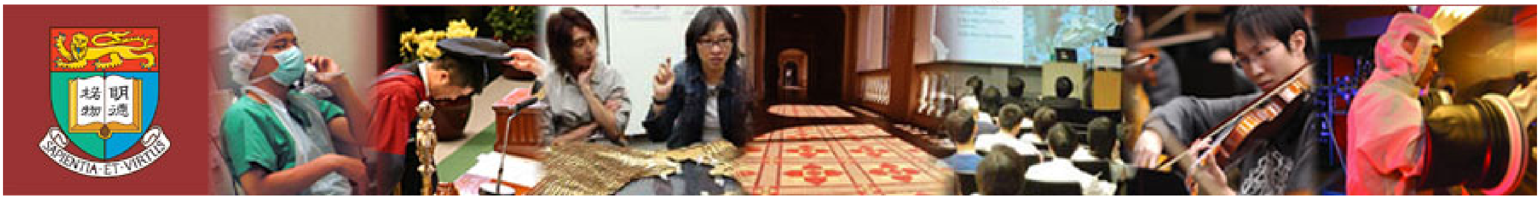

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Fricatives, affricates, and vowels in Cantonese-speaking children with cochlear implants: an acoustic study

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Abstract

The aim of the present study was to acoustically analyze speech performance of Cantonese-speaking children with cochlear implants over a three-month period, and compare it with that of the hearing controls. Three categories of sounds in Cantonese were focused: vowels /i/, /ɛ/, /a/, /ɔ/ and /u/ (first and second formant frequencies), fricatives /s/ and /f/ (noise centre of gravity), and affricates /ts/ and /tsʰ/ (accuracy, production pattern and duration). Twenty-one subjects with cochlear implants and 21 hearing subjects matched with age and gender were recruited. Speech samples were recorded and analyzed. The results showed that children with cochlear implants demonstrated statistically significant deviated performance for vowels, fricatives, and affricates when compared with the hearing controls. However, children with cochlear implants showed an overall improvement in speech performance for all the sound categories at the second recording. The results supported that prolonged use of cochlear implants brings beneficial effect.

Cochlear implantations have recently been widely accepted as an intervention methodology for both pediatric and adult patients with severe to profound hearing loss. As of December 2010, approximately 219,000 patients around the world have implanted the hearing device, according to the United States Food and Drug Administration (FDA; National Institute of Health, 2011).

Cochlear implant, an assistive hearing device, is a miniature electronic tool that consists of external and internal portions. It converts mechanical sound energy into coded electrical signals. Signals generated by the implant bypass damaged or missing hair cells in the cochlea, and directly stimulate the remaining intact auditory nerves.

Auditory experience is a crucial element for accurate acquisition of speech sounds (Moeller et al., 2007). With auditory deprivation, precise speech acquisition would be adversely undermined. As a result, delayed emergence of meaningful speech and hindered development in phonological system would be resulted from deficient pre-linguistic vocal development (Ertmer & Stark, 1995).

A number of research studies have advocated the effectiveness of cochlear implantation to improve speech perception, speech production and speech intelligibility in pre-lingually deaf children (Calmels et al., 2004; Eisenberg, 2007; Flipsen, 2008) as well as post-lingually deaf children and adults (Ito et al., 2002). Successful outcome to rehabilitation counts on a number of factors, which must include an appropriate and regular auditory-verbal therapy after implantation.

The factors that are considered to be vital for a successful implantation outcome involve age at implantation, duration of therapy, daily user-time, method of therapy, and family support (Geers et al., 2002; Tobey et al., 2003; Wie et al., 2007). Many authors have been stressing the value of early implantation (Tomblin et al., 2005; Connor et al., 2006; Nicholas & Geers, 2006; Tait et al., 2007).

