Title	Production of affricate consonants by Cantonese-speaking pediatric cochlear implant users
Author(s)	Chan, Shuk-yan, Carol; 陳淑欣
Citation	
Issued Date	2009
URL	http://hdl.handle.net/10722/173660
Rights	Creative Commons: Attribution 3.0 Hong Kong License

Production of affricate consonants by Cantonese-speaking pediatric cochlear implant users

Chan Shuk Yan, Carol

A dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2009.

Abstract

This study investigated the affricate consonants production by Cantonese-speaking pediatric cochlear implant (CI) users. Eighteen participants with CI aged from 3;10 to 6;10 years were compared to 18 normal hearing children with similar hearing experience. Production of words containing unaspirated and aspirated affricate consonants, /ts, tsH/, were elicited for 60 trials from each participant in a picture naming task. The speech production was analyzed perceptually and acoustically for voice onset time (VOT) measurement. Results indicated that pediatric CI users with 2;07 years CI experience produced more phonological errors than their hearing peers. However, their performance caught up with the normal with 4;08 years CI experience in average. Non-developmental phonological processes were found only in CI participants. Even though CI participants were able to contrast the aspiration feature on the basis of VOT, their VOT values were consistently shorter than normal limits. Early intervention of invisible and subtle distinctions in speech is warranted.

Auditory experience plays a crucial role in promoting the development of well-formed speech (Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson et al., 2007). Restricted auditory access to the acoustic-phonetic cues of speech negatively affects the child’s ability to articulate speech sounds (Eisenberg, 2007). Before invention of any devices to restore hearing, studies revealed that infants with hearing loss were delayed in phonetic development in multiple aspects, such as later onset of consistent canonical babble, smaller phonetic inventories and reduced variety of syllables containing true consonants (Moeller et al., 2007; van-Hapsburg & Davis, 2006). Therefore, auditory deprivation in childhood can substantially hinder the development of one’s speech recognition and production abilities.

Restoration of audition via a cochlear implant (CI) appears to have a beneficial impact on the trajectory of phonetic skill development of children with hearing impairment. A CI works by bypassing the damaged or missing hair cells of the cochlea to stimulate the auditory nerve directly with an electrical equivalent of the sound signal (Wilson & Dorman, 2008). Besides the use as sensory aids for external sounds, CIs also provide the users with auditory feedback to refine their articulatory gestures necessary for intelligible speech production (Chin & Pisoni, 2000). As a result, improved segmental (i.e. consonants and vowels) aspects of speech have been found in children with CIs (Chin, 2003). Moreover, CI users tend to expand their phonetic repertories and increase the variety of consonant features, and eventually improve conversational speech intelligibility (Osberger, Maso, & Sam, 1993; Flipsen, 2008).

Some detailed information about improvement in consonant production after cochlear implantation already exists in the literature. Chin (2002) studied the characteristics of stop consonants produced by twelve pediatric users of CI with an average age of 9;10 years. Results revealed that children with CIs produced atypical speech differed from English mainly in having additional non-English stops (Chin, 2002). However, most of the published researches are based on English-speaking population. Comparatively little has been reported about the consonant production of CI users of Cantonese, especially focusing on specific sound categories. Law and So (2006) examined the phonological abilities of Cantonese-speaking children with CIs or hearing aids. They found that CI users had better phonological skills in general than hearing aid users with a similar degree of hearing loss. However, no specific sound class was examined. Yuen (2007) investigated the stop consonant production of Cantonese-speaking CI children and found that they used both developmental and unusual phonological processes when producing stop consonants. In addition, they had more errors in aspirated stops than their unaspirated counterparts. Apart from Yuen (2007), there has been no research on the production of sound classes in Cantonese by CI users.

In light of the previous research studying the characteristics of consonant production in CI users, the present study specifically examines the affricate production of Cantonese-speaking pediatric CI users, in relation to their hearing-experience-matched, normal hearing peers. Affricates form a sound class in Cantonese. The two affricates, /ts/ and /tsH/, have a dental/alveolar place of articulation (Bauer & Benedict, 1997). The perceptual study by So and Dodd (1995) showed that 90% of their participants acquired affricate consonants by age five. Affricates are generally considered as a combination of a stop and a fricative component (Ladefoged, 2006). There are three stages in the time course of affricate production. The first stage is the movement of an articulator toward a stop closure; the second is the closure itself while the third is the release of the closure with a frication noise (Johnson, 2003).

The investigation of affricates is of interest because it is well established that children with varying degree of hearing loss have experienced particular difficulties with production of fricatives and affricates, which are sounds in high frequency with components up to 8kHz (Cheung & Abberton, 2000; Peng, Weiss, Cheung & Lin, 2004; Mildner & Liker, 2008). Law and So (2006) studied the phonological abilities in Cantonese-speaking children with profound bilateral hearing loss aged from 5;01 to 6;04 years and revealed that affricates were one of the consonant classes that was most likely to be missing from their repertories. This may be related to the effects of sensorineural hearing loss on high-frequency information (Moeller et al., 2007). The primary objective of this study is to investigate the affricate production of Cantonese-speaking CI users and compare their performance with normal hearing peers who have similar hearing experience.

