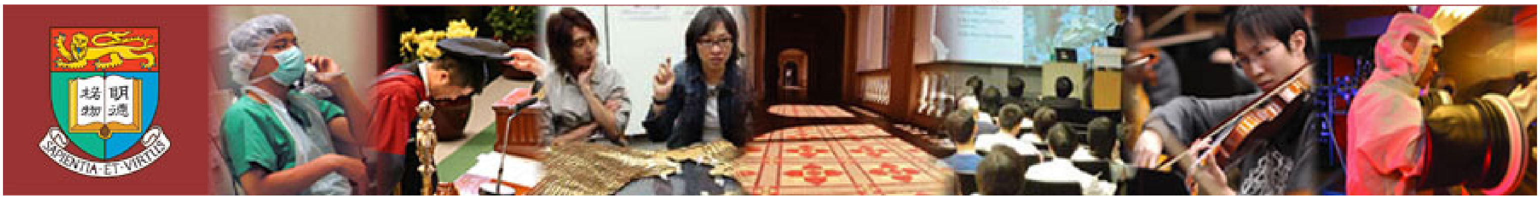

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Tone Production Ability in Cantonese-speaking Hearing-impaired Children with Cochlear Implants or Hearing Aids

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Abstract

This paper compares the tone production ability of 16 prelingually hearing-impaired Cantonese-speaking children (mean age = 5;08) with cochlear implants (CI) or hearing aids (HA), with norm from 8 normal hearing children. The participants completed a naming task. Tone productions were perceptually rated by 12 listeners and tone contours were displayed acoustically. Results showed that (a) children with normal hearing performed significantly better in tone production than children with hearing impairment (b) Cochlear implant and hearing aid users did not significantly differ in tone production ability (c) higher pitched tones (Tone 55 and Tone 25) were produced significantly better than lower pitched tones (Tone 21 and Tone 22) in the groups with cochlear implants or hearing aids.

Tone Production Ability in Cantonese-speaking Hearing-impaired Children with Cochlear Implants or Hearing Aids

Perception and production of speech is considerably challenging to children with profound hearing impairment. Delayed or disordered speech production patterns are frequently observed in these children (E. Tobey, 1993). Consonant and vowel errors were reported in many studies with English-speaking children, like Levitt, McGarr and Geffner (1987). In profoundly hearing-impaired Cantonese-speaking children with conventional hearing aids, both developmental phonological processes (e.g., delabialization, stopping, /h/ deletion and deaspiration) and non-developmental phonological processes (e.g., frication, addition, initial consonant deletion, and/or backing) were observed (Dodd & So, 1994).

The speech perception skills of hearing impaired children, which appeared to support their speech production abilities, were found to improve with the use of multichannel cochlear implants (Young & Killen, 2002). Multichannel cochlear implants (CI), which are surgically implanted electronic devices that help provide a sense of sound to profound hearing impaired individuals, have been available for over a decade. They do not work by amplifying sounds, as in the case of conventional hearing aids (HA); rather, they work by directly stimulating any functioning auditory neural elements inside the cochlea with coded electrical impulses, bypassing damaged or missing hair cells of the cochlear.

Cochlear implants have been found to improve consonants and vowel perception and production (e.g. Chin, 2003; Dawson et al., 1995; E. A. Tobey & Hasenstab, 1991). In particular, Geers, Brenner, & Davidson (2003) found that implanted children achieved unprecedented levels of speech perception skill four to seven years after implantation. Besides, E.A. Tobey, Pancamo, Staller, Brimacornbe, & Beiter (1991) found that a significantly greater number of children in their study produced stop, nasal, fricative, and glide consonants postimplant. Also, the study by Ertmer, Kirk, Sehgal, Riley and Osberger (1997) revealed that cochlear implantees' vowel production were significantly better than those of the tactile aid users after a comparable amount of device experience. Apart from the improved consonants and vowel perception and production skills, children with cochlear implants also imitate consonants, vowels, and diphthongs better than those with hearing aids (E. A. Tobey, Geers, & Brenner, 1994). Improvements were also observed in speech intelligibility (e.g. Tye-Murray, Spencer, & Woodworth, 1995; Dawson et al., 1995) and language development (Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). Early cochlear implantation was concluded as a cost-effective procedure that allowed children with hearing impairments to fit into a typical school, in a study by Geers and Brenner (2003), who studied the background and educational characteristics of prelingually deaf children implanted by five years of age. Nonverbal intelligence, gender, implant characteristics, and educational programs with emphasis in oral-aural communication were important factors for speech development (E. A. Tobey, Geers, Brenner, Altuna, & Gabbert, 2003).

The aforementioned studies in English language reveal that children with cochlear implant have shown improved phonological abilities, and the improvements are more significant than those achieved by peers with conventional hearing aids with similar degree of hearing loss.

Similar findings have been reported in Cantonese speaking children. Law and So (2006) studied the phonological skills of Cantonese-speaking children with prelingual, profound hearing loss, fitted with hearing aids or cochlear implants, and found that cochlear implant usage appeared to promote consonant feature production development to a greater degree than did the use of a hearing aid.

