1991).

	CI Group	HA Group
Part 1		
Picture naming error	5.3 (2.0)	6.6 (2.9)
Part 2		
Target	19.7 (3.1)	14.3 (4.1)
Tonal distracter	4.1 (2.7)	6 (2.4)
Segmental distracter	1.1 (1.5)	2.4 (1.5)
Semantic distracter	0.1 (0.4)	0.9 (1.5)

Discussion

The phonological abilities of the fourteen Cantonese-speaking children with bilateral profound hearing loss with cochlear implants or conventional hearing aids have been described in terms of their productions of consonants, vowels and tones, phonological rules and lexical comprehension. Moreover, the phonological abilities of subjects in CI group and HA group were also analyzed statistically to compare percentage of consonant, vowel and tone correct so as to provide a comparison of phonological abilities between groups. Results of the present investigation indicated that cochlear implant appears to promote the development of phonological abilities more than the use of conventional hearing aids does.

Phonological Units

All subjects, except subject B, made errors in production in syllable-initial or/and syllable-final consonants. The only sounds that were error-free in all of the subjects were the phonemes /p/, /m/, /w/. According to So & Dodd (1995), these three phonemes were found to be acquired in the early stage of phonological development of hearing children, so that 90% of children of 2;06-3;00 will have acquired these sounds. Moreover, it was found that the fricatives /s/ & /f/, affricates /ts/ and /ts^h/, and clusters /kw/ and /kw^h/ were most likely to be missing from children's repertories. Apparently, these findings revealed that the order of phoneme acquisition by profoundly hearing impaired children with cochlear implants or hearing aids follows the normal developmental trend. Concerning the relatively poorer performance of subjects' production of fricatives /s/ and affricates /ts/ and /ts^h/, contributing factors might be the fact these sounds includes all of the high frequency and low intensity phonemes, and both frequency and intensity are factors adversely affecting the audibility of phonemes (i.e., the higher frequency and lower intensity, the less audible sounds are to children with hearing impairment).

Furthermore, by inspection of the frequency of error for each initial consonant, it was found that the errors of aspirated stops /p^h/, /t^h/, /k^h/ were more than their unaspirated counterparts. The following factor may underlie these observations. First, although Cantonese does not have contrastive voicing, it does have an aspiration distinction which is analogous in that both voicing and aspiration are measurable in terms of voice onset time (VOT). Abnormal timing relationships during speech are a commonly cited problem in profoundly hearing-impaired speech and this might be factor contributing to the aspiration dimensions observed here (Tobey, et. al., 1991).

Blamey, et al (1995) reported more accurate productions of visible consonants than consonants occurring in the mid or posterior regions of the mouth. Subjects participating in this study also appear to use places of articulation that are similar to those previously reports for other profoundly hearing-impaired children. A greater proportion of the children use accurate visible, anterior places of articulation than less visible, posterior velar and palatal configurations. For example, when referring to table 3, subjects in this study yielded higher accuracy in producing bilabial and alveolar consonants (e.g., /p/, /n/, /t/), which have anterior place of articulation, than consonants produced more posteriorly (e.g., /k/). Indeed, consonants produced in the front of the mouth are generally more accurate because they are more visible and the lips are more restrained in movement than the tongue. Therefore, although with the constraint of hearing impairment, profoundly deaf children can still gain visual cues when producing these visible sounds.

The study by Dodd & So (1994) reported generally complete vowel and tone inventory of hearing impaired children who used hearing aids. Our data are in support of these previous observations. In comparison between consonant, vowel and tone production of subjects, it was found that for both the CI and HA groups of subjects, the performance on consonant production was significantly poorer than that of vowel and tone production. It might due to the fact that consonants are weaker in intensity, higher in pitch and shorter in duration, therefore hearing-impaired children will tend to produce more consonant errors than vowel and tone errors (Khouw, 1994). Concerning the vowel productions of subjects, most subjects had complete vowel inventories. This was indeed consistent to the phonological development of hearing children in which vowels were being used contrastively by 90% of children in the youngest group (2;00-

2;06) (So & Dodd, 1995). Moreover, both groups of hearing-impaired subjects' performance in producing vowels were significantly better than that of consonant production although the performance in diphthongs production was relatively poorer. It is likely that such performance of vowel production is a consequence of their general acoustic and/or articulatory properties. To the fact that vowels are more intense and of longer duration than consonants, it is then believed that vowel productions are easier to be perceived by residual hearing and can be cued by comparatively simpler and slower change of acoustic patterns. Concerning the relatively poorer performance in production of diphthong than that of monopthongs, attributing factors might include that fact that monophthongs are less complex and more static than diphthongs (Kirk & Tye-Murray, 1993).