Donaldson and Kreft (2006) studied the effect of vowel context (i.e. front, central, back) on consonant identification in CI users. They found that context effects were not equally distributed across consonants. In general, vowel context effects tended to be the strongest for the voiceless stops, nasals and glide liquids whereas the weakest for the voiceless fricatives and affricates (Donaldson & Kreft, 2006). As no published study reported the effects of vowel context on affricate production in Cantonese population, the secondary objective of the present study is to investigate the effect of vowel context on affricate production in Cantonese-speaking pediatric CI users as well as their peers with normal hearing.

Unlike English affricates which show voicing contrast, the two Cantonese affricates are contrasted by the presence and absence of aspiration. The articulatory differences between unaspirated and aspirated affricates can be expressed in terms of voice onset time (VOT) --- the duration of the period between release of a stop closure and the onset of voicing of the following vowel. VOT provides an objective means for quantifying the aspiration contrast in speech sounds. In Cantonese, unaspirated consonants have a short lag time while the aspirated cognates have a long lag time along the VOT continuum (Stokes & Ciocca, 1999; Tsui & Ciocca, 2000). Khouw and Ciocca (2007) found that adolescents with profound hearing impairment produced initial stops with no significant difference in the mean VOT between the unaspirated and aspirated cognates for all three places of articulation. As VOT is such an important acoustic correlate for specifying the aspiration contrast in Cantonese

(Khouw & Ciocca, 2007), the last objective of the present study is to compare the VOT difference in producing unaspirated and aspirated affricates between the two groups.

Considering the lack of research studies in Cantonese affricates, especially in the population with hearing impairment, the present study is set out to investigate the affricate production of Cantonese-speaking pediatric CI users by both perceptual and acoustic means. More practically, it is hoped that the findings would help clinicians to have a better understanding of how much CIs help children with profound hearing impairment to acquire affricates and the aspiration contrast between the cognate pair. In this study, the following hypotheses were predicted:

1. Cantonese-speaking pediatric CI users who have short CI hearing experience would have poorer affricate production than their normal hearing peers with similar hearing experience. However, CI users with longer CI experience were able to catch up with the normal. It is because a longer time may be needed for CI users' mature acquisition of high-frequency sounds after cochlear implantation (Serry, Blamey & Grogan, 1997).
2. The articulatory error patterns of Cantonese-speaking pediatric CI users would involve both developmental and non-developmental processes as suggested by previous studies (Dodd & So, 1994; Law & So, 2006).
3. It is expected that the performance in affricate production of pediatric CI users and their hearing-experience-matched peers does not vary across vowel contexts because the vowel

context effects tend to be the weakest in voiceless affricates (Donaldson & Kreft, 2006).

4. It is expected that Cantonese-speaking pediatric CI users would have significantly shorter VOT in the production of unaspirated affricates than the aspirated one. It is because CIs were beneficial to the perception and production of VOT contrast (Uchanski & Geers, 2003). However, it is expected that Cantonese-speaking pediatric CI users would have significantly shorter VOT than their normal hearing peers in the production of both unaspirated and aspirated affricates, because the control of VOT requires precise control and coordination of respiratory, phonatory and articulatory movements which are invisible (Lane & Perkell, 2005). CI users may need more time to master the skill in order to achieve normal limits.

Method

Participants

Eighteen Cantonese-speaking children with CIs aged from 3;10 to 6;10 years (mean = 5;03 years) and 18 Cantonese- speaking normal hearing (NH) children aged from 2;01 to 5;10 (mean = 3;08 years) participated in this study. The CI users were selected on the basis of the criterion of being prelingually deaf with unaided Pure Tone Average in the better ear of 90 dB HL or more at 500, 1000 and 2000Hz. They have worn multi-channel CI for at least one year and manifested no additional handicapping condition, such as mental retardation or cerebral palsy, which might have affected their speech ability. The NH children were studying in normal kindergartens and had no known speech, language, or hearing problems according to parents and teachers reports.

Table 1 shows the descriptive information of the grouping in this study. For the CI participants, they were equally divided into two groups. Participants who had shorter hearing experience with CI belonged to CIS group. They had received cochlear implantation for 2;07 years in average. In Cantonese-speaking normal hearing children, 75% of them should have acquired the unaspirated affricate /ts/ by 2;06 to 3;0 (So & Dodd, 1995). Participants who had longer hearing experience with CI belonged to CIL group. They had received cochlear implantation for 4;08 years in average. In Cantonese-speaking normal hearing children, 90% of them should have acquired unaspirated and aspirated affricates /ts, tsH/ by 4;06 to 5;0 (So & Dodd, 1995). Table 2 provides the information of the CI participants regarding their age, sex, years of experience with hearing aids and CIs, and unaided and aided pure tone averages for both ears. For the NH group, all participants were matched with CI participants in terms of sex and averaged hearing experience with CI (e.g. A 5;01 years boy with 3;02 years CI experience was matched with a 3;02 years NH boy).