This study aims to contribute to the understanding of progress of speech production accuracy in Cantonese-speaking pediatric population with cochlear implants, as other researchers did for Croatian-speaking pediatric population (Mildner & Liker, 2003; Liker et al., 2007; Mildner & Liker, 2008). This study is investigating Cantonese which is a Chinese dialect spoken by over 40 million people world-widely (Bauer & Benedict, 1997).

To further elaborate, Cantonese is a language, when compared with other alphabetic languages, possessing a different organization of phonological system in terms of phonotactic structure, number of manner/ place/ aspiration contrasting consonants, and lexicon-determining tonal contrasts. Cantonese is also known as a tonal language in which tonal contrast brings different lexical meaning; making it a difficult phonological system for second-language learners to master.

Six contrastive tones (high level ‘55’, high rising ‘25’, mid level ‘33’, low falling ‘21’, low rising ‘23’, and low level ‘22’); and three stopped tones (level tones assigned to three final oral stop consonants) are present in Cantonese. Nineteen initial consonants (oral stops /p, p^h, t, t^h, k, k^h/; labialized oral stops /k^w, k^{wh}/; fricatives /f, s, h/; affricates /ts, ts^h/; nasal stops /m, n, ŋ/; and approximants /l, j, w/) and six final consonants (oral stops /-p, -t, -k/ and nasal stops /-m, -n, - ŋ/) are included in Cantonese.

Law & So (2006) pinpointed that hearing impaired children could only produce unaspirated stop /p/ errorlessly. This hints that hearing impaired children are still encountering problem in accurate productions of other consonants. Hearing impaired children were also reported to show developmental and non-developmental phonological rules (Dodd & So, 1994; Law & So, 2006).

Acoustic features of the sound categories to be studied correlate with the physiological features (Ferrand, 2007). Physiological features can be contrasted in articulatory placement as in vowels and fricatives or contrasted in articulatory manner as in affricates. Table 1 shows the articulatory features of Cantonese fricatives and affricates.

The most salient acoustic features of vowels are defined by their first and second formant frequencies (F1 and F2) - correlating with tongue placement. F1 value defines the tongue/ vowel height- the higher the F1 value, the lower the tongue height. F2 value defines the tongue/ vowel frontness- the higher the F2 value, the greater the tongue frontness. For instance, /i/, a high and front vowel, has a low F1 value and high F2 value. Therefore, vowel space chart can be plotted based on the F1 and F2 values of different vowels.

Table 1. Articulatory manners and places of Cantonese fricatives and affricates.

	Labial-dental	*Alveolar*	
Affricate Consonants		ts	ts^h
Fricative Consonants	f	s	

Fricatives in Cantonese are distinguished by the place of constriction/ articulation. Noise energies in fricatives are produced by obstruction of airflow followed by turbulence. Alveolar fricative /s/ receives less obstruction than labial-dental fricative /f/. Therefore, acoustically, fricative /s/ carries greater noise energy or higher noise frequency than /f/.

Affricates in Cantonese are distinguished by aspiration contrast, not place of articulation. Production of this sound category requires combination and coordination of stop and fricative features. Aspiration following the stop-fricative component is further required in case of aspirated alveolar affricate /ts^h/. Therefore, both perceptual analyses of production accuracy and duration measurement are useful to discriminate the affricates /ts/ and /ts^h/, which are different in terms of aspiration contrast.

According to experimental findings from researches of alphabetic languages (Mildner & Liker, 2003; Liker et al., 2007; Mildner & Liker, 2008), there were several major problems presented by Croatian-speaking children with cochlear implants on different sound categories. When compared with hearing children, their vowels were more fronted (higher second format frequencies). Their fricatives were not sufficiently separated in terms of noise frequencies, in which discrimination between fricatives relies on noise frequencies' separation. Their affricates were longer in durations and were often substituted by fricatives, stops, or indiscriminable fricative noise. However, given increased hearing exposure, children with cochlear implants showed overall improvements for these categories of sounds in the subsequent recording dates.