Concerning the tone inventory, all subjects, except subject E, had complete tone inventory. This observation might due to the fact that as Cantonese is a tone language where relative change in tone is lexically significant and carries a heavy functional load. Therefore, it is unsurprising that rehabilitation programs provided the subject's Special Child Care Center will be focused at training on the contractiveness between tones. However, despite the fact that most subjects had complete tone inventory, they frequently showed substitution of entering tone by high level tone ($tone_1$). This observation was indeed similar to the findings of tone production of hearing children that according to So & Dodd (1995), hearing children first acquired two of the three level tones (high level and then mid level tones) followed by the high rise tone and then the three entering tone.

<u>Phonological Process</u>

All subjects showed the use of developmental phonological rules that are typical in the phonological development of Cantonese-speaking hearing children. Dodd & So (1994) identified the most frequent developmental rules used by Cantonese-speaking hearing-impaired children as stopping, cluster reduction and affrication. The result of the present study also showed similar results that eleven subjects used stopping and ten subjects used cluster reduction, although only two subjects showed affrication and nine subjects also used a fronting rule. The frequent use of the rule of stopping is indeed consistent to the aforementioned analysis. Hearing impaired children will have particular difficulties in producing fricatives and affricates owing to the fact these sounds includes all of the high frequency and low intensity phonemes. As a result, subjects' stopping errors frequently resulted in fricatives /f, s/ and affricates /ts, ts^h/ being realized as a plosive at their place of articulation. Concerning the frequent use of fronting, it might due to the fact that hearing-impaired children tend to produce consonant produced at the front of the mouth (Blamey et al., 1995), which might then contribute to their frequent use of fronting. On the other hand, cluster reduction was also a predominant error pattern for the subjects. It was noticed that subjects were more likely to delete /$k^{(h)}$/ in /$k^{(h)}$w/. The fact that fewer words begin with /w/ than with /k/ in children's early vocabularies and the maintenance of /w/ would reduce homonymy might account for this error pattern (So & Dodd, 1995). Indeed, these frequent rules used by the subjects of this present study are consistently used by Cantonese-speaking hearing children until about age 3;06 (So & Dodd, 1995).

In addition to these developmental rules, subjects were also found to use unusual rules, including initial consonant deletion and backing, which are atypical to the phonological development of Cantonese-speaking hearing children. Six subjects used at least one of these two unusual rules. English-speaking hearing-impaired children were found to omit many consonants and the omissions occur primarily in word-final positions and relatively infrequently in word-initial positions (Levitt & Stromberg, 1983). This pattern was not observed in the profoundly hearing-impaired Cantonese-speaking subjects in this present study in which both initial consonant and final consonant deletion were shown in six of the subjects. The difference between English- and Cantonese-speaking children with hearing loss may be attributable to the languages' different phonological and syntactic structures (So & Dodd, 1994). English has a broad range of final consonants and clusters and some of which are syntactic markers showing possession, tense and plurality, whereas Cantonese has only eight syllable-final consonants without any syntactic markers. Therefore, less linguistic information is carried by word-final segments in Cantonese. To the fact that the more complex the syntax, the more likely a child with phonological disorders is to make phonological errors, the relatively better performance in final consonant production of Cantonese-speaking hearing-impaired children than that of English-speaking hearing-impaired children can then be explained (Crystal, 1987).