Table 1. Descriptive information of subject groups

Group	Number of participants	Age (Mean)	CI experience (Mean)
CIS	9	3;10-5;01 (4;08)	1;03-3;05 (2;07)
CIL	9	4;06-6;10 (5;09)	3;06-5;11 (4;08)
NHS	9	2;01-3;04 (2;07)	---
NHL	9	3;07-5;10 (4;08)	---

Note: **CIS** = cochlear implant users with shorter CI experience; **CIL** = cochlear implant users with longer CI experience; **NHS** = normal hearing children with younger age; **NHL** =

normal hearing children with older age

Table 2. Descriptive information for participants wm,k,ith cochlear implantation

Group	P	CA	Sex	AI	HA exp	CI exp	Train exp	Unaided PTA (dB HL)		Aided PTA (dB HL)	
								right	left	right	left
CIS	A	3;10	M	0;06	1;00	1;03	2;03	120	120	50	50
	B	4;00	F	0;03	1;02	1;07	2;09	100	120	55	50
	C	4;08	M	0;07	0;07	2;10	4;01	100	100	40	40
	D	4;09	F	0;10	0;06	2;01	3;06	103	92	40	55
	E	4;10	F	0;04	1;02	3;05	3;10	120	95	45	60
	F	4;11	M	0;00	0;08	3;05	4;03	120	120	35	35
	G	5;00	M	0;02	1;08	2;05	4;03	110	110	40	40
	H	5;00	M	0;05	0;11	3;03	4;00	120	120	35	35
	I	5;01	F	0;06	1;02	3;02	2;01	90	115	50	50
CIL	J	4;06	M	0;02	0;00	3;06	4;00	105	120	50	40
	K	5;04	M	0;01	1;00	3;10	4;00	120	110	40	40
	L	5;06	F	0;09	0;10	3;08	3;08	120	120	50	50
	M	5;06	F	0;09	0;10	3;08	3;08	120	120	50	50
	N	5;09	F	0;01	0;03	4;05	4;08	110	120	40	40
	O	5;11	M	0;07	0;03	4;05	4;08	105	115	35	35
	P	6;02	F	0;06	1;01	4;03	5;04	100	120	38	38
	Q	6;03	M	0;06	0;09	4;04	4;11	115	110	45	45
	R	6;10	F	0;03	0;06	5;11	5;11	115	100	43	55

Note: **P** = participant; **CA** = chronological age (years); **M** = male; **F** = female; **AI** = age of identification of hearing impairment (years); **HA exp** = hearing experience with hearing aids before cochlear implantation (years); **CI exp** = hearing experience with cochlear implants (years); **Train exp** = training experience for speech, language and hearing (years); **PTA** = pure-tone average of thresholds at 500, 1000 and 2000Hz.

Speech Material

Ten pairs of monosyllabic words with /ts/ and /tsH/ as initial consonants were used in the present study. The words in each set were selected such that they differ only in the target feature (aspirated and unaspirated affricate), while the vowel and tone were kept constant (minimal contrastive pairs). To ensure a more natural production, all stimulus words were embedded in a carrier phrase (meaning ‘I read ___ for you to hear’) during the recording.

Recording Procedure

Each participant was assessed in a quiet room. After rapport was built up, each participant was invited to read each word embedded in the carrier phrase for three times at a comfortable loudness level. The participants were provided with cards on which Chinese characters and corresponding pictures representing the citation words were printed. The syllables were presented in a random order. If the participant was unable to name the picture, the target word would be provided for imitation. Speech samples were recorded by the author using a microphone that was placed at a distance of 15cm from the mouth. The recorded samples were immediately digitalized at a sampling frequency of 22.05 kHz and 16 bits/sample and amplified by using a multi-channel conditioning amplifier. Digitalized signals of 60 trials from each participant were stored on a PC computer for later analysis.

Data analysis

The responses were online transcribed using International Phonetic Alphabet (International Phonetic Alphabet [IPA], 1999) by the author who had received training in phonetic transcription. The phonological processes used by each participant were later recorded based on the online transcription. A phonological process was judged to be used by a participant if he or she demonstrated the use of it at least twice in different target words.

For the acoustic analysis, VOT values (in milliseconds) were measured from the digitalized speech samples by using a speech analysis software (Praat v. 4.3). Such measurements were obtained by examining digital waveform displays in conjunction with wideband spectrograms (window size of 5ms) to mark the estimates of the release of stop occlusion (as indicated by an abrupt onset of energy in the formant frequency range) and the onset of the following vowel (as indicated by the first regularly spaced vertical striations following the stop release). The VOT measurements of the three productions for each affricate were averaged for each participant.

Reliability Measurements

For phonological analysis, 10% of the data were randomly selected and re-transcribed by the author about two weeks after the first transcription to determine the intra-rater reliability. Another 10% of the data were randomly selected and transcribed independently by another speech therapy clinician, for evaluation of inter-rater transcription reliability. The intra- and inter-rater reliability across transcriptions were calculated by dividing the number of agreements about the occurrence of speech sounds by the total number of sounds produced and multiplied by one hundred. Intra-rater transcriptions showed 91.25% agreement and inter-rater transcription showed 85.0% agreement.

