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Vowels production by Cantonese-speaking children with cochlear implant

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Abstract

This study investigated vowels production by Cantonese-speaking children with

cochlear implant. Nineteen subjects with cochlear implant age ranged 2;05 to 6;01

years old were compared to 19 hearing children. All participants were required to

produce 51 words, covering seven Cantonese monophthongs /a, i, E, O, u,

y, J/ and ten Cantonese diphthongs /ui, Oi, ai, iu, Ey, Ai, ou, ei,

au, Au/. The production accuracy was compared. Error patterns were investigated

by phonological process and acoustic analysis. The production accuracy from

cochlear implant subjects with hearing experience less than two years was

significantly different than that of hearing children with similar hearing experience. A

developmental and universal phonological acquisition process was observed.

Developmental phonological rules were found in erroneous production. Articulatory

complexity played an important role in vowels acquisition in CI groups. The result

demonstrated a positive influence of cochlear implant on vowels production in

Cantonese-speaking children.

Children with impaired auditory system had been of great research interest over decades. Both Speech-Language pathology and audiologist concerned the relationship between auditory input and speech production. With the advance of technology, cochlear implant had become a satisfactory compensation for profound hearing-loss patient who did not benefit from traditional hearing aid (HA). A cochlear implant (CI) is an electronic devise that acts as a sensory aid by converting mechanical acoustic energy into coded electrical energy to stimulate surviving auditory neurons, by-passing nonfunctional hair cells in cochlea. Researchers found that profoundly deaf children with cochlear implants demonstrated improved accuracy in pronunciation (Dawson, Blamey, Dettman, Rowland, Barker & Tobey, 1995), increased in phonetic repertories and consonant features and eventually improved overall speech intelligibility (Tobey, Angellette, Murchison, Nicosia, Sprague et al., 1991). Law and So (2006) did a parallel study on Cantonese-speaking children with CI and HA and found that children with cochlear implants had better phonological skills and demonstrated positive consonant development than HA user.

In view of the above, speech production had become a major locus of research in children with hearing loss. Although Ertmer & Shark (1995) reported that hearing impaired children had incomplete prelinguistic vocal development, which contributed to delay in emergence of meaningful speech and restrictions in phonological development, there seemed to be a clear acquisition sequence of productive abilities. For Cantonese-speaking children, tone and intonation appear early, followed by vowels and consonant at last (Dodd & So, 1994). Of all phonological aspect produced by CI children, consonants had been widely investigated in English (Chin, 2003; Chin & Pisoni, 2000), Cantonese (Dodd & So, 1994; Law & So, 2006, and Mandarin (Peng, Weiss, Cheung & Lin, 2004). Reduced consonant inventories and distorted

phonological process were reported. Little had been reported solely on the vowel development and production in cochlear implant population.

Vowels system was among the first acquired phonemic items of prelingually deaf children who received multichannel cochlear implants (Miyamoto, Osberger, Robbins, Myres, & Kessler, 1993). Investigations on vowels production from CI subjects were mostly in English-speaking population. Ertmer, Kirk, Sehgal, Riley & Osberger (1997) did a study on ten CI-children. Vowels production skills from cochlear implant group were found to be significantly better than those of the hearing aids users after twenty months of implant experience. A few years later, Ertmer (2001) did a single-case study on a congenitally deaf child, Hannah, who received CI at 19 months. The emergence and production of vowels were analyzed perceptually and acoustically. A total of nine different vowels were recorded during her first year of implant experience and vowels space was near normal as measured acoustically. Substantial developmental progresses in vowels development was recorded during her first year of implant use. Till now most researches focused on phonological acquisition and development in cochlear implant users learning English. Comparatively little was reported about the features of vowels acquisition and production of implant users from other language background. Yet such research could help regional professionals thoroughly identify the influence of distorted auditory input on vowels production.

In Cantonese-speaking population, the first Cochlear Implant Surgery on profoundly deaf children was done in 1995 (Hong Kong Society for the Deaf, 2004). It was not surprising that little was published describing acquisition and production of Cantonese phonology children with cochlear implant until recent decades. Law & So in 2006 made a comparison of phonological abilities between Cantonese-speaking

children using hearing aids and cochlear implants. In same year Barry, Blamey and Fletcher (2006) described the factors affecting vowels phonemes acquisition by Cantonese-speaking CI users. A non-linear approach was used to determine the rate and order of vowel acquisition. None of them had analyzed the vowels production by phonological process nor acoustic analysis. Our study aimed to provide more solid information on Cantonese vowels production by children with cochlear implants.

The Cantonese vowels inventory comprised of 11 monophthongs and 11 diphthongs (Li, 1985, Lee 1993, Zee 1993). Among the 11 monophthongs, there are seven long monophthongs/a, I, E, O, u, y, J/ and four short monophthongs /A, I, T, U/. The seven long monophthongs can be used in open syllables, while the short one [I] and [U] only occur before the velar /k/ and /N/, [T] occurs before final alveolar consonant /t/ and /n/ and [A] occurs before final plosive consonant /p/, /t/, /k/ and nasal /m/, /n/, /N/. The short monophthongs [A, I, T, U] could only be produced in combination of final consonant. They were considered to be in complementary distribution of /a, i, J, u/ respectively. In order to eliminate the carry-over effect of final consonant to monophthongs production, the phonological test used in this clinical study adopted traditional classification system. Thus, only seven long monophthongs were included in the study. The ten diphthongs of Cantonese are /iu, Au, au, ou, ei, Ai, ai, ui, Oi, Ty/. Zee (1993) identified a colloquial diphthong /Eu/, but it was not included in this study due to the restricted number of phonological combination. According to the International Phonetic Association (1999), monophthongs could be classified according to place of articulation in oral cavity (i.e. front, middle, back) and position of tongue (high, mid, low). Appendix 1a shows all standard Cantonese monophthongs arranged according

to their place of articulation and position of tongue. Diphthongs (Appendix 1b) follow similar classification scheme as monophthongs.

In Cantonese-speaking population, children with normal hearing should acquire monophthongs by 2; 00 (So & Dodd, 1995) and diphthongs by 3; 00 (Cheung & Abberton, 2000). Though a growing number of papers had been published in Cantonese-speaking CI users, the mean subject age was too high for emergent vowels analysis, e.g. the mean age for hearing-impaired group in Dodd & So (1994) was 5;05, in Law & So (2006) the mean age of CI group was 5;08 and HA group was 5;07 years, and in Barry et al. (2006) the mean age of CI group is 4; 03 etc. The mean age went beyond the critical period of Cantonese vowels acquisition and development. No detail Cantonese vowels analysis could be done. This study, moreover, gave additional purpose to fill in the research gap of children with cochlear implant in emerging age.