Nevertheless, there are still controversies on whether cochlear implants are effective in improving suprasegmental elements like tone and intonation, which require the encoding of voice pitch information. The suprasegmental elements serve important functions in a variety of languages. The syntax of all known languages appears to depend on pitch variations extended over sequences of speech. With reference to a grammatical hierarchy, these variations frame the linear development of all utterances (Leon & Martin, 1972). Besides, the lexicon of nontonal languages, such as English and German, employ melodic factors in accentual contrasts. Nickerson (1975) suggested that intonation was particularly difficult for hearing impaired talkers, which might due to the deprived auditory referent in the frequency domain. However, more recent research suggested that language-matched normal and hearing-impaired children might not be very different in their production of contrastive stress production (Weiss, Carney, & Leonard, 1985), and many hearing-impaired children had the ability to benefit substantially from training in the production of intonation (Allen & Arndorfer, 2000).

Voice pitch information is even more important in tonal languages (e.g. Cantonese) in which lexicon depends on a system of height opposition based on the differences in level as well as on changes in pitch (Leon & Martin, 1972).

Cantonese is a widely spoken tonal language. It is the major language spoken by the people in Hong Kong, the city of Guangzhou, and the province of Guangdong in the Peoples Republic of China. Globally, Cantonese is used by speech communities of 1000 or more people in more than 65 countries (Bauer & Benedict, 1997). It is generally accepted that there are 19 consonants, 11 vowels, 11 diphthongs and six contrastive tones in Cantonese. Specifically, the contrast in tone marks a difference in lexical meaning. Cantonese tones are characterized by tone level (high, mid and low) and tone contour (rising, falling and level) (Fok-Chan, 1974). Based on the tone-letter notation system by

Chao (1947), the six contrastive lexical tones can be described impressionistically as tone 55 (high level), tone 25 (high rising), tone 33 (middle level), tone 21 (low falling), tone 23 (low rising), and tone 22 (low level). The numerical values in brackets describe the level of the pitch at the beginning and the endpoint of the tone.

Given the heavy functional load of tone in Cantonese, it is apparent that the quality voice pitch information conveyed by hearing devices would have a relationship with the perception and hence the production of speech in hearing-impaired children. Various studies have shown that children with cochlear implant demonstrate great difficulty in perceiving Cantonese tones. Aisha (2000) found that cochlear implanted children performed at about chance level in identifying the six tones. Similarly, Lee, van Hasselt, Chiu and Cheung (2002) found that tone perception score was significantly lower in cochlear implanted children when compared to normal hearing children, and the pattern of tone perception development of the implantees did not seem to follow that of normal children. In addition, study by Ciocca, Francis, Aisha and Wong (2002) suggested that cochlear implantees had great difficulty in extracting the pitch information needed to identify Cantonese lexical tones accurately. Nevertheless, Kwok et al. (1991) found that in adults with single-channel cochlear implants, tone perception was possible and significantly better than those with hearing aids. Besides, J. G. Barry et al. (2002) reported on the ability of children with cochlear implant to discriminate pitch variations in Cantonese by using an experimental procedure based on play audiometry. Implant users were shown to derive sufficient pitch information to discriminate most tone contrasts relatively successfully with performance being most variable for contrasts involving tones clustered in the lower register of the speaker's fundamental frequency range. No significant benefits for aiding pitch discrimination were observed to be offered by higher electrode stimulation rates.

There are few studies investigating the tone production in hearing-impaired children. Study in Mandarin revealed that the tone patterns produced by children with cochlear implants tended to be flat, with some other pattern being irregular resulting in degraded intelligibility of the tone patterns (Xu, Li, Hao, Xue, & Han, 2004). Peng, Tomblin, Cheung, Lin and Wang (2004) study yielded agreeing results, that the majority of prelingually deaf children with cochlear implants did not master Mandarin tone production. However, it was found that a small group of participants demonstrated nearly perfect skills of Mandarin tone production and perception.

There are no specific studies hitherto comparing the tone production ability of Cantonese-speaking hearing-impaired children with cochlear implants or hearing aids. Dodd and So (1994) found that most children in their study with binaural hearing aids exhibited mastery of productive tone. J. Barry, Blamey, Lee and Cheung (2000) investigated the process of tone development and differentiation of three Cantonese-speaking hearing-impaired children with cochlear implant, and concluded that the rate of acquisition of the tonal inventory was found to be slower than the rate of development of the vowel inventory for those children. Tone55 was found to be acquired before Tone25, while none of the participants acquired Tone21 in the time frame of the study. Recent study by Lee, Tong and van Hasselt (2007) suggested that children should receive their implant before two where they would be able to achieve around 80% accuracy in tone production within one year of implant use. Acoustically, the study of Khouw and Ciocca (2006) with adolescents revealed that production of intended tones was not reliably distinguished by average f0 and f0 change over the second half of the vocalic segment, which were important cues for accurate identification of Cantonese tones produced by speakers with normal hearing.

The disagreeing findings in previous studies thus call for an investigation in the tone production in Cantonese-speaking hearing-impaired children with cochlear implants or hearing aids. The following research questions will be investigated: How well do children with hearing aids or cochlear implants perform in tone production task? Do children with conventional hearing aids perform better in tone production task when compared to children with cochlear implants? Are there any differences between the tone contours produced by hearing-impaired children and normal hearing children? In the present study, the tone production ability in Cantonese-speaking prelingually hearing-impaired children will be examined and compared, with norm from a group of normal hearing children. The clinical implication from the present findings would also be discussed.