For VOT measurement, 10% of the data were randomly selected and re-measured by the author two weeks after the first measurement to evaluate the intra-judge reliability. To determine the inter-judge reliability, another 10% of the data were randomly selected and analyzed independently by another speech therapy clinician, who was also experienced in acoustic measurement. Absolute percent errors were calculated to indicate the intra- and inter-judge reliability of measurement. Results indicated an absolute percent error of 5.84% between the first and second measurements by the author. An absolute percent error of 18.27% was found between the measurements made by the author and another judge.

Results

Percentage Error Analysis

The mean and standard deviation of percentage errors for the aspirated and unaspirated affricate consonants in the CI and NH groups are shown in Table 3. The percentage errors for each affricate consonant made by each group were compared. A 2 x 2 x 2 (group x hearing experience x aspiration contrast) three-way repeated-measures analysis of variance (ANOVA) analyses indicated significant interaction between group and hearing experience [$F(1,32) = 4.163$, $p = 0.050$]. Two subsequent 2 x 2 (group x aspiration contrast) two-way repeated measures ANOVAs (one for each hearing experience) were carried out to test for significant differences in percentage errors between each group with short and long hearing experience respectively.

For children with shorter hearing experience, a 2 x 2 (group x aspiration contrast) two-way repeated measures ANOVA indicated no significant interaction between group and aspiration contrast [F(1,16) = 0.062, p = 0.807] and no main effects in aspiration contrast [F(1,16) = 0.554, p = 0.468]. However, significant main effects were found in group [F(1,16) = 4.869, p<0.05]. Therefore, the CIS group exhibited significantly higher percentage errors than the NHS group in the production of both the unaspirated and aspirated affricate consonants.

For children with longer hearing experience, another 2 x 2 (group x aspiration contrast) two-way repeated measures ANOVA indicated no significant interaction between group and aspiration contrast [F(1,16) = 1.333, p = 0.265]. No main effects were found in aspiration contrast [F(1,16) = 1.333, p = 0.265], as well as in group [F(1,16) = 0.319, p = 0.580]. Therefore, the difference in percentage errors in the production of both the unaspirated and aspirated affricate consonants was not significant between the two groups with longer hearing experience (CIL and NHL).

Table 3. The mean and standard deviation of percentage errors in affricate production by the CI and NH groups

	Percentage error (%)			
Target	CI group		NH group	
	CIS	CIL	NHS	NHL
/ts/	42.2 (35.2)	4.4 (7.3)	12.2 (19.2)	1.1 (3.3)
/tsH/	44.4 (38.4)	4.4 (7.3)	13.3 (21.2)	4.4 (8.8)

Phonological Processes

The percentage of occurrence of phonological processes used to account for all errors made by both groups of children in the production of each affricate are shown in Table 4. Developmental processes in Table 4 were rules used by more than 10% of a normative sample of NH Cantonese-speaking children (So & Dodd, 1995). They were stopping (e.g., /tsHa$_{55}$/ → [tHa$_{55}$]), deaffrication (e.g., /tsa$_{55}$/ → [sa$_{55}$]) and deaspiration (e.g., /tsHa$_{55}$/ → [tsa$_{55}$]). On the other hand, non-developmental processes were rules that used rarely by hearing children acquiring Cantonese (Dodd & So, 1994). They were initial consonant deletion (e.g., /tsa$_{55}$/ → [a$_{55}$]), backing (e.g., /tsa$_{55}$/ → [ka$_{55}$]) and aspiration (e.g., /tsa$_{55}$/ → [tsHa$_{55}$]). In the present study, regardless of unaspirated or aspirated affricates, the NH children had fewer phonological processes (2-3 processes) than the CI children (5 processes). No NH children had non-developmental processes, but 38.9% (n = 18) of the CI children had non-developmental processes in the production of both affricates. With respect to the CI group, stopping was the most frequent process used in the production of both unaspirated and aspirated affricates. For the NH group, stopping was the major process concerning unaspirated affricates while deaspiration was the major process concerning aspirated affricate consonants.

Table 4. Percentage of occurrences of phonological processes used by the CI and NH groups in the (A) unaspirated affricate and (B) aspirated affricate production.

A

	Percentage of occurrences (%)			
	CI group		NH group	
Phonological processes	CIS	CIL	NHS	NHL
Developmental rules				
Stopping	28.9	0	12.2	0
Deaffrication	4.4	2.2	0	1.1
Non-developmental rules				
Initial consonant deletion	5.6	0	0	0
Backing	3.3	0	0	0
Aspiration	0	2.2	0	0

B

Phonological processes	Percentage of occurrences (%)			
	CI group		NH group	
	CIS	CIL	NHS	NHL
Developmental rules				
Stopping	28.9	0	8.9	0
Deaffrication	1.1	0	1.1	0
Deaspiration	24.4	3.3	5.6	4.4
Non-developmental rules				
Initial consonant deletion	1.1	0	0	0
Backing	0	1.1	0	0

Vowel context

In Cantonese, the vowel contexts were divided into three groups according to places of articulation (front, central and back). The effects of vowel context on affricate consonant production in Cantonese were investigated. The mean percentages errors in affricate production with different vowel contexts in both the CI and NH groups are shown in Table 5.