The aim of this study is to investigate the production of Cantonese vowels /i/, /ɛ/, /a/, /ɔ/ and /u/, fricatives /s/ and /f/, and affricates /ts/ and /ts^h/ by children with cochlear implants, and compare with that of the hearing children with similar hearing experience over two data points by acoustic method. This study also aims to promote understanding of how the phonological systems of Cantonese-speaking population with hearing impairment operate; and provide further insights into assessment and remediation for Cantonese-speaking cochlear implant users.

Based on the above accounts, the following hypotheses are deduced. When compared with hearing children, due to deprivation of early auditory experience,

(a) Cantonese-speaking children with cochlear implants would have a compressed and more fronted vowel space;

(b) Cantonese-speaking children with cochlear implants would produce fricatives with noise frequency bands overlapped; and

(c) Cantonese-speaking children with cochlear implants would produce affricates with longer duration, higher percentage of inaccurate productions and substitutions.

Despite the above deviated performance, with prolonged auditory experience, (d) Cantonese-speaking children with cochlear implants would have an overall improvement in production accuracy for all the sound categories- vowels, fricatives, and affricates across time of measurement.

Method

Participants

Twenty-one Cantonese-speaking hearing impaired children with cochlear implants (CI) aged from 12;01 to 18;10 years (M = 15;05) and 21 Cantonese-speaking hearing children with normal development (NH) aged from 6;03 to 15;07 years (M = 11;07) were recruited to participate in this study. Table 2 lists the descriptive information of their grouping and Table 3 lists the descriptive information of the CI subjects. They were divided into two subgroups according to their cochlear implant experiences. Eleven CI subjects in the first subgroup (CIS) were with shorter post-implant hearing experience- ranging from 6;03 to 11;10 years (M = 9;06). Ten CI subjects in the second subgroup (CIL) were with longer post-implant hearing experience- ranging from 12;04 to 15;07 years (M = 13;05).

By the age of 4;06 to 5;00 years, 90% of the hearing Cantonese-speaking children should have acquired alveolar fricatives /s/, labio-dental fricative /f/, unaspirated alveolar affricate /ts/ and aspirated alveolar affricate /ts^h/ (So & Dodd, 1995) involved in this study. The subjects recruited for both the CI and NH groups in this study were all aged above 6;02

Table 2. Descriptive information of subject groups.

Group	*Number of Subjects*	*CA*	*CI Experience*
CIS	11	12;01-18;10	6;04-11;11
CIL	10	14;03-18;08	12;05-15;07
NHS	11	6;03-11;10	NA
NHL	10	12;02-15;10	NA

Note. CA = chronological age (years); CI Experience = experience of cochlear implant (years); CIS = cochlear implanted subjects with shorter post-implant hearing experience; CIL = cochlear implanted subjects with longer post-implant hearing experience; NHS = hearing controls with younger age; NHL = hearing controls with older age.

years old, and hence, they should have already acquired all these phonemes.

All the CI subjects were selected upon criteria of being diagnosed as bilateral severe-to-profound or profound hearing impairment pre-lingually (three-frequency Pure Tone Average between 90 to 120 dB HL), had been using hearing aids and with no concomitant disorders, such as mental retardation and cerebral palsy which may have influence on the children's speech performance.

For the hearing subjects (NH), they were all matched with the gender and duration of cochlear implant experiences of the CI subjects, for example, a 17;09 female with 6;03 years of cochlear implant experience was matched with a hearing 6;03 female. With normal development and no known concomitant disorders, they were recruited from different local mainstream public schools.

Table 3. Descriptive information of CI subjects at the first recording date.