It is hypothesized that the hearing-impaired group would perform significantly worse than the normal hearing group, due to the degraded auditory input. Despite the difficulty reported in tone perception, children with conventional hearing aids are predicted to have better tone production ability than those with cochlear implants, as conventional hearing aids allow reception of the whole range of frequencies ,yet cochlear implants only transmit those frequencies at the points that the electrodes are turned on, resulting in the loss of stimulation in certain ranges of frequencies. Also, when compared to the normal hearing group, the tone produced by the hearing-impaired group may tend to be flat, as a reflection of the impoverished pitch encoding provided by the hearing aids or cochlear implants.

Method

Participants

Twenty-four Cantonese-speaking children participated in the study, in which eight of whom have normal hearing (serve as a norm); while the other 16 were prelinguistically profound hearing-impaired, with eight fitted with cochlear implants, and the other eight fitted with hearing aids. The participants in CI and HA groups were preliguistically hearing impaired with sensorineural hearing loss, with pure-tone average thresholds in the better ear of 90 dB HL or more at 0.5, 1.0, and 2.0 kHz. They wore hearing aids/ turned on cochlear implant for 10 hours or more every day and had no known additional disorders, as well as not at risk of any cognitive delay, sensory or neurological deficit. The three groups were well-matched in terms of chronological age (Pearson correlation coefficient r (HA and CI) = 0.936, r (HA and normal) = 0.905, r (CI and normal) = 0.942; mean age = 5;8). The mean hearing age for the CI group was 4;03 (ranged from 3;02 to 5;05) while that for HA group was 3;11 (ranged from 2;03 to 5;07). The mean length of cochlear implant experience was 3;06 (ranged from 2;03 to 4;10) for the CI group. All hearing aids and ear molds of the children with hearing aids were fitted by professional audiologists using hearing standard prescription or manufacturer's algorithms. The prescriptive hearing aid formulae could be different across different manufacturers, and this was not controlled in this study. The participants with hearing impairments attended child care centres for hearing impaired children for 3 hours per day, 5 days per week. The number of years of auditory and speech training for the hearing-impaired groups ranged from 1;07 to 5;03. Speech and auditory training were provided in the child care center by teachers for the deaf and speech therapists.

All participants were monolingual Cantonese speakers using multiword utterances. The subject details are shown in Table 1:

Table 1. Descriptive information for participants

P	C.A.	Sex	Unaided level dB HTL PTA (R)	Unaided level dB HTL PTA (L)	Aided level dB HTL PTA (R)	Aided level dB HTL PTA (L)	Age of identification of hearing loss	Brand of device	Speech-coding Strategy	H.A (CIe)	Y.T
CI1	5;03	F	125-130	105-120	Bi	35-55	0;01	B	SPEAK	3;11 (3;06)	3;03
CI2	5;04	F	115-120	115-120	Bi	40-55	Birth	A	SPEAK	3;05 (2;08)	3;00
CI3	6;05	F	113	105	Bi	43	Birth	C	N/A	4;00 (4;00)	4;02
CI4	6;01	F	100-120	105-120	Bi	35-55	0;01	A	SPEAK	5;00 (3;07)	5;02
CI5	5;00	F	111	113	60	58	Birth	A	SPEAK	4;00 (2;03)	4;00
CI6	6;03	M	105	117	Bi	37	Birth	A	SPEAK	5;05 (4;09)	5;03
CI7	6;04	M	125-130	130-135	Bi	30-45	1;00	A	SPEAK	5;03 (4;10)	1;07
CI8	4;10	M	95	95	Bi	35-50	0;04	B	SPEAK	3;02 (2;03)	2;08
HA1	6;03	M	120	120	Bi	30-50	Birth	G/H	-	4;09	3;09
HA2	6;04	M	95	95	Bi	50-55	1;10	D/E	-	5;07	3;09
HA3	5:04	M	90	90	Bi	38	Birth	F	-	4;04	4;00
HA4	5;05	M	95	90	Bi	33	Birth	F	-	4;03	4:01
HA5	6;02	M	110-115	105-110	40-60	35-50	2;06	E	-	3;05	3;02
HA6	5;05	M	120-125	85-90	Bi	30-50	3;00	F	-	2;03	1;07
HA7	4;08	F	100	95	53.3	47	Birth	N/A	-	2;06	2.03
HA8	5;08	F	120-125	120-125	Bi	50-55	0;08	D	-	4;00	3;05
N1	5;11	M	-	-	-	-	-	-	-	-	-
N2	5;09	F	-	-	-	-	-	-	-	-	-

N3	5;03	M	-	-	-	-	-	-	-	-	-
N4	6;03	F	-	-	-	-	-	-	-	-	-
N5	5;05	M	-	-	-	-	-	-	-	-	-
N6	5;02	M	-	-	-	-	-	-	-	-	-
N7	5;02	F	-	-	-	-	-	-	-	-	-
N8	5;08	M	-	-	-	-	-	-	-	-	-

Note. P = participants; M = male; F = female; R = right; L = left; C.A = chronological age; PTA = pure-tone average of thresholds at 500, 1000, and 2000 Hz; HTL = hearing threshold; H.A = hearing age; CIe = length of CI experience; Y.T = years of speech and auditory discrimination training; Bi = binaural; A = Nucleus ESPrit 3G-L; B = Nucleus 24 ESPrit 3G-L; C = Cochlear CI24R (CS); D = Phonak Supero; E = Siemens Swing S3+; F = Phonak MAXX211; G = Perseo 311d; H = Claro 311d; N/A = not available.