With respect to the CI group, a 2 x 3 (aspiration contrast x vowel context) two-way repeated-measures ANOVA showed no significant interaction between aspiration contrast and vowel context [$F(1,17) = 1.360$, $p = 0.260$]. No significant main effect was found in aspiration contrast [$F(1,17) = 0.106$, $p = 0.749$], as well as in vowel context [$F(1,17) = 0.486$, $p = 0.495$].

Similar results were found in the NH group, another 2 x 3 (aspiration contrast x vowel context) two-way repeated-measures ANOVA indicated no significant interaction between aspiration contrast and vowel context [F(1,17) = 0.321, p = 0.579]. No significant main effect was found in aspiration contrast [F(1,17) = 1.000, p = 0.331], as well as in vowel context [F(1,17) = 0.321, p = 0.579]. Therefore, there was no statistically significant difference in the accuracy of affricate production among different vowel contexts for both the CI and NH groups.

Table 5. Mean percentages errors in affricates with different vowel contexts by the (A) CI and (B) NH groups.

A

	Percentage error (%)	
Vowel context	/ts/	/tsH/
Front /i/	27.8	33.3
Central /a/	27.8	22.2
Back /O/	22.2	27.8

B

	Percentage error (%)	
Vowel context	/ts/	/tsH/
Front /i/	0.0	11.1
Central /a/	11.1	5.6
Back /O/	5.6	11.1

VOT measurements

The mean and standard deviation for VOT values from speech samples produced by the CI and NH groups are presented in Table 6. A 2 x 2 x 2 (group x hearing experience x aspiration contrast) three-way repeated-measures ANOVA analyses were used to determine if VOT values were significantly different between the CI and NH groups; short and long hearing experience; and among aspirated and unaspirated affricates. Repeated-measures ANOVA revealed no significant interaction between any independent variables [F(1,32) = 1.659, p = 0.207]. However, significant main effects were found in group [F(1,32) = 7.384, p<0.05], in hearing experience [F(1, 32) = 8.348, p<0.05], as well as in aspiration contrasts [F(1,32) = 361.488, p= 0.000].

Three conclusions were drawn from the above results. Firstly, regardless of hearing experience, the CI group consistently showed significantly shorter VOT values than the NH group in the production of both unaspirated and aspirated affricates. Secondly, no matter in the CI or NH group, children with longer hearing experience showed longer VOT values than those with shorter hearing experience in the production of both the unaspirated and aspirated affricates. Lastly, it was shown that aspirated affricates exhibited longer VOT values than unaspirated affricates in both the CI and NH groups, no matter with shorter or longer hearing experience.

Table 6. Mean and standard deviation for VOT values in affricate production by CI and NH groups

Target	VOT values (ms)			
	CI group		NH group	
	CIS	CIL	NHS	NHL
/ts/	39.7 (11.5)	48.1 (5.4)	49.9 (6.3)	53.0 (6.8)
/tsH/	82.1 (27.4)	108.8 (16.1)	105.7 (16.0)	112.2 (12.6)

Discussion

Percentage Error Analysis

The results of the present study revealed that pediatric CI users showed substantial improvement in the production of affricates as a function of implant use. For children with short CI experience (CIS group), they exhibited significantly higher percentage errors than their hearing-experience-matched peers (NHS group) in the production of both unaspirated and aspirated affricate consonants. With continuous and prolonged use of the device, the CI users (CIL group) increased their performance and approached that of the NH children with same duration of hearing experience (NHL group). These results were in accord with previous studies detailing increased speech production performance as a function of implant use in English-speaking populations. Serry et al. (1997) investigated the phonetic inventory development in a group of children with CI who were five years old or younger at the time of implant, they found that all consonants were acquired by their participants in the first four years of implant use. Nasals, stops, glides and liquids were acquired earlier and more completely than fricatives and affricates over the 4-year post-implant period (Serry et al., 1997).

The fact that pediatric CI users took a longer time than their peers with similar hearing experience to tackle the production of affricates might be attributed to their different courses of speech development. For the NH children, the general course of speech acquisition was such that auditory speech perception preceded production (Kishon-Rabin, Taitelbaum, Muchnik, Gehtler, Kronenberg, & Hildesheimer, 2002); therefore, they were able to utilize the auditory feedback to fine-tune their articulatory behavior since birth. For children with profound hearing impairment, the development was the opposite --- production preceded perception (Kishon-Rabin et al., 2002). In the present study, most of the participants did not wear any auditory prosthesis (either hearing aids or CIs) for the first and half years of their lives, speech production developed primarily on the basis of visual cues. After cochlear implantation, they no longer relied mainly on visual information for acquiring speech, but also on auditory information. It was likely that a longer time was needed for CI users to learn to relate the auditory feedbacks gained by the CIs to their articulatory gestures. It was no wonder that affricates posed extra difficulties to them since the high frequency information of the frication noise was not available in their lives previously, even with the help of hearing aids (Uchanski & Geers, 2003). As times went by, children with CI became more experienced in monitoring their auditory feedback for the purpose of maintaining articulatory precision and for detecting errors (Tye-Murray, Spencer & Gilbert-Bedia, 1995). Therefore, longer CI experience would normalize the developmental course in the production of affricate consonants in children with prelingual profound hearing impairment. This outcome supported the previous hypothesis that although CI was a feasible prosthetic aid for conveying information about the higher frequencies, a longer time may be needed for beginners to detect and utilize those sounds before significant improvement could be found (Serry et al., 1997).