Group	*Subject*	*Sex*	*CA*	*Pre-Op. PTA*	*Age at Implant*	*Post-Op. PTA*	*CI EXP*	*Implant Side*
CIS	A	M	12;01	112	2;11	38	9;02	L
	B	F	12;08	108	2;10	43	9;11	R
	C	F	13;02	107	5;11	23	7;03	R
	D	M	13;04	112	4;11	45	8;05	L
	E	M	14;07	105	5;00	40	9;07	R
	F	F	15;06	98	10;03	45	7;03	L
	G	M	15;06	100	6;08	38	8;10	R
	H	M	16;06	112	5;00	48	11;06	R
	I	M	17;01	113	5;02	35	11;11	R
	J	F	17;09	115	11;05	38	6;04	R
	K	M	18;10	117	7;06	45	11;04	R
CIL	L	F	14;03	105	1;10	37	12;05	L
	M	F	16;02	110	4;01	57	14;01	L
	N	F	16;04	112	2;01	43	14;03	R
	O	F	16;08	115	2;01	40	14;07	L
	P	F	17;03	90	4;01	43	13;02	R
	Q	F	17;05	110	3;11	28	13;06	L
	R	F	18;01	110	4;09	62	13;04	R
	S	M	18;01	117	4;09	38	13;04	L
	T	M	18;01	105	2;06	37	15;07	R
	U	M	18;08	98	5;02	37	13;06	R

Note. CA = chronological age (years); Pre-Op. PTA = pure tone average of thresholds (dB HL) before cochlear implantation at 500, 1000, 2000 Hz; Post-Op. PTA = pure tone average of thresholds (dB HL) after cochlear implantation at 500, 1000, 2000 Hz; CI EXP = experience of cochlear implant (years); M = male; F = female.

Speech materials and recording procedures

All recordings were conducted individually in a quiet room after rapport was built up. A computer connected with a microphone and an external sound card (brand: Aardwark), and installed with Praat software was employed to record speech samples.

For collecting the Cantonese vowels, the participants were asked to repeat non-sense syllable combinations after the experimenter- /pipi/, /pipɛ/, /pipa/, /pipɔ/ and /pipu/. For collecting fricatives and affricates, the participants were asked to name pictures of daily objects with written Chinese characters provided. If the participants failed to name the pictures correctly, the target was provided for imitation.

Common object names with alveolar fricative /s/, labio-dental fricative /f/, unaspirated alveolar affricate /ts/, and aspirated alveolar affricate /ts^h/ were chosen as stimuli. Fricatives and affricates consonants in numbers three (/sam^1/), four (/sei^3/), seven (/ts^{h}ɐt^7/), and ten (/sɐm^6/) were also selected. Data were collected at two data points- first (early December 2011) and second (early March 2012), with time span of three months.

Data Analysis

Vowels /i/, /ɛ/, /a/, /ɔ/ and /u/ embedded in respective non-sense words were extracted from spectrograms generated by the Praat software. They were then analyzed in terms of first and second formant frequencies (F1 and F2 respectively) and presented in a formant-defined vowel space chart. Fricatives /s/ and /f/ were analyzed in terms of respective noise frequencies. Centre of gravity and its standard deviation were used for quantifying noise frequencies. Both the centre of gravities and the noise frequency bands determined by their standard deviations were used to plot a comparison line chart. Affricates /ts/ and /ts^h/ were analyzed in terms of percentage of accurate production versus substitutions/ omissions (i.e. pattern of stop-fricative components) and in terms of total durations. Values of total durations were used to plot a comparison bar chart. Results generated were subjected to statistical tests as stated in the next section.

Reliability Measurements

For acoustic analysis, ten percent of the data were randomly selected and re-done by the author two weeks after the first analysis to determine the intra-rater reliability. Another ten percent of data were randomly selected and analyzed independently by another final year student clinician to evaluate inter-rater reliability. The intra- and inter-rater reliabilities across acoustic analyses were calculated by dividing the number of agreements by the total number of phonemes involved and multiplied by 100. Intra-rater analyses showed 97.9% agreement and inter-rater analysis showed 96.8% agreement. Disagreements were resolved by consensus. Only the consensus data were employed in the analysis.