Researches done on phonological development of cochlear implant-users were mostly based on perceptual transcription data. The transcriptions were based on subjective auditory perception. Reliability of phonetic transcription was questionable (Shriberg and Lof, 1991). Wesimer (1984) demonstrated acoustic analysis strategies to refine phonological analysis in speech and hearing research. Walton & Pollock (1993) performed acoustic analysis of vowels error patterns in five children to validate the perceptual judgement describe in earlier study by Pollock and Hall (1991). Acoustic support on perceptual transcription from Cantonese-speaking children was, for the most part, absent from the literature. Hence, to provide full complementation to our transcription, a portion of acoustic measures would be employed to lend credibility to the limitation of perceptual transcription.

On the whole, this study attempted to fill up the research gap on Cantonese vowels production of CI children in emerging age. Objective acoustic analysis on perceptual judgement was also performed. We predicted the following:

1. The production accuracy would improve as hearing experience increases for children with cochlear implants. Dodd & So (1994) stated a developmental delay, rather than deviation, in phonological skills reported in children with hearing loss. Better phonological skills were shown in children with cochlear implants than those with hearing aids (Law & So, 2006). Cochlear implant hearing experience showed positive influence on CI-recipient's speech accuracy. Same would be applied for children with cochlear implants on vowels production.

2. Despite some additional atypical rules, the phonological process and rules used by both CI and normal hearing children would be similar. Dodd & So (1994) indicated the phonological processes from hearing-loss group were similar to those used by hearing children. Similar patterns were also found in children with cochlear implants (Law & So, 2006). The same would be predicted for Cantonese vowels.

Method

Participant

Thirty-eight Cantonese-speaking children participated in the study, in which half of whom have normal hearing (serve as norm); while the other half were preliguistically profound hearing loss children with cochlear implant (CI). The normal and CI children were further divided into two groups (small and large) according to their chronological age and CI experience respectively. The chronological age in two normal groups were well-matched with the CI experience in two CI groups (Pearson

correlation coefficient *r* (CIS and NS) = 0.568, mean age = 1;03; *r* (CIL and NL)
=0.616, mean age = 2;11). Table 1 shows the descriptive information of the grouping
in this study.

Table 1. Descriptive information of the subject groups

Grouping	No. of subjects	Age (mean)	CI exp. (mean)
CIS	10	2;05-5;10 (3;10)	0;05-1;08 (1;02)
CIL	9	3;03-6;0 (4;10)	2;02-4;06 (2;11)
NS	10	0;08-1;08 (1;04)	N/A
NL	9	2;03-3;08 (2;11)	N/A

Note. CIS = children with CI experience shorter than 2 years; CIL = children with CI
experience longer than two years; NS= normal hearing children with age below 2;0;
NL= normal hearing children with age above 2;0.

The 19 participants in CI groups were pre-linguistically hearing impaired with
sensorineural hearing loss, with pure-tone average thresholds in better ear of 85dB HL
or more at 0.5, 1.0 and 2.0kHz. Of all CI participants, 13 had hearing aid fixed before
implantation. The HA exposure duration ranged from 1;06 to 4;09. However the HA
users could not be benefited from prodound hearing loss patient with PTA above
90dB in 250kHz (Tomblin, Spencer, Flock, Tyler, Gantz,1999). Benefit from HA on
speech perception and production for profound hearing loss patient was limited
(Myer, Svirsky, Kirk & Miyamoto, 1998; Snik, Vermeulen, Brokx, Beijk & Broek,
1997). The effect of HA exposure over CI experience on phonological development
was thus abrogated. The CI participants turned on cochlear implant for 10 hours or
more every day and had no known additional disorders, as well as any risk of
cognitive delay, sensory or neurological deficit. All multichannel cochlear
implantation were done in Hong Kong public hospitals. The ear molds were later

fitted by professional audiologists using hearing standard prescription or manufacturer's algorithms. The prescriptive hearing aid formulae could be different across manufacturers, and this was not controlled in this study. The CI participants attended child care centers for hearing impaired children for 6 hours per day, 5 days per week. The number of years of speech and auditory training for the hearing-impaired groups ranged from 0;05 to 2;04 in CIS group and 1;03 to 4;03 in CIL group. Speech and Auditory training (SAT) was provided by teachers for the deaf and speech therapists. All participants were native monolingual Cantonese speakers. The subject details are shown in Table 2:

Table 2. Descriptive information for participants

P	C.A.	Sex	Unaided level dB HTL		Aided level dB HTL			AI	CI exp.	SAT exp.
			PTA (L)	PTA (R)	PTA (L)	PTA (R)	250Hz			
CIS1	5;10	M	115	115	45	50	50	5;05	0;05	1;11
CIS2	2;07	F	100	100	95	40	50	1;10	0;09	0;05
CIS3	4;01	M	125	125	N/A	45	50	3;01	1;00	1;04
CIS4	4;08	M	125	125	52	N/A	55	3;06	1;02	2;04
CIS5	4;0	M	115	115	47	47	55	2;09	1;03	1;03
CIS6	2;05	M	97	117	N/A	45	50	1;03	1;03	0;05
CIS7	4;06	F	100	95	N/A	50	50	3;01	1;05	1;05
CIS8	3;04	M	85	110	N/A	40	55	1;11	1;05	1;05
CIS9	3;0	M	110	50	35	N/A	45	2;06	1;06	0;11

CIS10	4;0	F	95	100	45	N/A	50	2;04	1;08	1;11
CIL1	4;05	F	110	110	N/A	41	55	2;03	2;02	2;04
CIL2	3;10	F	100	100	70	71	60	1;07	2;03	2;09
CIL3	4;10	M	111	115	N/A	45	60	2;07	2;03	2;04
CIL4	3;03	M	110	115	N/A	45	60	1;00	2;03	1;03
CIL5	6;01	M	110	100	N/A	45	45	2;07	2;06	3;05
CIL6	4;03	M	100	110	N/A	50	50	1;04	2;11	2;02
CIL7	5;08	M	125	125	40	N/A	50	1;11	3;09	4;03
CIL8	5;05	M	115	105	42	N/A	45	1;01	4;05	3;04
CIL9	6;0	M	115	115	35	N/A	35	1;06	4;06	3;05

Note. P= participant; C.A.=chronological age; M=male; F=female; PTA= pure-tone average of thresholds at 500, 10000, and 2000Hz; AI= age of implant; CI Exp.= CI experience duration; SAT Exp. = Speech and Auditory Training experience duration.

* refer to Table 1 for the notation of group CIS, CIL, NS, NL.

The same amount of normal-hearing children was recruited. Nine children age ranged from 0;08 to 1;08 were assigned to NS group, while ten children age ranged 2;04 to 3;08 were assigned to NL group. Their mean ages were well-matched with hearing-age of hearing-loss subjects.