Lexical Comprehension

Subjects of both groups were able to name most of the photo stimuli presented in the Cantonese Lexical Comprehension Test (So & Varley, 1991). In Part two of the test in which subjects were required to choose target photo against the presence of three distracters including tonal, segmental and semantic distracters, subjects most frequently chose the target photo and there was no significant performance difference across both groups. It was indeed unsurprising that hearing aid users could perform as well as cochlear implant users although the speech perception skills of cochlear implant were well-documented to be better than hearing aid users (Au, et al., 2000; Miyamoto, Kirk, Robbins, Todd, Riley, 1996; Osberger, Miyamoto, Kirk, Todd, & Robbins, 1995 & Miyamoto, Osberger, Robbins, Myres, Kessler, & Pope, 1991). Factors contributing to this finding might be the fact that subjects were put in a situation in which they were able to use lipreading and hearing together in recognizing words in the test. Therefore, subjects' performance in word recognition were not affected by just the quality of the their hearing or speech perception ability but they could also rely on cues by lipreading especially when discriminating between target and segmental or semantic distracters. Moreover, although the test was in a closed-set discrimination format with the test stimuli assumed to be within the children's capacity for language after the naming test in Part one so as to fulfill the purpose of putting greater weight on the hearing abilities of the child, it may not remove the influence of differing linguistic abilities among the children (Boothroyd, 1995). Therefore, with the variability of linguistic factors presented in the test, although with the notion that hearing aid users will have relatively poorer speech perception abilities, it was not surprising that the hearing aid users' performance was insignificantly poorer than that of cochlear implant users.

Concerning subjects' error pattern in auditory discrimination, it was found that for both groups, subjects were most likely to choose tonal distracters. Such result was consistent to the result of the study conducted by Dodd & So (1994) and it was hypothesized that hearing-impaired children should encounter specific difficulties in discriminating two words which differed in tone only. It was because tonal distracters do not carry visible information, for example, lip movement or tongue movement. Therefore, it is not surprising that hearing-impaired children will perform worse as they can merely rely on their impaired hearing ability to discriminate against words differed in tone only. Nevertheless, as all the stimuli in the lexical comprehension test were restricted to single word level, undoubtedly it overlooked the importance of contextual cues such as context of the utterances that subjects could get through daily conversations. Another limitation of this closed-set test is that it reduces the value of the result as an evaluation of the children's speech perception performance in everyday situations (Blamey et al., 2001).

Comparison of cochlear implant users and hearing aid users' performance

Results of the present investigation indicated that the consonant production accuracy for the cochlear implant users exceeded the performance of hearing aid users and this result was indeed predicted. There was statistically significant difference between the performance in consonant production between the two groups such that the CI users' accuracy of consonant production was significant higher than that of HA users. By inspection of the raw data in the tables, those children with the best consonant production accuracy were cochlear implant users. Such results were consistent with the previous studies on English-speaking children, which found that consonant production appeared to be aided by information provided by multichannel cochlear implants that a greater repertoire of consonants is observed in the spontaneous speech of children with cochlear implants (Tobey et al., 1991) and increased accuracy of consonant production occurs (Geers & Tobey, 1992). The study of Geers et al. (1994) in which the performance imitated speech production and spontaneous connected speech of cochlear implant users, hearing aid users and tactile aid users were compared, revealed that cochlear implant users showed the most improvement after one year of training. Moreover, children with cochlear implants also demonstrated considerable improvements in imitation of consonants in both initial and final positions of syllables and in repetition of a series of syllables in which different consonants were alternated. On the other hand, the speech performance of children wearing hearing aids improved more slowly. Thus, the results of the present study confirm the above observations.

Indeed, previous studies have advocated that information provided via cochlear implants' electrical stimulation of remaining intact auditory nerve fibers might serve as important feedback for achieving more nearly normal consonant production (Geers & Tobey, 1992). Auditory feedback is of paramount importance in speech production as it informs speakers about the consequences of their articulatory gestures and how these consequences compare to sounds produced by other speakers. Also, auditory feedback can also provide information for monitoring ongoing speech production and for detecting errors. Indeed, several investigators have hypothesized that once speech motor patterns become established, cochlear implants serves as an important global calibrator for auditory feedback which provide immediate and non-stop feedback to the users regarding their speech production (Geers & Tobey, 1992). As many of the articulatory features in the cochlear implant children continue to emerge and solidfy into established motor patterns, greater improvement across various speech features than children wearing hearing aid will then be demonstrated. For instance, concerning the aforementioned notion that children who have profound hearing impairment are more likely to produce "visible" phonemes and words correctly than "nonvisible" phonemes and words. It is then possible that once profoundly hearing-impaired children receive a cochlear implant, they may become less reliant on visual information for acquiring speech and more reliant on auditory information.