Results

Data from each target sound category were subjected to a two-way repeated measures ANOVA statistical test- investigating any significant interactions between four groups across two data collection points [Four (Group) x Two (Date Point)]. Simple main effect was investigated when there was a significant main effect in any factor. The significant level was set at .05. Their statistical performances were summarized in Table 4.

Vowels

To begin with, vowel spaces of children with cochlear implants showed a compressed configuration when compared with that of the hearing controls. However, there were general expansions of vowel spaces of the hearing impaired groups across time of measurement. Their vowel spaces are presented in Figures 1 and 2.

At the first data point, both CIS and CIL groups produced significant lower vowel height (higher F1) for vowels /i/ [$F(3, 76) = 51.243$, $p < .05$], /ɛ/ [$F(3, 76) = 18.825$, $p < .05$], /ɔ/ [$F(3, 76) = 6.965$, $p < .05$] and /u/ [$F(3, 76) = 10.354$, $p < .05$] than the hearing controls. But they produced significant higher vowel height (lower F1) for vowel /a/ [$F(3, 76) = 8.606$, $p < .05$] than the hearing controls.

At the first data point, both CIS and CIL groups produced significant reduced vowel frontness (lower F2) for vowels /i/ [$F(3, 76) = 16.503$, $p < .05$] and /ɛ/ [$F(3, 76) = 40.130$, $p < .05$] than the hearing controls. But they produced significant greater vowel frontness (higher F2) for vowels /a/ [$F(3, 76) = 5.305$, $p < .05$], /ɔ/ [$F(3, 76) = 14.947$, $p < .05$] and /u/ [$F(3, 76) = 52.236$, $p < .05$] than the hearing controls.

Table 4. Summary of statistical results of comparisons between groups across data points.

	F values (for p < .05)*				
Vowels	*/i/*	*/ɛ/*	*/a/*	*/ɔ/*	*/u/*
First Format					
Main Effect across *data points*	8.966*	1.276	2.241	3.975	0.820
Main Effect across *groups*	51.243*	18.825*	8.606*	6.965*	10.354*
Interaction between two factors	3.566*	0.433	1.093	1.360	0.029
Second Format					
Main Effect across *data points*	1.808	0.119	1.234	1.264	2.719
Main Effect across *groups*	16.503*	40.130*	5.305*	14.947*	52.236*
Interaction between two factors	0.605	0.040	0.424	0.596	0.969
Fricatives	*/s/*			*/f/*	
Noise Frequency					
Main Effect across *data points*	6.457*			8.717*	
Main Effect across *groups*	68.720*			71.183*	
Interaction between two factors	2.240			3.357*	
Affricates	*/ts/*			*/ts^h/*	
Durations					
Main Effect across *data points*	120.914*			16.022*	
Main Effect across *groups*	931.695*			98.403*	
Interaction between two factors	40.343*			5.355*	