Procedures

All 39 participants were assessed in a quiet room in Child Care Center by the student author. The first five minutes were spent establishing rapport with the children through conversation and free play. The data collection started after the children explored the environment and were happy to cooperate. A picture naming task was

administered to elicit production of the seven Cantonese monophthongs /a, I, E, O, u, y, J/ and ten diphthongs /ui, ei, Oi, ai, Ai, Ty, iu, ou, Au, au/. Special care was taken to ensure that participants could hear and understand the instructions. The participants were asked to name 51 pictures in the tests. The 51 words from picture-naming test comprised of target vowels and diphthongs in three initial-consonant variations. All of the monophthongs and diphthongs were elicited under consonant-vowel monosyllabic single word level (see the Appendix 2). The targeted words were chosen from the Cantonese Pre-school Language Development Guide upon the highest frequency and lowest imagebility by Hong Kong preschoolers.

Data Analysis

All sessions were audio-recorded for subsequent phonetic transcription. The subjects' productions were transcribed using the International Phonetic Alphabet (International Phonetic Association, 1999) within one day after the sessions. Ten percent of the data were re-transcribed by the same final year student clinician one week after the first transcription to determine the intra-rater reliability. Another ten percent of the data was transcribed independently by another final year student clinician for evaluating inter-rater transcription reliability. The intra- and inter-rater reliability across transcription was calculated by dividing the number of agreements on the correctness by the total number of sounds produced and multiplied by one hundred. Intra-rater transcriptions showed 97.6% agreement and inter-rater transcription showed 82.6% agreement. Disagreements were resolved by consensus, with the two transcribers auditing the tape recordings together. All analyses used the consensus transcription.

The production accuracy for monophthongs and diphthongs of each subject was calculated. It was calculated by the number of phoneme correct divided by the total number of production trials times one hundred. The mean percentage correct was an average of all correct percentage across subjects in same groups and conditions. The number of production error was investigated individually and present statistically in column graph.

For phonological process analysis, the percentage of phonological process occurrence was calculated. It referred to the number of subject that have used the particular process twice or more in proportion to the total number of subjects in particular group.

It is well known perceived transcription and judgement were subjective. Inter-rater and intra-rater inconsistency were found. Minor change in production, like Subphonemic contrast, could not be detected perceptually. Hence, acoustic analysis was done in 20% of the subjects' production in each group. Computer software, named PRAAT, was used. The phoneme, from monophthongs and diphthongs group, with highest inter-rater disagreement perceived as correct was taken for spectrographic display to analysis its formant frequency and formant pattern.

Result

Comparison of groups' percentage correct for Cantonese vowels

All the subjects, both CI subjects and normal hearing subjects, had completed the picture-naming task. The percentages of monophthongs and diphthongs correct in each group were shown in Table 1.

Table 1. Cantonese vowels production by children with normal hearing and CI.

	Mean Percentage correct (%)	
Groups	Monophthongs (S.D.)	Diphthongs (S.D.)

CIS	87.62 (14.05)	65.33 (24.95)
CIL	96.82 (5.33)	83.70 (22.24)
NS	92.06 (7.14)	87.03 (8.89)
NL	94.70 (5.55)	92.96 (3.09)

Note. For the definition of CIS, CIL, NS, NL, please refer to Table 1 for illustration.

In monophthongs and diphthongs production, monophthongs achieved higher accuracy rate than diphthongs. The three groups (CIL, NS and NL) had mean percentage correct over ninety percent (CIL- 96%, NL-94%, NS- 92%). Production performance declined in diphthongs. Group with normal hearing was apparently better than CI children, with NL group achieved 92%, followed by NS for 87%. CI children with longer experience (83%) has much better accuracy than hearing experience shorter than two years (65%).

On the whole, the percentage correct was subjected to a two-way repeated measures analysis of variance (ANOVA; Group x Monophthongs, Diphthongs) having four independent groups (CISs, CIL, NS, NL) and two levels of Cantonese vowels categorization (monophthongs, diphthongs). There was a statistically significant main effect for four groups, $F(3, 102) = 4.046$, $p < .05$. There was also a statistically significant main effect between vowels and diphthongs, $F(1, 34) = 19.984$, $p < .05$. The interaction between the two independent variables (i.e. groups and condition) was also statistically significant, $F(3, 102) = 10.68$, $p < .05$.

For the production variables, simple main effect for vowels and diphthongs production in groups was further analyzed to elaborate the significant difference between groups. It was found that the simple main effect for diphthongs production between four groups was statistically significant, $F(3,34) = 4.655$, $p < .05$, but not for monophthongs, $F(3,34) = 1.864$, $p > .05$. In diphthongs, post-hoc test further
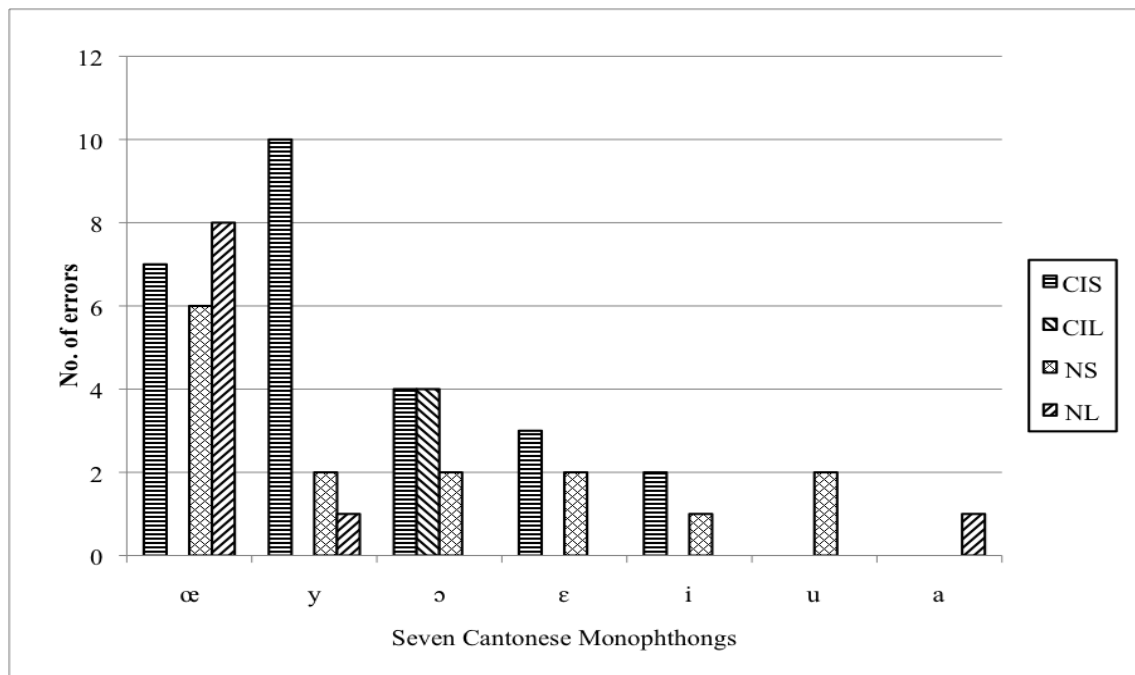
confirmed the significant difference was shown in CIS and NS comparison only. This indicated children with less than two years of hearing exposure performed statistically worse than those with two years or more. The longer duration of auditory exposure contributed to better diphthongs production.