General Summary

The present study described the phonological abilities of fourteen Cantonese-speaking children with cochlear implant or hearing aids by investigating their phonological units and phonological rules. The results revealed that all, except one subject had incomplete phonetic repertories and all subjects showed complete vowel and tone inventories. In the introduction we predicted that the phonological processes and rules used by both groups of children will be primarily be the same as those would be expected in normally hearing children acquiring Cantonese. The only developmental phonological rule that was absent in this present study was deaffrication. Apart from developmental phonological rule, similar to both the observations of English-speaking hearing-impaired children and the result obtained by So & Dodd (1994), the Cantonese-speaking hearing-impaired children in this study also used some unusual phonological rules that are atypical to normal development.

Another prediction that children having cochlear implant would have better phonological skills than children having hearing aids with similar degree of hearing loss was confirmed. It was found that the percentage correct in consonant production of cochlear implant users was significantly higher than that of hearing aid users, although no significant difference was found for percentage correct in vowel and tone production. In other words, it was found that cochlear implant user appeared to promote the development of consonant feature production to a greater degree than did the use of a hearing aid. Thus, the spectral, intensity, and timing information provided by the cochlear implants appears to obtain greater consonant production benefits than hearing aid and greatly aid the acquisition of speech features including place and manner of articulation (Geers & Tobey, 1992). Moreover, it was believed that cochlear implants' electrical stimulation of remaining intact auditory nerve fibers might serve as important feedback for achieving more nearly normal consonant production leading to better consonant production skills of cochlear implant users (Geers & Tobey, 1992).

After all, despite the fact that cochlear implantation have proved to be a viable and effective rehabilitation for children with profound hearing loss (Dowell & Cowan, 1997; Lenarz et al., 1999), continuous future efforts should be warranted in the area of evaluating the speech production skills of children with profound hearing impairment, particularly as technology improves in the development of new devices and improved implant processing schemes.

Limitations of the Study

The relatively small number of subjects used in this study limits the generalizability of the claims from the results. An ideal study would need a larger number of children. Also, the age range of the subjects is also limited (from five to six years old), therefore conclusions are limited to the phonological abilities of hearing-impaired children in a particular age range.

Besides, the present investigation was generally focused at subjects' consonant production. It is because many consonants are weaker in intensity, higher in pitch and shorter in duration, therefore hearing-impaired children tend to produce more consonant errors than vowel and tone errors and results of the present study do really confirm this hypothesis. Therefore, the study focus at consonant productions is more valuable for clinical implication. However, in future study, vowels and tones could also be studied thoroughly so as to obtain a complete view of the phonological abilities of hearing-impaired children with cochlear implants or hearing aids.

Furthermore, in order to comprehensively investigate the influence of profoundly hearing-impaired children with cochlear implant, longitudinal studies may be desirable. Longitudinal study of collecting speech samples pre- and post-implantation can create a clear picture on the improvement on children's phonological abilities, including any increase in phonetic repertories and higher accuracy in consonant, vowel and tone productions, after implantation.

Finally, it is recommended that in future study, speech intelligibility, which describes the degree of success with which others recognize a person's speech, can also be compared between cochlear implant users and hearing aid users, or between pre- and post-implantation for cochlear implant users. Such an investigation on speech intelligibility can provide another means of for judging individual's competence in oral communication.

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Appendix A

Word list for the 57 photos in the Cantonese Segmental Phonology Test (So, 1992, Research Version)

Target Words	Phonetic Transcriptions	Word Meaning
1. 眼	ŋan$_5$	eye
2. 襪	mɐt$_7$	sock
3. 梨	lei$_2$	pear
4. 鞋	hai$_4$	shoes
5. 鈕	nɐu$_2$	button
6. 餅	pɛŋ$_2$	biscuit
7. 手	sau$_2$	hand
8. 琴	k^{h}ɐm$_4$	piano
9. 碗	wun$_2$	bowl
10. 蕉	tsiu$_1$	banana
11. 雞	kɐi$_1$	chicken
12. 檯	t^{h}ɔi$_2$	table
13. 裙	kw^{h}ɐn$_4$	skirt
14. 花	fa$_1$	flower
15. 蘋果	p^{h}iŋ$_4$	apple
16. 刀	tou$_1$	knife
17. 瓜	kwa$_1$	melon
18. 魚	jy$_2$	fish
19. 床	ts^{h}oŋ$_4$	bed
20. 巴士	pa$_1$ si$_2$	bus
21. 千秋	ts^{h}in$_1$ ts^{h}ɐu$_1$	swing
22. 電話	tin$_4$ wa$_2$	telephone
23. 麵包	min$_6$ pau$_1$	bread
24. 杯	pui$_1$	cup
25. 牛奶	ŋau$_4$ nai$_3$	milk
26. 鴨	ap$_3$	duck
27. 水	sœy$_2$	water
28. 腳	kœk$_8$	foot
29. 狗	kɐu$_2$	dog
30. 燈	tɐŋ$_1$	lamp
31. 月利	lei$_6$	tongue
32. 奶	nai$_3$	milk
33. 表	piu$_1$	watch
34. 企	k^{h}ei$_5$	stand