Phonological Processes

Both the CI and NH children were shown to use phonological processes that were typical of the phonological development of Cantonese-speaking children. Stopping and deaspiration were the most common processes for the unaspirated and aspirated phonemes respectively in normal Cantonese acquisition (So & Dodd, 1995; Cheung & Abberton, 2000). Such findings were replicated in the NH group in the present study, in which stopping accounted for 91.6% of all error patterns in the production of unaspirated affricates while deaspiration accounted for 50% of that in the production of aspirated affricates.

For the CI group, the present study showed that stopping accounted for 61.9% and 48.1% of all the error patterns in the production of the unaspirated and aspirated affricates respectively. The data reported here also coincided with the findings from Dodd and So (1994), who identified the most frequent developmental rules used by Cantonese-speaking children with profound hearing impairment as stopping. Moreover, all CI participants in our study demonstrated stopping of affricates to the homorganic plosives /t/ rather than to bilabial plosives /p/ which was easier to produce. Such findings demonstrated the effectiveness of cochlear implants in perceiving place of articulation accurately in Cantonese as it was in English (Tye-Murray et al., 1995). On the other hand, only two CI participants demonstrated deaffrication in some of the production of affricates. This indicated that the production of fricative-component posed more difficulty than the stop-component in the production of affricates for CI users. It might be caused by a motor difficulty in the control of an obstruction of airflow followed by a constriction of articulators to produce a fricative noise (Cheung & Abberton, 2000).

Apart from developmental processes, seven CI participants (four in the CIS group and three in the CIL group) were also found to use non-developmental processes such as initial consonant deletion and backing which were atypical in the phonological development of Cantonese-speaking hearing children (Law & So, 2006). The development of atypical articulatory behaviors might be attributable to the children's attempt to substitute visual input and non-auditory feedback before cochlear implantation for auditory input and feedback after implantation (Higgins, McCleary, Carney & Schulte, 2003). Abnormal articulatory patterns persisted in the CIL group when the auditory signal became more accessible implied that direct intervention was warranted (Higgins et al., 2003).

Vowel context

The correctness of affricate production was not affected by different vowel contexts for both the CI and NH groups. These findings resembled those reported in previous studies based on English-speaking populations (Donaldson & Kreft, 2006). Yuen (2006) also found that different vowel contexts resulted in similar Cantonese stop consonants production performance in the CI and NH groups. This was because vowel place contrast was best perceived and produced by pediatric CI users within the first year of implant use (Kishon-Rabin et al., 2002). The equally well perception of vowel place contrast could be attributed to the working mechanism of cochlear implants. Several electrodes separated between second formant (F2) values that mediated differences in vowel place. Sensations from electrodes that were significantly apart from each other appeared to be immediately noticeable even with little implant experience (Kishon-Rabin et al., 2002). The prediction that affricate production was not affected by vowel contexts in both groups was thus confirmed.

VOT measurements

VOT was an important acoustic correlates for specifying the voicing contrast in English and the aspiration feature in Cantonese (Khouw & Ciocca, 2007). The results in the present study showed that both the CI and NH groups were capable of producing distinctive unaspirated and aspirated affricate consonants on the basis of VOT. The findings here were in agreement with those reported previously. Normal hearing children produced a statistically significant VOT contrast at labial, dental and velar places of articulation by the age of 2;06 years (Clumeck & Barton, 1981). For our CI participants, the measured VOTs for both affricates in the present study agreed fairly well with those reported by Peng (2008), who compared the production of aspirated phonemes by Cantonese-speaking CI users and hearing aid users. Therefore, it was proved that CIs were beneficial to the perception and production of VOT contrast (Uchanski & Geers, 2003).

No previous reports have compared the affricate production by pediatric CI users to their hearing peers with similar hearing experience. The results revealed that although the CI users were able to produce an aspiration contrast based on VOT, they consistently produced shorter VOT than their normal hearing peers in both the unaspirated and aspirated affricates. The tendency for individuals with profound hearing impairment to produce shorter VOT than normal hearing individuals was attributed to the difficulty they experienced in coordinating laryngeal and oral gestures. The control of VOT required precise timing of glottal and supraglottal events and a high degree of temporal coordination of articulatory events which were not visible and thus were particularly vulnerable to deafening (Lane, Wozniak & Perkell, 1994; Khouw & Ciocca, 2007). Therefore, even though aspiration contrast was transmitted via audition after cochlea implantation, it might still be difficult for CI users to detect and utilize the auditory information in relation to the invisible articulatory movements about the timing cues of voice onset. Achieving an appropriate aspiration contrast on the basis of VOT involved an intricate coordination of the timing and magnitude of movements in the respiratory, laryngeal, and supraglottal systems, such as regulation of speech breathing, the glottal opening-closing gesture, the relative timing of the oral constriction, modulation of the stiffness of the vocal tract walls and folds etc (Lane & Perkell, 2005). Since the timing was critical and the gestures were complex, perhaps more CI experience was required before children with profound hearing impairment could achieve normal VOT limits.