A within group repeated measure on monophthongs and diphthongs were made to indicate production difference by same subject group. Statistical significance were found in both CIS group, $t(9) = .005$, $p < .05$, and NS group, $t(9) = .010$, $p < .05$. No significant difference between vowels and diphthongs production was reported for CIL , $t(10) = .087$, $p > .05$, and NL group, $t(10) = .288$, $p > .05$. The vowel production in CIS and NS group were significantly better then diphthongs. It showed that children in emerging language stage acquired vowels much faster then diphthongs. Greater performance variation across individuals was recorded in diphthongs than vowels.

**Comparison of individual phonemes' error occurrence**

For each vowel tested, subjects were required to produce it in three randomized trials. The total number of production in each vowel by all subjects including CI and hearing one was 114. Figure 1 showed the number of errors occurred in each Cantonese monophthong by different subject group. Among all, /ɔ/ has the highest number of error production, followed by /y/ and /o/ with over ten error productions out of 114 trials. Primary vowels /a/, /u/, /i/, /ɛ/ only had a few (fewer than five) erroneous incidence recorded. Secondary vowels /ɔ/, /y/ had more errors than the primary one. The CI groups contributed over half of all errors.

Figure 1. Error production of Cantonese monophthongs by CI and hearing roups

The production error in Cantonese diphthongs could be seen in *Figure 2*.

Figure 2. Error production of Cantonese diphthongs by CI and hearing groups.
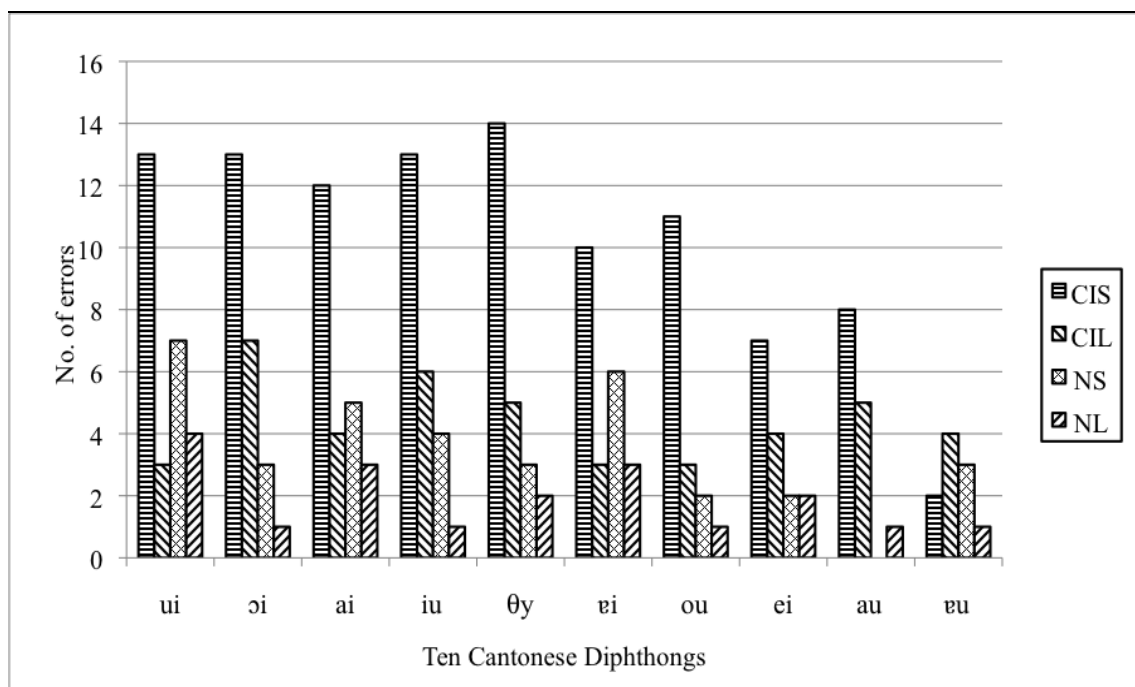
Unlike the monothphthongs production, no hierarchy of difficulties were

recorded in the diphthongs. /ui/ was recorded as highest erraneous production while

/ʌu/ with the least. Over 40% of the errors in all diphthongs were contributed by CIS group.

Phonological Process Analysis

The phonological processes used to account for all errors made by all groups were shown in Table 2.

Table 2. Phonological process used in CI children and normal hearing children

| Phonological process	Percentage of occurrence (%)			
	CIS	CIL	NS	NL
Developmental Rules				
Fronting	10	11.11	0	0
Diphthong reduction	90	44.44	70	0
Unusual Rules				
Backing	40	11.11	10	22.22
Centralization	10	0	0	0
Diphthongization	10	0	0	11.11

Five phonological processes were recorded. The first two rules in Table 2 were those used by more than 10% of a normative sample of Cantonese-speaking children with normal-hearing ability (So & Dodd, 1995). They were fronting (e.g. /ɔ/ → [e]) and diphthong reduction (e.g. /ui/ → [u]). The other three are the unusual rules, namely backing (e.g. /ɐ/ → [ɔ]), centralization (e.g. /y/ →[ʈ]) and diphthongization (e.g. /ɔ/ → [ou]). Overall, hearing groups had fewer phonological rules than the CI groups. The CI children showed both the developmental and non-developmental phonological process. Fewer processes were observed with longer hearing experience. CIS group had five phonological processes in which diphthong reduction the highest number of

incidence in production. Apart for backing, the other process (centralization and diphthongization) were below 10% in all four groups, which was counted as randomized errors. The percentage of process occurrence reduced as the hearing experience and chronological age increases.

Acoustic Validation

Of the seven monophthongs, /J/ was identified with greatest inter-rater disagreement, produced from the disyllabic word /kHJ5/. Figure 3 showed the its spectrogram displayed produced by subject in four groups.