35. 海	hɔi$_2$	sea
36. 耳	ji$_3$	ear
37. 牙	ŋa$_4$	tooth
38. 龜	kwɐi$_1$	tortoise
39. 盆	p^{h}un$_4$	basin
40. 粥	tsuk$_7$	congee
41. 貓	mau$_1$	cat
42. 褲	fu$_3$	trousers
43. 吹	ts^{h}œy$_1$	blow
44. 葉	jip$_6$	leaf
45. 黃	wɔŋ$_4$	yellow
46. 糖	t^{h}ɔŋ$_2$	candy
47. 車	ts^{h}ɛ$_1$	car
48. 樹	sy$_6$	tree
49. 飲	jɐm$_2$	drink
50. 雪糕	syt$_7$ kou$_1$	ice-cream
51. 電視	tin$_6$ si$_6$	television
52. 腳板	kœk$_8$ pan$_2$	foot
53. 水壺	sœy$_2$ wu$_2$	bottle
54. 筷子	fai$_3$ tsi$_2$	chopsticks
55. 西瓜	sɐi$_1$ kwa$_1$	watermelon
56. 洗面	sɐi$_2$ min$_4$	wash face
57. 校服裙	hau$_6$ fuk$_9$ kw^{h}ɐn$_4$	uniform

Appendix B

Word list for the naming test in Part 1 of the Cantonese Lexical Comprehension Test (So & Varley, 1991).

Target	Word Meaning
1. 門	door
2. 牆	wall
3. 企	stand
4. 頸	neck
5. 包	bread
6. 餅	biscuit
7. 湯	soup
8. 損	hurt
9. 窗	window
10. 耳	ear
11. 跑	run
12. 寫	write
13. 凳	chair
14. 蟹	crab
15. 樹	tree
16. 老	old
17. 喉	hose
18. 牛	cow
19. 吹	blow
20. 嘴	mouth
21. 魚	fish
22. 爬	crawl
23. 相	photo
24. 肚	tummy
25. 箱	box
26. 笑	smile
27. 田	field
28. 槍	gun
29. 梨	pear

Appendix C

Word list for the comprehension test in Part 2 of the Cantonese Lexical Comprehension Test (So & Varley, 1991).

	Target	Tonal	Segmental	Semantic
1. Soup	湯	糖	燈	奶
2. Crab	蟹	鞋	奶	魚
3. Gun	槍	牆	箱	刀
4. Tree	樹	鼠	射	花
5. Field	田	天	停	池
6. Crawl	爬	怕	牙	訓
7. Pear	梨	月利	俾	蕉
8. Ear	耳	椅	雨	鼻
9. Write	寫	蛇	鼠	讀書
10. Run	跑	拋	飽	跳
11. Wall	牆	唱	床	門
12. Box	箱	上	槍	罐頭
13. Hurt	損	船	鼠	傷心
14. Smile	笑	小	跳	錫
15. Fish	魚	雨	鼠	龜
16. Door	門	滿	盆	窗
17. Tree	樹	書	射	花
18. Box	箱	相	窗	罐頭
19. Blow	吹	鎚	追	黐
20. Tummy	肚	吐	抱	手
21. Biscuit	餅	病	頸	飽
22. Old	老	路	肚	年青
23. Stand	企	旗	被	坐
24. Photo	相	上	水	相機
25. Neck	頸	鏡	餅	膝頭
26. Bread	包	飽	貓	餅
27. Window	窗	唱	箱	門
28. Hose	喉	口	牛	桶
29. Cow	牛	勾	頭	門
30. Mouth	嘴	追	水	眼
31. Chair	凳	燈	唱	檯