Materials

A set of 12 pictures was used to elicit the production of the target words. The speech stimuli consisted of a set of monosyllabic consonant-vowel words, which represented common objects and concepts that were familiar to children at preschool level (e.g. /fa$_{55}$/ (flower), /wa$_{25}$/(picture), /kwa$_{33}$/(hang), /ŋa$_{21}$/(tooth), /ma$_{23}$/(horse), /ha$_{22}$/(below) and /pO$_{55}$/(ball), /fO$_{25}$/(fire), /fO$_{33}$/(classroom), /hO$_{21}$/(river), /tsO$_{23}$/(sit), /ŋO$_{22}$/(hungry)), since children were more successful at perceiving tones on words than on nonwords (Lee, Chiu, & van Hasselt, 2002). Words were used in the present study to minimize the probability of bias in data. Each picture showed an object, adjective or illustration of a motion representing a word exemplifying a target tone. The target word was written at the bottom of the picture as a written cue. A written cue of "ŋɔ$_{23}$ tuk$_{2}$ kɔ$_{33}$ ___ tsi$_{22}$ pei$_{25}$ nei$_{25}$ t^{h}eŋ$_{55}$" (I read the word ___ to you) in Chinese traditional characters was provided to the child as a written cue of the carrier phrase.

Procedures

1. Tone production task

Participants were assessed in a quiet room by the researcher individually. Hearing aids or cochlear implants of the hearing-impaired speaker were checked by the Ling's Seven Sound Test to ensure the reported functioning. The child was first asked to read aloud all the target words on the pictures upon modeling by the researcher. Then, the picture cards were presented one by one to the participant to elicit his production. Each picture card was presented to the participant three times in a random manner. After that, the same set of pictures was presented in a random manner three times as well, in which the participants were asked to produce the target words embedded in a carrier phrase "ŋɔ$_{23}$ tuk$_{2}$ kɔ$_{33}$ ___ tsi$_{22}$ pei$_{25}$ nei$_{25}$ t^{h}eŋ$_{55}$" (I read the word ___ to you). Appropriate cues such as semantic or syllabic cues were given when the child failed to produce the target word. The speech samples were recorded with a microphone connected to a Bruel & Kj{r Type 2812 MKII Two Channel Microphone preamplifier and a SONY portable Minidisc recorder MZ-R70. A 10cm mouth-to-microphone distance was maintained during recording.

After the recording, the speech samples were low-pass filtered at 22kHz and digitized at sampling rate of 44.1kHz with Praat software (Boersma & Weenink, 2006).

2. Perceptual rating of the tone productions

The tone production samples were divided into three panels according to the pattern shown in Appendix A. Each panel consisted of a same number of productions from all the speakers with all the six tones. The three panels of samples were then rated by 12 native speakers of Cantonese, who had received training in Cantonese phonetics but had no previous experience in listening to the speech of the individuals with hearing impairment. They were not informed of the objectives of the present study. They were instructed to rate the tone (Tone 55, Tone 25, Tone 33, Tone 21, Tone 23, Tone22) of what they heard from the recording for each production. For the carrier phrases, listeners were instructed to rate the target word only. They were reminded to rate the production based on the tones produced and minimizing the effect of any phoneme error.

3. Data analysis

The tone production data for each of the three groups of speakers was subjected to the perceptual rating mentioned above. These data were summarized as tone confusion matrixes. Percentage correct tones (PCT) was also calculated for each group and tone. The differences between different tones and groups in PCT were analyzed with one-way ANOVA using the SPSS v.15 software.

Besides, with the use of Praat software (Boersma & Weenink, 2006), the F0 of each target word produced by a typical speaker of each group was measured and then plotted into tone contours for qualitative analysis.

Ten percent of the stimuli was rated twice by all the listeners to obtain intra-rater reliability. The average intra-rater reliability and inter-rater point-to-point reliability across ratings was 92.8% (ranged from 88.9% to 100.0%) and 82.0% (ranged from 79.4% to 85.3%) respectively. This was calculated by dividing the number of agreements about the occurrence of speech sounds by the total number of sounds produced and multiplying by 100.

Results

Perceptual rating of tone production

1. Comparison of results in word condition and carrier phrase condition

The percent correct tone (PCT) from a perceptual rating of tones produced by children with cochlear implant, hearing aids or normal hearing in carrier phrase and word condition are shown in Table 2. While the average PCT (percent correct tones) observed for the children with CI, HA and normal hearing in production of single words by perceptual rating were 66.25%, 60.51% and 75.49% respectively, the average PCT in production of carrier phrases were 71.94%, 73.47%, 87.22%, which were consistently higher than that of words across all three groups. Two-tailed t-test showed statistically significant difference between the means score of the three groups in word situation (mean = 0.68, s.d. = 0.467) and in carrier phrase situation (mean = 0.78, s.d. = 0.417), with Pearson r = 0.308 ($p < 0.001$).