Figure 3. Spectrogram of vowel /kHJ5/ from subject in four groups. Top left: CIS; Top Right: NS; Bottom left: CIL; Bottom right: NL.
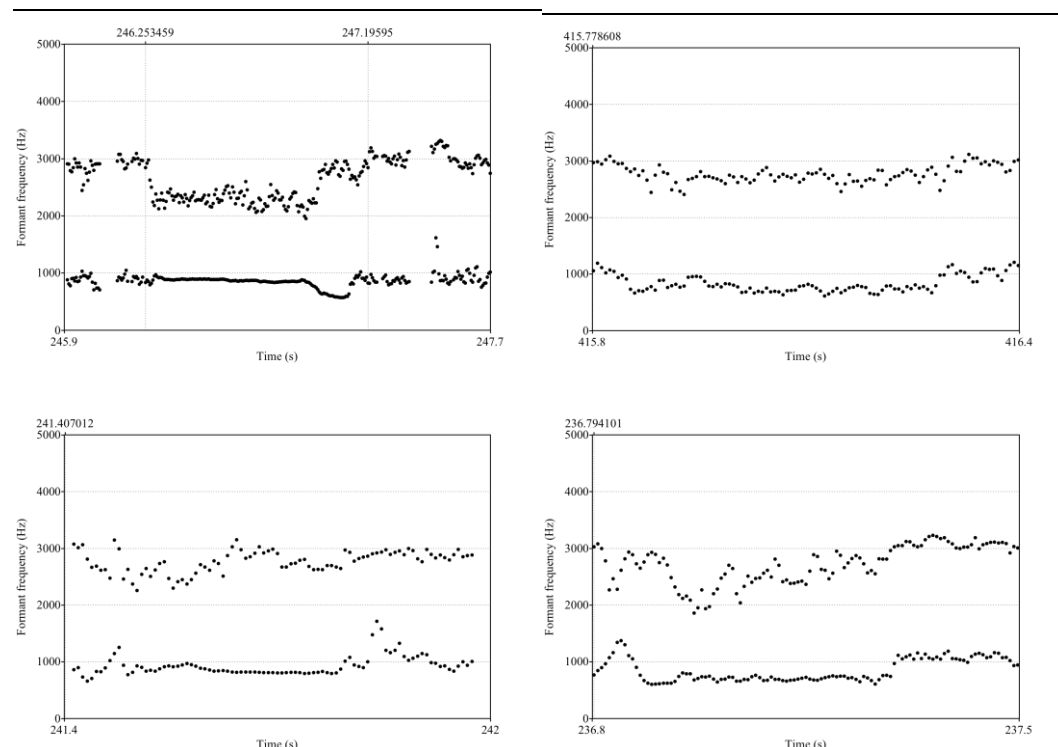

For monophthongs, acoustics pattern was consistent across four groups. The first formant (F1) was stable across subjects with different ages and hearing conditions. Mid-level of tongue height, represented by first formant, remained

unchanged even in children with cochlear implant. For second formant (F2), which concerned the tongue frontness, showed similar pattern in four groups. Unstable central tongue position was reflected from the fluctuating line in second formant. No apparent difference was found across four groups. Perceptual judgement corresponded to the acoustic data displayed.

The diphthong with greatest disagreement was /ai/, produced from the disyllabic word /hai2/. Figure 5 showed the its spectrogram displayed produced by subject in four groups.

Figure 4. Spectrogram of diphthong /ai/ from subject in four groups. Top left: CIS; Top Right: NS; Bottom left: CIL; Bottom right: NL.
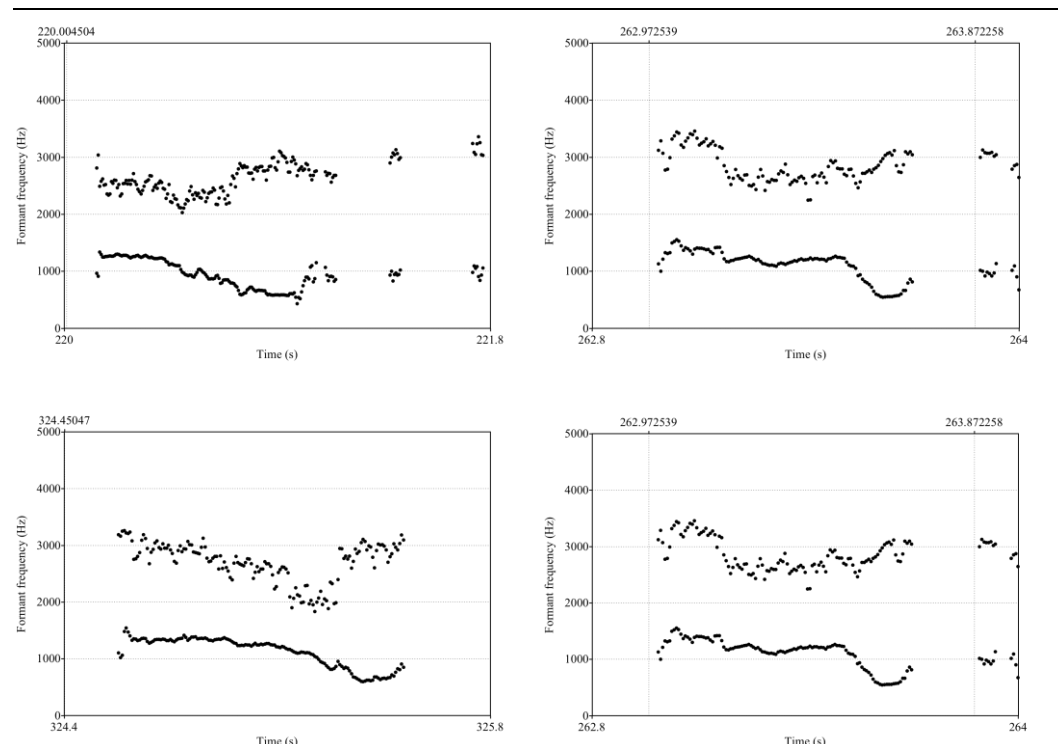
Unlike the monophthongs, diphthong production required a smooth transition from first vowel to the second one. A clear alternation of F1 and F2 should be seen in diphthong production. Here, the spectrogram of CIS subject was different from the other three. The transition from /a/ to /i/ was incomplete. The length of rising formants in F2 was shortened. A discrete pattern of monophthong /i/ was showed. The

distorted pattern, however, was not seen in production by CIL subject. With increase in hearing experience, a mature pattern of diphthongs would be expected. Perceptual judgement hence could not detect changes in emerging diphthongs in CIS subject.

Discussion

The vowels performance by CI and normal-hearing children were described in terms of production accuracy and phonological process involved. Performance on error occurrence was analyzed across four groups. Perceptual validation by acoustics measures were done.