Clinical implications

The present study contributed to our current knowledge about the affricate production in children who were deprived of sounds in the first few years of their lives and then developed phonetic representations via CIs. The data reported here showed that pediatric CI users needed more than 2;07 years to produce affricates perceptually comparable to their NH peers. Based on the acoustic analysis, it took even more than 4;08 years for them to produce VOT values within normal limits. Therefore, it is necessary for speech therapists to develop aural rehabilitation programs well suited to the needs of CI children in order to maximize the effectiveness of treatments. Massaro and Light (2004) implemented a computer-animated talking head as a language tutor for speech perception and production for seven children with severe hearing loss aged from 8;0 to 13;0 years. The computer program illustrated articulation by making the skin transparent to reveal the movement of tongue, teeth, and palate during production of different phonemes. More importantly, it showed supplementary articulatory features for some distinctions in spoken language that could not be heard easily even when hearing was restored with CIs, such as illustrating vibration of the neck to show voicing and turbulent airflow to show frication (Massaro & Light, 2004). The program was found effective for all participants in their study. Perhaps a Cantonese version of such program can be developed. It is hoped that similar findings in Cantonese-speaking populations might be replicated since such a program can heighten learners' awareness of the articulation of those invisible and subtle distinctions in speech (Massaro & Light, 2004).

Limitations and Further study

The main focus of the present study was to find out the relationship between the length of implant use and the performance in affricate production. However, besides the length of implant use, other endogenous and exogenous factors such as children's non-verbal intelligence, preverbal and non-verbal competencies, types of education programs and family support are also important in influencing production outcomes (Pisoni, 2000; Uchanski & Geers, 2003). Continuous efforts are warranted in the area of evaluating factors affecting the acquisition of phonemes by Cantonese-speaking CI users.

References

Bauer, R. S., & Benedict, P. K. (1997). *Modern Cantonese Phonology.* Berlin: Mouton de Gruyter.

Cheung, P., & Abberton, E. (2000). Patterns of phonological disability in Cantonese-speaking children in Hong Kong. *International Journal of Language and Communication Disorders, 35,* 451-473.

Chin, S. B. (2002). Aspects of stop consonant production by pediatric users of cochlear implants. *Language, Speech, and Hearing Services in Schools, 33*, 38-51.

Chin, S. B. (2003). Children's consonant inventories after extended cochlear implant use. *Journal of Speech, Language, and Hearing Research, 46*, 849-862.

Chin, S. B., & Pisoni, D. B. (2000). A phonological system at 2 years after cochlear implantation. *Clinical Linguistics and Phonetics, 14,* 53-73.

Clumeck, H., & Barton, D. (1981). The aspiration contrast in Cantonese word-initial stops: data from children and adults. *Journal of Chinese Linguistics, 9*, 210-225.

Dodd, B. J., & So, L. K. H. (1994). The phonological abilities of Cantonese-speaking children with hearing loss. *Journal of Speech and Hearing Research, 37*, 671-679.

Donaldson, G. S., & Kreft, H. A. (2006). Effects of vowel context on the recognition of initial and medial consonants by cochlear implant users. *Ear and Hearing, 27*, 658-677.

Eisenberg, L. S. (2007). Current state of knowledge: speech recognition and production in children with hearing impairment. *Ear and Hearing, 28,* 766-772.

Flipsen, P. (2008). Intelligibility of spontaneous conversational speech produced by children with cochlear implants: A review. *International Journal of Pediatric Otorhinolaryngology, 72*, 559-564.

Higgins, M. B., McCleary, E. A., Carney, A. E., & Schulte, L. (2003). Longitudinal changes in children's speech and voice physiology after cochlear implantation. *Ear and Hearing, 24*, 48-70.

International Phonetic Association (1999). *Handbook of the International Phonetic Association: a guide to the use of International Phonetic Alphabet.* Cambridge, UK: Cambridge University Press.

John, K. (2003). *Acoustic and auditory phonetics (2nd ed.).* Malden, MA: Blackwell Publishing.

Kishon-Rabin, L., Taitelbaum, R., Muchnik, C., Gehtler, I., Kronenberg, J., & Hildesheimer, M. (2002). Development of speech perception and production in children with cochlear implants. *The Annals of Otology, Rhinology and Laryngology, 111*, 85-90.

Khouw, E., & Ciocca, V. (2007). An acoustic and perceptual study of initial stops produced by profoundly hearing impaired adolescents. *Clinical Linguistics and Phonetics, 21*, 13-27.

Ladefoged, P. (2006). *A Course in Phonetics (5th ed.).* Boston, MA: Thomson, Wadsworth.

Lane, H., & Perkell, J. (2005). Control of voice-onset time in the absence of hearing: A review. *Journal of Speech, Language, and Hearing Research, 48,* 1334-1343.

Lane, H., Wozniak, J., & Perkell, J. (1994). Changes in voice-onset time in speakers with cochlear implants. *Journal of the Acoustical Society of America, 96,* 56-64.

Law, Z. W. Y., & So, L. K. H. (2006). Phonological abilities of hearing-impaired Cantonese-speaking children with cochlear implants or hearing aids. *Journal of Speech, Language, and Hearing Research, 49,* 1342-1353.