Table 2. Percentage correct tone (PCT) from a perceptual rating of tones produced by children with cochlear implant, hearing aids or normal hearing in carrier phrase and word condition

	Group	**PCT (%)**						**Average PCT (%)**	**Range of PCT (%)**
		55	25	33	21	23	22		
Carrier phrase	CI	94.23	85.10	74.04	54.90	68.75	54.59	71.94	54.59-94.23
	HA	95.50	86.06	76.00	74.13	65.10	44.00	73.47	44.00-95.50
	Normal	99.51	83.82	87.98	95.00	83.02	73.96	87.22	73.96-99.51
Single word	CI	91.83	80.77	48.00	56.73	67.71	52.45	66.25	48.00-91.83
	HA	89.00	85.00	38.00	61.98	47.60	41.50	60.51	38.00-89.00
	Normal	83.65	86.06	59.43	78.65	79.17	66.00	75.49	59.43-86.06

A plausible explanation for the phenomenon is that in the production of carrier phrase, pitch normalization was made possible by the words preceding and following the target word. The listeners had access to a tonal framework within which to judge the pitch level of the tone to be produced on the target word. Also, as the stimuli were presented in carrier phrase in medial position, any rise or drop of intonation that might affect the perceived tone values were prevented (Vance, 1976). Considering daily conversations were more in the form of phrase rather than single word, the performance of carrier phrase should also mimic the daily performance of the three groups. With regard to such observation, the tone production in carrier phrase was used in successive analysis.

2. Differences in tone production score between the CI, HA and normal groups

Using the tone production score as the dependent variable, results of one-way ANOVA, $F(2, 3453)=49.661$, $p < .05$, indicated significant differences between CI, HA and normal groups. Post hoc test results showed that significant differences exist between CI and normal group as well as between HA and normal group. Specifically, differences between groups within each tone were investigated. Significant differences were found in all except Tone 25 (Tone 55: $F(2, 573)=4.634$, $p < 0.05$; Tone 33: $F(2, 573)=8.763$, $p < 0.05$; Tone 21: $F(2, 573)=45.467$, $p < 0.05$; Tone 23: $F(2, 573)=8.788$, $p < 0.05$; Tone 22: $F(2, 573)=18.722$, $p < 0.05$). Among these tones with significant differences between groups (except tone 4), the normal group had the highest mean score, and post-hoc test results show that the differences were between the CI and normal group as well as HA and normal group, with no significant differences between the CI and HA group. For tone 4, there were significant differences between all the three groups, with normal group having the highest score, followed by HA group and then by CI group.

3. Differences in tone production score between the six tones

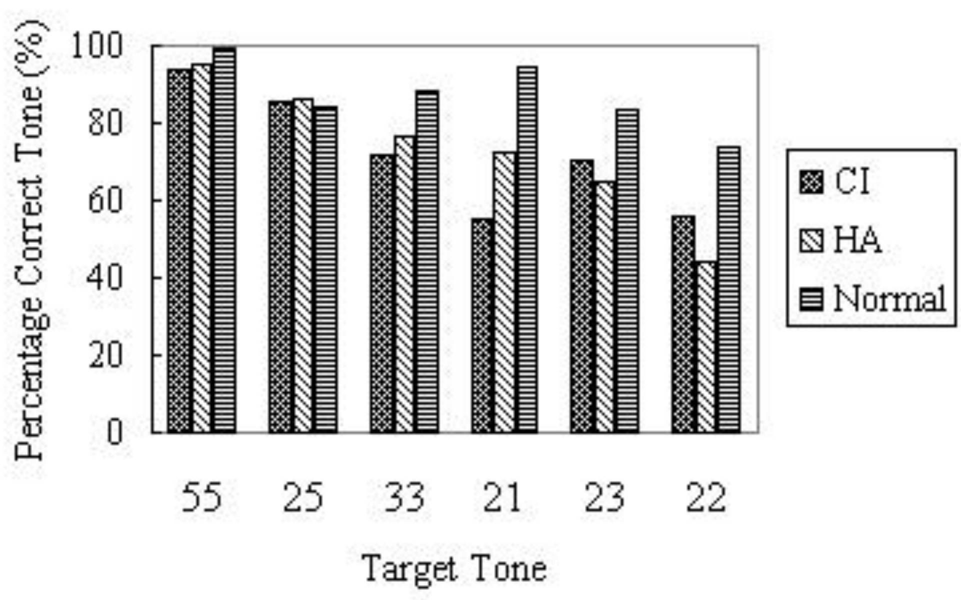
Tone confusion matrixes from the perceptual rating results by adult listeners are displayed in Table 3 for each of the groups by the performance in carrier phrase condition.

Table 3. Tone confusion matrix from a perceptual rating of tones produced by children with cochlear implant, hearing aids or normal hearing in carrier phrase condition. Confusions are shown as a proportion of total target productions for each tone.