General comparison of the four groups was first made between vowels and diphthongs production. The overall performance of vowels was significantly better than diphthongs. The production accuracy increased with ages and hearing experience. The older in age and the longer the hearing exposure, the higher the percentage correct was recorded. Both children with normal hearing and cochlear implant follow the developmental process in vowels acquisition. Children with cochlear implant demonstrated a developmental delay, rather than deviance, in vowels acquisition. This was in accordance with our prediction on improved production accuracy as hearing age increased.

For hearing exposure below two years, children with cochlear implant performed significantly worse than those with normal hearing. It could be attributed to the distorted auditory input by the electrical stimulation of cochlear. The distorted input is less precise in acoustics than natural sound system that requires a longer training time for auditory discrimination. The greater standard deviation in cochlear implant groups revealed greater individual difference in production accuracy. In time, cochlear implant children with hearing exposure more than two years reduced the erroneous production in monophthongs, together with a reduction across individuals'

difference. Diphthongs, from CI groups, were still in process of acquisition as seen in comparison to normal hearing children aged two or above. The four groups, except CIS, have mastered the monophthongs production with accuracy rate above 92%. Subjects from CIL group even performed better than NS group. As predicted, monophthongs acquisition preceded diphthongs in all groups. A developmental phonological learning process was seen in both normal hearing and cochlear implant children.

Unlike monophthongs, significant difference was found in diphthongs production across four groups, greatest difference was obtained between CIS and NS groups. Even with an increase in hearing exposure, CIL group was found inferior to NS group. According to Stokes and Wong (2002), articulatory complexity was a dominant factor in vowels acquisition in hearing children between 15 to 18 months. Children with cochlear implant had just mastered the monophthongs production by 18 months. An increase in articulatory complexity in diphthongs gave weight to functional load in perception and production. A longer time of, not solely exposure duration, auditory rehabilitation was required to achieve higher production fidelity. The acquisition of diphthongs required both adequate auditory exposure plus articulatory maturation. Role of articulatory complexity, on the country, for monophthongs production was not in high priority.

Barry, Blamey and Fletcher (2006) did a study to confirm the factors of vowels phonemes by pre-linguistically deafened cochlear implant users. They proposed a combination of perceptual, articulatory, and linguistic parameters contributed to acquisitions and development. Detail assessment on individual phoneme performance in our study could give insight to the above finding.

Comparison of individual phonemes' error occurrence was done to detect the track of acquisitions in four groups. Difference between monophthongs and diphthongs were evident. A clear acquisition pattern was identified in monophthongs, which would be discussed first followed by diphthongs. No errors were found in primary monophthongs /a/ & /ɔ/, while greatest number of error recorded in /ɔ/ & /y/. The acquisition pattern could be explained by the theory of articulatory complexity in phonological development. According to Jackobson (1968), the sequence of vowels emergence was determined by the complexity of articulatory movement. He proposed the segments of less complex features develop first. A completion of monophthong structure was required to facilitate diphthongs acquisition. Discussed by Stoel-Gammon and Herrington (1990), the central low vowel is most easily articulated, followed by high front and high back vowels. In Cantonese, the central low vowel /a/ developed first, followed by the high front vowel /i/, and then to high back vowels /u/. Primary monophthongs were easier to articulate than secondary monophthongs that finer adjustment had to be achieved for precise articulation. Tse (1991) did a longitudinal study on a single child on vowel development, that the maximally contrasted vowels /i/ and /a/ were acquired first. Case study in (1993) by Tse further confirmed the last vowels to be acquired were /y/ and /ɔ/. Same pattern could be seen in our study. Over 50% of the total errors were secondary monophthongs. They develop subsequent to primary one. Even in secondary monophthongs which are harder to be articulated, most of the errors were made by CIS group. Our study confirmed the rule of articulatory complexity in Cantonese monophthongs acquisition in cochlear implant children.

The articulatory traits on vowels were especially important for children with cochlear implant. Auditory training places its role to shorten the delay gap in

phonological development. Over the decade, heavy emphasis was place on visual and tactual cues on perception and production in auditory and speech rehabilitation (Sherrick, 1984; Miyamoto, Robbins, Osberger, Todd, Riley et. al,1995). Developmental information on vowels' place traits places an important role in their order of acquisition. Stokes and Wong (2002) mentioned that children could achieve secondary vowel /y/ and /ɹ/ in 24-27 months. Reviewing data from cochlear implant groups, no error was found in both secondary monophthongs for CI children with hearing exposure 24 months or above, even normal hearing children demonstrated erroneous production in /ɹ/. There was the positive effect from auditory training in CI group that further enhances children speech production and ameliorates the normal one without rehabilitation.

A universal developmental progress of vowel acquisition could also be found from our monophthongs result. Study by Selby, Robb and Gilbert (2000) showed the corner tense vowels [i, u, C, Y] were acquired before the lax vowels [U, V, I] in English-speaking children aged 15-36months. Paschall (1983) reported 20 Amercian English-speaking children aged 16-18 months demonstrated higher accuracy in vowels /a, i/ than mid and r-colored vowels. Study from T'sou, Lee, Tung, Cheung, Ng et al. (2006) on Hong Kong Cantonese Articulation Test showed /i, u, E, O, a/ should be achieved by two years old; secondary monophthongs /y/ and /ɹ/ should be achieved by three and four years correspondingly. For Children with distorted auditory input and hearing experience, their progress of acquisition corresponded to regional and universal study in other language background. The acquisition rate was fast and could be achieved by two years of age. The delay gap was short. Thus universal developmental process was seen in children with cochlear implant.

In diphthongs production, no particular order of acquisition could be detected in individual phoneme from CIS group. It indicated an emerging stage in diphthongs development that individual differences were seen in great variety. With increase in exposure time, significant improvement was found in CIL group. The significant improvement indicated the diphthongs were acquired beyond two years of age. A competent monophthongs ability is prerequisite to diphthongs acquisition. Hearing experience was hence beneficial to diphthong production.

Unlike the vowels, here diphthongs do not follow any universal acquisition process. It could be explained by the languages' difference in phonological and structures between them (Dodd & So, 1994). Cheung (1990) stated an interesting result that eight Cantonese diphthongs appeared before the mastery of secondary vowels /y, ɔ/. Only /au/ was comment acquired by 2;06 and /ai/ by 3;0. Our finding here however does not support the above. The improvement of CIL over CIS, on the contrary, followed the feature complexity hierarchy proposed by Stokes and Wong (2002). Diphthongs components differ across four features (tenseness, roundness, height, and anteriority). The lower the feature complexity of the diphthongs (e.g. /ei/, /ou/), the earlier the cochlear implant children could produce correctly. In addition, movement direction contributes to acquisition progress. The further the movement (e.g. front-back /iu/, back-front /ui/), the later the production accuracy was achieved. Thus, diphthongs with marginal shifting (e.g. /ɐu/, /ei/, /ou/) improve most significantly when hearing exposure increase in children with cochlear implant.