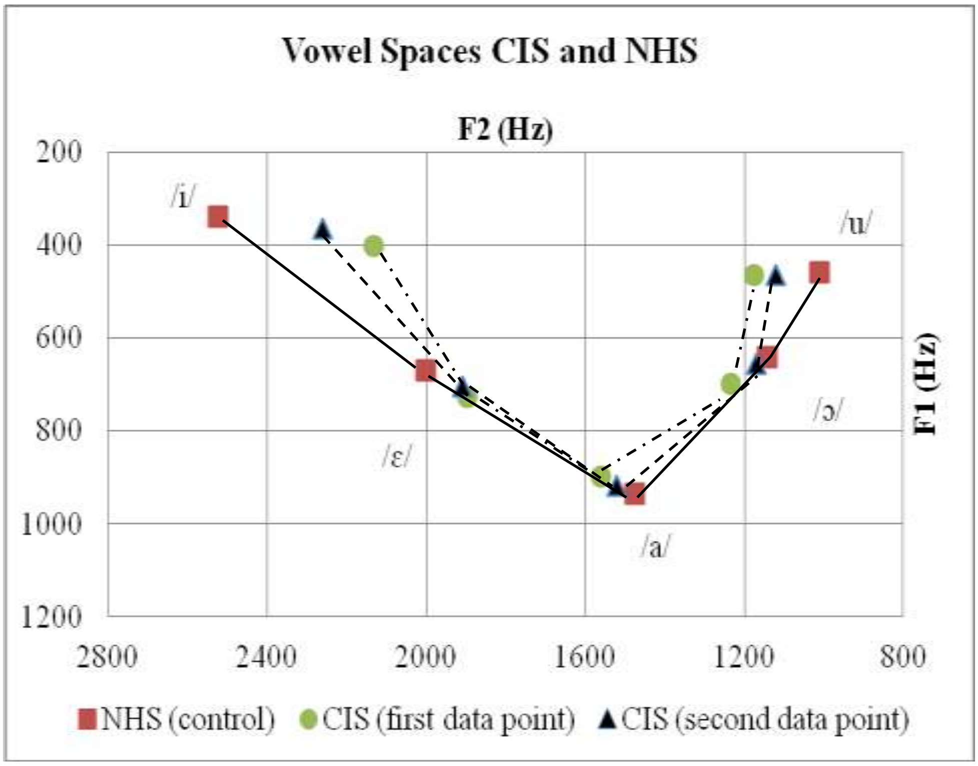


Figure 1. Vowel spaces of CIS and NHS groups.

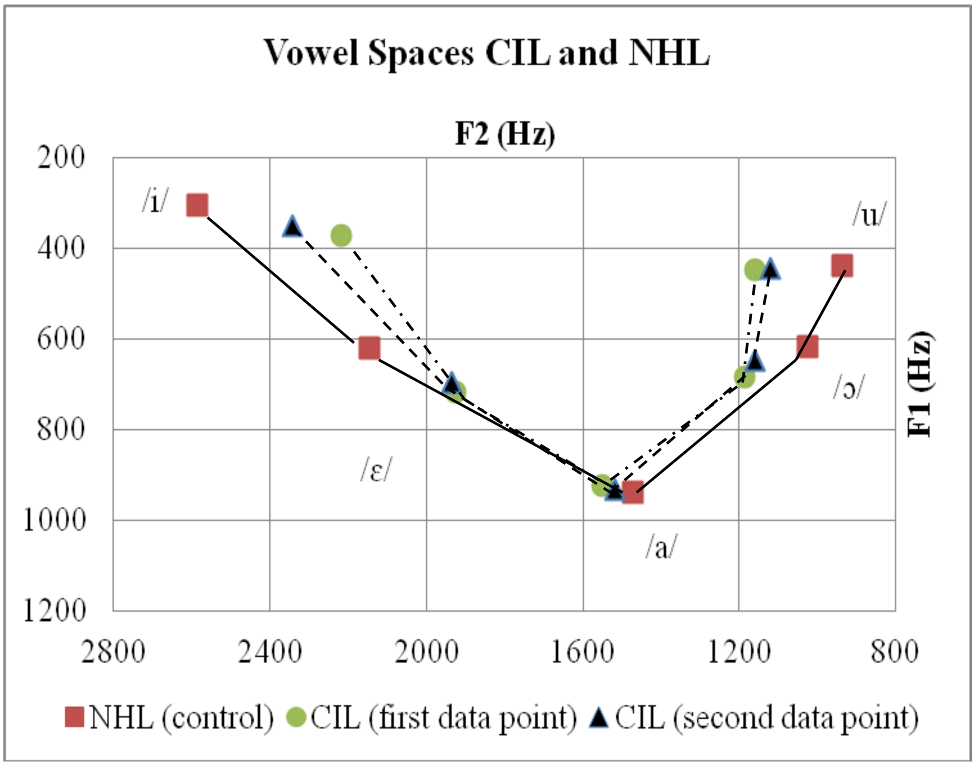


Figure 2. Vowel spaces of CIL and NHL groups.