		Tone Production					
Target	**Group**	55	25	33	21	23	22
	CI	**94.23**	0.00	*11.54*	0.49	1.04	5.61
55	HA	**95.50**	0.48	8.50	3.06	0.00	5.00
	Normal	**99.51**	0.98	0.96	0.00	0.00	0.00
	CI	0.00	**85.10**	1.92	7.84	*11.46*	0.51
25	HA	1.00	**86.06**	1.50	1.02	*18.75*	5.00
	Normal	0.00	**83.82**	4.33	0.00	4.72	0.00
	CI	5.77	9.62	**74.04**	*13.73*	*12.50*	*19.39*
33	HA	3.50	6.73	**76.00**	8.67	*13.54*	*12.00*
	Normal	0.00	6.86	**87.98**	0.00	9.43	8.85
	CI	0.00	0.00	1.44	**54.90**	3.65	3.57
21	HA	0.00	1.92	6.50	**71.43**	1.04	*20.50*
	Normal	0.00	0.98	0.48	**95.00**	0.94	7.81
	CI	0.00	1.92	1.92	*13.24*	**68.75**	*16.33*
23	HA	0.00	2.40	2.50	5.10	**65.10**	*13.50*
	Normal	0.00	3.43	0.48	0.50	**83.02**	9.38
	CI	0.00	3.37	9.13	9.80	2.60	**54.59**
22	HA	0.00	2.40	5.00	*10.71*	1.56	**44.00**
	Normal	0.00	3.92	5.77	4.50	1.89	**73.96**

The criterion of consistent confusion with another tone was set as more than 10% of the productions were rated to the other tone. From the above confusion matrix, it can be seen that that the normal group, as expected, had the best performance, with no tone consistently confused with another tone. Nevertheless, in the group with hearing aids, though Tone 55, Tone 25 and Tone 33 were not consistently confused with other tones, Tone 21 (71.43%) was confused with Tone 22 (10.71%), Tone 23 was confused with Tone 25 (18.75%) and Tone 33 (13.54%) while Tone 22 (44.00%) was confused with Tone 33 (12.00%), Tone 21 (20.50%), and Tone 23 (13.50%). In the group with cochlear implant, the performance in Tone 55 and Tone 25 were similar, with no consistent confusion with other tones. However, Tone 33 (74.04%) was confused with Tone 55 (11.54%), Tone 21 was confused with Tone 33 (13.73%) and Tone 23 (13.24%), Tone 23 was confused with Tone 25 (11.46%) and Tone 33 (12.50%), whereas Tone 22 was confused with Tone 33 (19.39%) and Tone 22 (16.33%). The graph for the tone production score of the six tones in the three groups are shown in Figure 1:

Figure 1. Percentage correct tone of the CI, HA and normal groups across the six tones

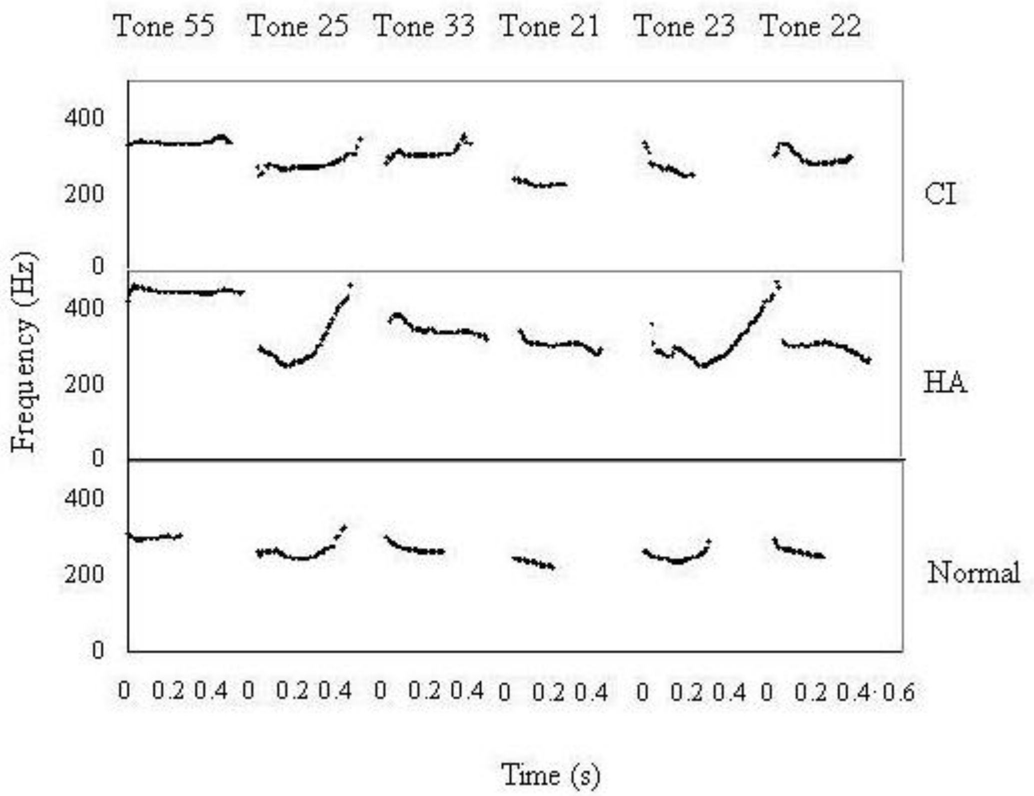


The above graph revealed that Tone 55 and Tone 25 scored higher than other tones in the hearing-impaired groups, with Tone 55 having the best performance and Tone 22 having the worse performance across all the three groups.

Tone contours

The plots for a subject typical for each subject group were shown in Figure 2:

Figure 2. Comparison of Tone Contours Produced by a Typical Subject of Each Group.