Last the linguistic factor, defined as the ambient frequency of occurrence, was least mentioned in speech and auditory training for CI users. It refers to the relative frequency of occurrence of individual phonemes in a particular population. It is

important to determine the order of acquisition of phonemes in later speech development (Stoel-Gammon, 1998; Munson, 2001). Barry, Blamey and Fletcher (2006) applied it to study the influence on Cantonese vowels acquisition in normal-hearing children. However, both monophthongs and diphthongs performance in our data do not support findings in cochlear implant groups. For children with distorted auditory input, articulatory and feature complexity are dominant factor in vowels acquisition.

Phonological process

The inaccurate production of monophthongs and diphthongs all subjects were analyzed by phonological process. Two developmental phonological rules, fronting and diphthong reduction, were used. In Dodd and So (1994) study on hearing-impaired Cantonese-speaking children, fronting was of frequent use in consonant production. In our study, fronting was only shown in children with cochlear implant, specifically on the mid-central vowels /O/ and /T/. The finding corresponded to our previous discussion on the articulatory distinctiveness on monophthongs acquisition. The mid-central vowel required finer adjustment on tongue positions. Fronting indicated subjects were in transitional period towards precise articulation. Diphthong reduction, likewise, was in support of the articulation complexity in acquisition. Children with hearing age below two (CIS and NS) are in acquisitional stage that high percentage of reduction was shown in all ten diphthongs. The process indicated an overloading in phoneme articulation. Children tended to produce easier phoneme first. Failure in monophthongs acquisition would hinder the development in diphthongs. With increase in hearing experience and success in monophthongs acquisition, the occurrence of diphthong reduction reduced.

For children over two years of hearing exposure, the percentage of diphthong reduction decreased. The process appeared in CIL group reduced by half. None was found in subjects from NL group. Reduction occurred in /ui, Oi, ai, Ai, iu/ only. This maybe because these five were with greatest tongue transition and temporal organization (Zee, 1993; Cheung, 2000). Cochlear implant children needed to overcome perceptual and articulatory difficulty to achieve accurate production.

Three atypical phonological rules, backing, centralization, diphthongization, were recorded. Only subjects in CIS group used all three rules while the other three groups used only backing and/or diphthongization. Both backing and centralization are found in secondary vowels /y/ and /ɝ/. Marginal shifting in horizontal axis is recorded, e.g. /y/ → [u] and /ɝ/ → [O]. On the contrary, a vertical upward shift was shown in diphthongization, e.g. /O/ → [ou] and /a/ → [ei]. However, the occurrence of centralization and diphthongization was too low to generalize for valid conclusion. To conclude, the result in phonological processes supported the discussion of articulatory and feature complexity in phonological development. Our result confirmed the prediction, that phonological processes identified in cochlear implant subjects were similar to those with normal hearing.

Acoustics Analysis

The results of the acoustic analysis of the selected data demonstrated that, in our study, perceptual judgement were a valid and reliable means of describing monophthongs pattern. Discrepancy between perceptual transcription and acoustic analysis was shown in diphthong production. The two transcribers, without any professional phonetic training, showed substantial validity on monophthongs perception. Whereas minor changes in diphthongs could not be detected. Loizou & Poroy (2000) proposed our perceptual difficulty depended upon acoustics complexity

of vowels. The acoustics properties of vowels could be described in terms of intensity and/or spectrum stability. The intrinsic vowel intensity highlighted its saliency in perception. Monophthongs with higher intensity could easily be perceived than less intense one. In Cantonese vowels, /a/ is the most intense while /i/ is the least intense one (Hsu, 2004). Our auditory system would automatically focus on anterior /a/ yet neglect the posterior /i/. Hence, incompletion of vowels transition could not be detected.

Limitation

The relatively small number of participants studied would limit the generalisability of the present study. The result may only represent a limited estimation of vowels production ability of children with cochlear implants at emerging age.

Acoustic analysis of children's formant structure required a good deal of subjective interpretation. In our study, only static measures of formant frequency were analyzed. To give a more comprehensive picture for analysis, that measures of dynamic acoustic properties, like spectral change over time, could be included to provide further insight to the nature of disordered vowel production (e.g. Neary, 1989; Strange, 1989)

Clinical implication

Our study showed that performance of children with longer hearing exposure was significantly different from shorter duration, so as the normal group. The use of cochlear implant promoted speech production. Developmental process in phonological error was detected. To apply our study in therapeutic approach, developmental sequence of Cantonese vowels of could be taken into consideration during therapeutic discussion. The order of phonological training could follow

acquisition norm in hearing population. It should be noted that the phonological process of children with cochlear implant made should be developmental errors. Any unusual process should be regarded as disordered whom should be referred to speech therapist for thorough assessment. Since articulatory complexity played a major role in acquisition, the use of tactile and verb cues for finer tongue adjustment should be encouraged in acquiring secondary vowels and diphthongs.

Conclusion

The present study showed that (a) the production accuracy from cochlear implant subjects was significantly different than that of hearing children with similar hearing experience, (b) developmental phonological rules were found in erroneous production, (c) Articulatory and feature complexity played an important role in the rate of monophthongs and diphthongs acquisition in CI children, (d) A developmental and universal phonological acquisition process was observed. Future CI development should examine to improve articulatory precision for CI user. In addition, any ways of post-implant training could be investigated to optimize their phonological ability and hence improving overall speech intelligibility.

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Appendix

Appendix 1a. Cantonese Monophthongs.

The 11 Cantonese vowels:
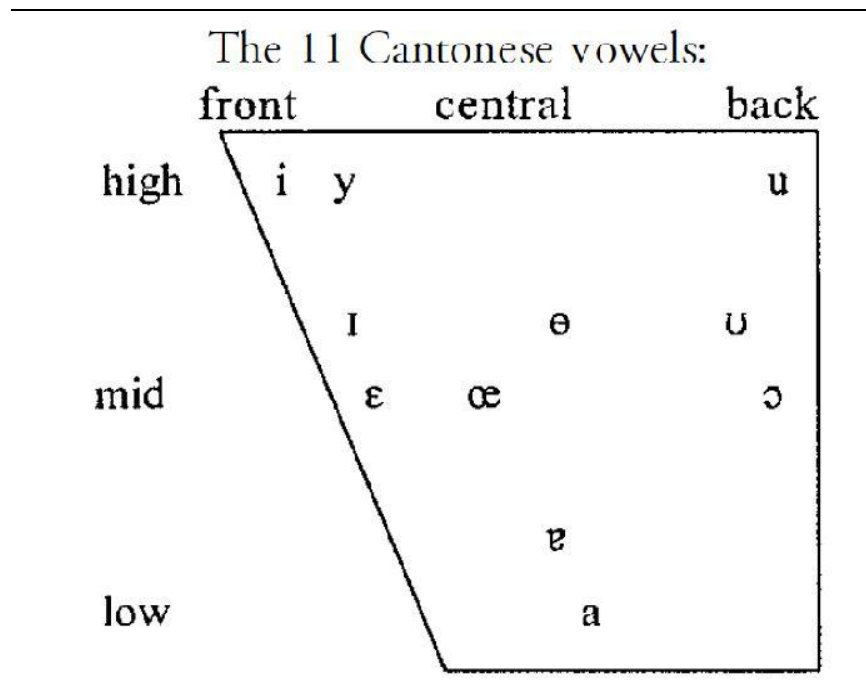
Appendix 1b. Cantonese diphthongs.