Massaro, D. W., & Light, J. (2004). Using visible speech to train perception and production of speech for individuals with hearing loss. *Journal of Speech, Language, and Hearing Research, 47,* 304-320.

Mildner V., & Liker, M. (2008). Fricatives, affricates, and vowels in Croatian children with cochlear implants. *Clinical Linguistics & Phonetics, 22,* 845-856.

Moeller, M. P., Hoover, B., Putman, C., Arbataitis, K., Bohnenkamp, G., Peterson, B. et al. (2007). Vocalizations of infants with hearing loss compared with infants normal hearing: part I – phonetic development. *Ear and Hearing, 28,* 605-627.

Osberger, M. J., Maso, M., & Sam, L. K. (1993). Speech intelligibility of children with cochlear implants, tactile aids, or hearing aids. *Journal of Speech and Hearing Research, 36*, 186-203.

Peng, I. C. W. (2008). *Production of aspirated phonemes in Cantonese-speaking children with* *cochlear implants or hearing aids*. Unpublished dissertation. The University of Hong Kong.

Peng, S. C., Weiss, A. L., Cheung, H., & Lin, Y. S. (2004). Consonant production and language skills in Mandarin-speaking children with cochlear implants. *Archives of Otolaryngology: Head & Neck Surgery, 130*, 592-597.

Pisoni, D. B. (2000). Cognitive factors and cochlear implants: some thoughts on perception, learning, and memory in speech perception. *Ear and Hearing, 21*, 70-78.

Serry, T., Blamey, P., & Grogan, M. (1997). Phoneme acquisition in the first 4 years of implant use. *The American Journal of Otology, 18,* S122-S124.

So, L. K. H., & Dodd, B. J. (1995). The acquisition of phonology by Cantonese-speaking children. *Journal of Child Language, 22*, 473-495.

Stokes, S. F., & Ciocca, V. (1999). The substitution of [s] for aspirated targets: perceptual and acoustic evidence from Cantonese. *Clinical Linguistics and Phonetics, 13,* 183-197.

Tsui, I. Y. H., & Ciocca, V. (2000). Perception of aspiration and place of articulation of Cantonese initial stops by normal and sensorineural hearing-impaired listeners. *International Journal of Language and Communication Disorders, 35*, 507-525.

Tye-Murray, N., Spencer, L., & Gilbert-Bedia, E. (1995). Relationships between speech production and speech perception skills in young cochlear-implant users. *Journal of the Acoustical Society of America, 98*, 2454-2460.

Uchanski, R. M., & Geers, A. E. (2003). Acoustic characteristics of the speech of young cochlear implant users: a comparison with normal-hearing age-mates. *Ear and Hearing, 24*, 90S-105S.

van-Hapsburg, D., & Davis, B. L. (2006). Auditory sensitivity and the prelinguistic vocalizations of early-amplified infants. *Journal of Speech, Language, and Hearing Research, 49,* 809-822.

Wilson, B. S., & Dorman, M. F. (2008). Cochlear implants: a remarkable past and a brilliant future. *Hearing Research, 242*, 3-21.

Yuen, C. W. K. (2007). *Production of stop consonant by Cantonese-speaking cochlear implant users*. Unpublished dissertation. The University of Hong Kong.

Acknowledgment

I would like to express my sincere thanks to Dr. Lydia So for her generous support and guidance on this dissertation; Dr. Lawrence Ng for the help with statistical analysis; Mr. Norman Lo and Ms. Eliza Chan for their assistance with data collection and reliability check.

Grateful thanks are also given to principals, teachers, children, and their parents in Bradbury Special Child Care Centre, Sheung Tak Special Child Care Centre and Suen Mei

kindergarten for their support and participation in this study.

Appendix: Word list

No	**Unaspirated affricate** /ts/			**Aspirated affricate** /tsH/		
	Words	Phonetic transcription	Meaning	Words	Phonetic transcription	Meaning
1.	遮	/**tsE**$_{55}$/	Umbrella	車	/**tsHE**$_{55}$/	Car
2.	紙	/**tsi**$_{35}$/	Paper	(牙)齒	/**tsHi**$_{35}$/	Teeth
3.	渣	/**tsa**$_{55}$/	Squeezing	叉	/**tsHa**$_{55}$/	Fork
4.	左	/**tsO**$_{35}$/	Left	(清)楚	/**tsHO**$_{35}$/	Clear
5.	追	/**tsJy**$_{55}$/	Chasing	吹	/**tsHJy**$_{55}$/	Blowing
6.	蕉	/**tsiu**$_{55}$/	Banana	超(人)	/**tsHiu**$_{55}$/	Superman
7.	早	/**tsou**$_{35}$/	Morning	草	/**tsHou**$_{35}$/	Grass
8.	剪	/**tsin**$_{35}$/	Cutting	錢	/**tsHin**$_{35}$/	Money
9.	奬	/**tsJN**$_{35}$/	Prize	腸	/**tsHJN**$_{35}$/	Sausage
10.	鐘	/**tsuN**$_{55}$/	Clock	蔥	/**tsHuN**$_{55}$/	Spring onion