Each line represents F0 of the vowel part of a Cantonese syllable produced by the participants (CI7, HA6, N8). The F0s for the normal-hearing child showed the typical high and flat (Tone 55), high and rising (Tone 25), mid-level and flat (Tone 33), low and falling (Tone 21), low and rising (Tone 23) and low and flat (Tone 22) contours.

The CI and HA participants made various errors in tone production. Tone 55, Tone 25 and Tone 21 are similar to the normal pattern, with relative high and level, high and rising, and low and falling contours respectively. However, for the CI children, rather than producing a contour rising from low-level for Tone 23, a contour falling from high level and then rising to mid-level was produced. The level tones, Tone 33 and Tone 22, were found rising and dipping respectively, yet both cluster around similar frequencies. For the HA children, the contour of Tone 23 resembles that of Tone 25, rising to high-level rather than mid-level. The mid and low level tones are at their corresponding levels yet both are found slightly falling rather than flat.

Discussion

The tone production abilities of Cantonese-speaking children with profound hearing loss with cochlear implants or conventional hearing aids were described and compared in terms of perceptually rated percentage correct tone (PCT) and acoustically displayed tone contours. Results indicated that the tone production abilities of CI and HA groups were significantly worse than normal group, yet no significant differences in tone production ability was observed between children with cochlear implants or conventional hearing aids, with some other pattern being irregular resulting in degraded intelligibility of the tone pattern.

Overall performance across the CI, HA and normal groups

Results of the tone production task revealed that the overall percent correct tone (PCT) for normal children (87.22%) was significantly higher than those for the hearing-impaired groups. This agrees with the finding from So and Dodd (1995) that most of the children with normal hearing mastered all the production of tonal contrasts by two years of age. For the hearing impaired group, the tone production ability of children with hearing aids was slightly better than those with cochlear implants. Nevertheless, both of the hearing-impaired groups achieved more than 70% in average percent correct tone score. This as well agrees with Dodd and So (1994) that a group of Cantonese-speaking hearing impaired children with hearing aids generally exhibited mastery of productive tone. The result appears to support the findings in English intonation studies, that language-matched normal and hearing-impaired children may not be very different in their production of contrastive stress production (Weiss et al., 1985), and many hearing-impaired children had the ability to benefit substantially from training in the production of intonation (Allen & Arndorfer, 2000). However, contradictions were found with the studies in Mandarin, in which the tone patterns produced by children with cochlear implants were found to be flat (Xu et al., 2004), and that the majority of prelingually deaf children with cochlear implants did not master Mandarin tone production (Peng et al., 2004). A noteworthy point is that in these two Mandarin studies, though the participants were reported to use oral communication, no auditory or speech training was mentioned. Considering the results from English studies, the effect of training may be a plausible explanation to such findings. The participants in the present study all received 1;07 to 5;03 years of auditory training after the fitting of devices. Due to the tonal nature of Cantonese, where tone conveys lexical meaning and carries a heavy functional load, it is important for Cantonese-speaking children to acquire tonal perception and production. Intensive training with great effort in tones has been provided by teachers of the deaf as well as speech therapists. Our findings may hence echo with the effect of intensive training, and provide support to early and intensive auditory rehabilitation.

The present results showed no significant difference between the overall tone production abilities between the HA and CI group. This agrees with the study by Law and So (2006), which suggested that cochlear implantation significantly improves the users' production ability in consonant but not in vowel and tone when compared to conventional hearing aids.

Results do not agree with the hypothesis that the performance in tone production of children with hearing aid would be better than those with cochlear implant. Considering the frequency domain, speech is characterized by rapidly changing amplitude peaks and valleys across the spectrum. Those fast spectral variations characteristics of the vocal tract, enhance the energy in certain frequency regions and attenuate the energy in others (Osberger & Koch, 2000). In order to represent speech faithfully, the coding strategy must reflect the parameters of frequency, amplitude and time, in its electrical stimulation code (Osberger & Koch, 2000). Specifically, fundamental frequency information is particularly important to the perception of tones. The frequency information is conveyed by the site of simulation determined by the insertion of the electrode array. The present technology commonly used in Hong Kong, as well as in our participants, is multi-channel Nucleus ESPrit3G-L or Nucleus 24 ESPrit3G-L, in which the electrode array is 25mm long and has 22 electrode bands arranged longitudinally. The 22 electrode bands were turned on according to the mapping conducted by audiologist. The ESPrit™ 3G delivers information to 20 of the 22 implant electrodes, which deliver the best combination of familiar tonality, clarity and intelligibility. The SPEAK speech processing strategies used selects six to ten maxima (loudest sounds) from each sound input to stimulate the respective electrodes along the electrode array. Hence, there are chances that the exact fundamental frequency information of the tone may not be included in the selected maxima, which in turn decreases the efficiency of the transmission. On the other hand, conventional hearing aids work by amplification and thus transmitting a continuous band of frequencies. This underlying limitation seem to imply that the tone production ability of CI group would be worse than that in HA group, yet no significant difference was observed in the present study. Auditory and speech training after cochlear implantation may contribute to the improved performance in CI users, and again this stress the importance of training.