The 11 Cantonese diphthongs:
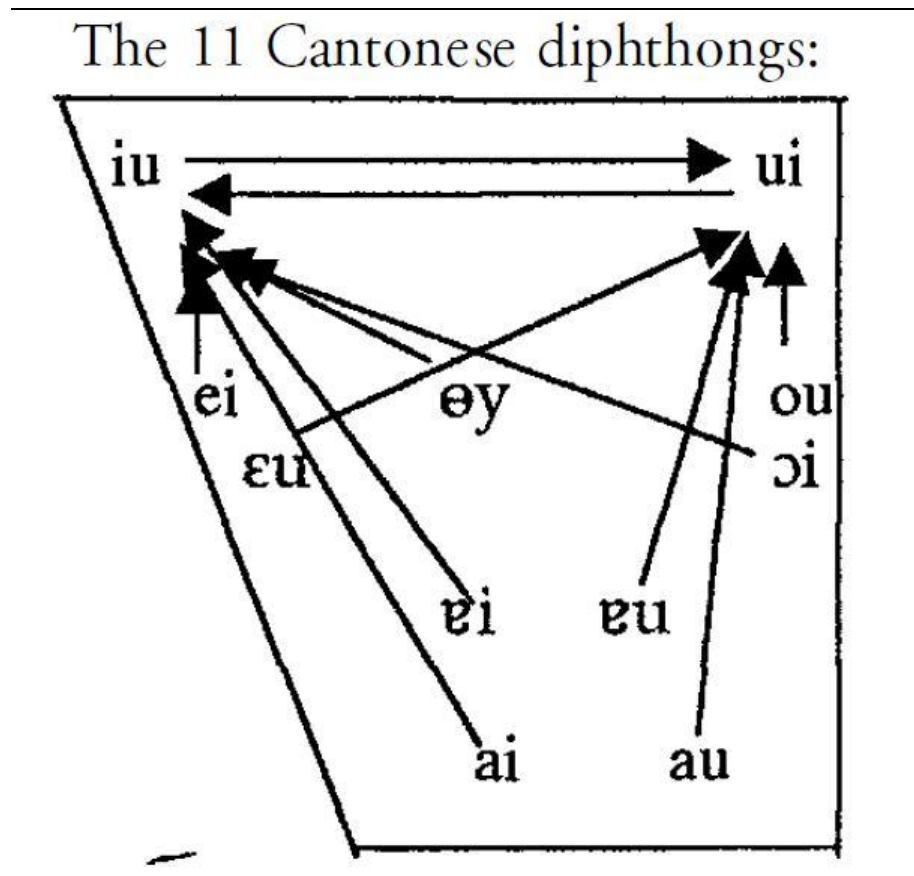
Appendix 2. Item list for the 51 pictures in the picture naming task.

Item No.	Phonetic transcriptions	Word meaning	Item No.	Phonetic transcriptions	Word meaning
1	ma2	horse	28	tsHOi3	vegetable
2	fa1	flower	29	hOi2	sea
3	ha6	down	30	kOi3	cover
4	di1	alphabet D	31	hai5	crab
5	yi6	two	32	mai5	buy
6	si1	lion	33	lai1	pull
7	pO1	ball	34	kAi1	chicken
8	fO2	fire	35	sAi2	wash
9	tsO2	left	36	wAi3	feed
10	sy1	book	37	tsTy2	lips
11	tsy1	pig	38	tsHTy1	blow
12	su6	tree	39	nTy2	girl
13	tsE1	umbrella	40	tsiu1	banana
14	sE4	snake	41	siu1	laugh
15	tsHE1	car	42	biu1	watch
16	ku5	drum	43	tou1	knife
17	fu2	tiger	44	tHou5	tummy
18	wu1	dirty	45	tsHou5	grass
19	hJ1	boot	46	kAu5	nine
20	tJ2	ear	47	hAu2	mouth
21	kJ3	saw	48	tsHAu4	head
22	pui1	cup	49	pau1	bread
23	fui1	grey	50	Nau5	bite
24	mui4	younger sister	51	nau6	scold

25	pei2	nose
26	sei3	four
27	fei1	fly

Appendix 3. Consent Form.

University of Hong Kong

Faculty of Education

Division of Speech and Hearing Sciences

Dear parents,

I am LEE Hiu Tung Irene, a year 4 student at the division of Speech and Hearing Sciences of University of Hong Kong. I am going to conduct a research project entitled "Vowels production by Cantonese-speaking children with cochlear implant". The research will investigate the Cantonese vowels production of Hong Kong children with cochlear implants. This can provide us a better understand on the hearing ability of Cantonese-speaking children with cochlear implants.

The participants will first complete a hearing screening and picture-naming task which is to be held in their child care centre. Children will be asked to look at pictures and read aloud the corresponding Cantonese word. The production will be audio-recorded. The whole procedure will take about 30 minutes.

The above procedure has no potential risks. Any personal information of the participants will not be disclosed to anyone, and will be completely confidential. The participation in the research is voluntary. You and your children can withdraw from this research at anytime without negative consequences. If you agree your children to participate in this research, please sign the consent form attached.

If you have any questions on the research, please feel free to contact me (Tel: 9586-1711; Email: irenelht@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 cooperation and participation are highly appreciated.

Yours sincerely,

LEE Hiu Tung, Irene

Division of Speech and Hearing Sciences

The University of Hong Kong

Parent / Guardian Consent Form

Student name(**IN BLOCK LETTER**): ＿＿＿＿＿＿＿ Sex: ＿* M / F＿

Date of Birth: ＿＿＿＿/＿＿＿＿/＿＿ (dd/mm/yyyy)

Class: ＿＿＿＿＿＿＿＿ (*am / pm/ whole day)

   I understand the research purpose and its content, and I * will / will not give

permission for my child to participate in the research,

(* Please delete if inappropriate)

Parent name(**IN BLOCK LETTER**) : ＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

Parent signature: ＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿

Date: ＿＿＿＿＿＿＿＿＿＿＿＿＿＿