Comparison of performance in different tones in children with CI or HA

Among the six tones, the hearing impaired children demonstrated a better performance in Tone 55 and Tone 25, which are higher pitched tones, and worse performance in Tone 33, Tone 21, Tone 23 and Tone 22, which are lower pitched tones. In particular, Tone 55 and 25 had the best performance and Tone 21 and Tone 22 had the worse performance. Considering the frequency properties of the tones, the results agree with earlier studies of tone production in hearing impaired children. For instance, studies of tone productions in Mandarin-speaking children (e.g. Peng et al., 2004; Su, 1985 cited in Peng et al, 2004), revealed that high pitched tones (Mandarin Tone 1 and Tone 4) had better production scores than the lower pitch tones (Mandarin Tone 2 and Tone 3).

Besides, the phenomenon of better performance in production in higher pitched tones when compared to lower pitched ones may be explained with regard to the perception ability. In children with cochlear implants, contrasts involving the higher level tones are more readily discriminated than those involving combinations involving Tones 33, 21, 23 and 22 (J. G. Barry et al., 2002). Ciocca, Aisha, Francis & Wong (2000) also observed that pre-linguistically deafened children using a Nuclear-22 implant with SPEAK processing strategy were most successful in identifying tonal contrasts involving the high level tones and least successful in identifying tones clustered in the lower part of the speaker’s voice register. Study by Lee, Cheung, Chan, & van Hasselt (1997) with post-linguistically deafened adults using the same device and processing strategy observed similar results. Considering the bunch of observations in the tone perception pattern in hearing impaired individuals, it can be suggested that the pattern of tone production performance observed in this study is a reflection of the perceptual information conveyed through the devices. The children had a better perception ability in higher pitched tones than that in lower pitched tones, and hence their performance in higher pitched tones (Tone55 and 25) are superior than that in lower pitched tones (Tone 33, 21, 23 and 22).

The observation that Tone 23 was consistently confused with Tone 25 in both HA and CI groups in perceptual rating test conforms to the pattern of their tone tour contours. In HA children, Tone 23 was found resembling that of Tone 25, rising to high-level rather than mid-level, while in the CI children, rather than producing a contour rising from low-level for Tone 23, a contour falling from high level and then rising to mid-level was produced. All of these contours clustered at similar range of frequencies. Thus, it is not surprising that Tone 23 was confused with Tone 25 perceptually. Also, physiological correlates (vocal effort) may offer an explanation for this case. In Cantonese, Tone 25 and Tone 23 are rising tones. Snow (1998) pointed out that rising tones require more physiological effort on the part of the speaker (i.e., laryngeal tension) to modify the normal contour. Tone 25 has a larger difference in f0 onset and f0 offset than Tone 23, and the f0 offset is at a higher frequency than that of Tone 23. Children with hearing impairment receive special training in tone production upon fitting of hearing aids or cochlear implant, and at the same time, they learn to coordinate and control their vocal effort to produce the rising tones. To produce the differentiation between Tone 25 and Tone 23, one needs fine control of laryngeal tension. Tone 25, with the larger frequency change, may be easier to produce than Tone 23, which has a smaller frequency change and predictably even finer control, resulting in the different performance observed for the two tones.

Limitations of Present Study

The relatively small number of participants studied would limit the generalisability of the present study. The result may only represent a limited estimate of tone production ability of children with cochlear implants or hearing aids, due to the few brands of cochlear implants or hearing aids used by the participants.

Clinical implication

Despite the device limitation in frequency transmission, results showed that the performance of children with cochlear implant was not significantly different from that of children with conventional hearing aids, with both reaching over 70% in average PCT. Taking into account the better phonological ability in consonant and vowel productions in children with cochlear implant compared to those with hearing aids (e.g Law & So, 2006; Wei et al., 2000), cochlear implant is recommended for speakers of tonal languages to improve overall speech intelligibility. Extended post-fitting auditory training and stimulation is also highly recommended for the best outcome.

Suggestions for future research

Regarding the overall better tone production score in carrier phrase with target word in medial position condition than in single word condition rated by listeners, due to the pitch normalization and eliminated risk of rise or drop of intonation that might affect the perceived tone values (Vance, 1976), it is recommended that future research on tone production make use of carrier phrase with target word in the medial position for more accurate results which resembles daily conversational situations. Ways of post-fitting training should be investigated to optimize the tone production ability of cochlear implant users.

Conclusion

The present study shows that (a) children with normal hearing perform significantly better in tone production than children with hearing impairment (b) no significant difference was found for the tone production ability between cochlear implant users and hearing aids users (c) higher pitched tones (Tone 55 and 25) are produced significantly better than lower pitched tones (Tone 21 and Tone 22) in the groups with cochlear implants or hearing aids. Future CI development should examine ways to improve tone perception for CI users. In addition, ways of post-fitting training should be investigated to optimize their tone production ability and hence improving overall speech intelligibility.

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Appendix A

Distribution of trials for perceptual rating test for the three Panels (A, B, C)

Target		**Trial**		
Phonetic Transcriptions	Word	1st	2nd	3rd
fa$_{55}$	花	A	B	C
wa$_{25}$	畫	C	A	B
kwa$_{33}$	掛	B	C	A
Na$_{21}$	牙	A	B	C
ma$_{23}$	馬	C	A	B
ha$_{22}$	下	B	C	A
pO$_{55}$	波	A	B	C
fO$_{25}$	火	C	A	B
fO$_{33}$	課	B	C	A
hO$_{21}$	河	A	B	C
tsO$_{23}$	坐	C	A	B
NO$_{22}$	餓	B	C	A

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