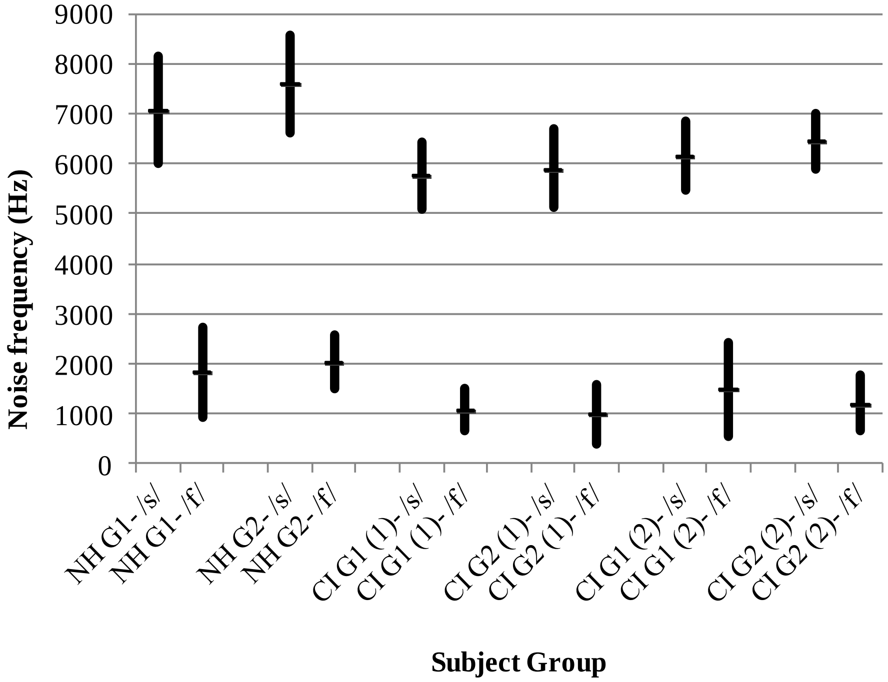
At the second data point, both CIS and CIL groups demonstrated improvements in producing a "closer-to" hearing controls' patterns in terms of both F1 and F2 frequencies when compared with the first data point. Both CIS and CIL groups showed the most significant improvement in vowel height for vowel /i/ across time [$F(1, 76) = 8.966$, $p < .05$]. Although no statistical significances were observed, both CIS and CIL groups also showed improvement in vowel heights for vowels /ɛ/ [$F(1, 76) = 1.276$, $p = .262$], /a/ [$F(1, 76) = 2.241$, $p = .139$], /ɔ/ [$F(1, 76) = 3.975$, $p = .050$] and /u/ [$F(1, 76) = 0.820$, $p = .775$]; and in vowel frontness for vowels /i/ [$F(1, 76) = 1.808$, $p = .183$], /ɛ/ [$F(1, 76) = 0.119$, $p = .731$], /a/ [$F(1, 76) = 1.234$, $p = .270$], /ɔ/ [$F(1, 76) = 1.264$, $p = .264$] and /u/ [$F(1, 76) = 2.719$, $p = .103$] as supported by their means plots and exact numerical changes. Vowel /a/ in both CIS and CIL groups, showing the proximal performance with the hearing controls among all the vowels, was a pivotal point for expansion in their formant-defined vowel spaces across time.

Fricatives

Children with cochlear implants produced fricatives with reduced noise frequencies and narrower separation in noise centre of gravity between fricatives when compared with that of the hearing controls. However, there were improvements in fricatives' production for the hearing impaired groups across time of measurement. Centre of gravity measures and standard deviations of fricatives are showed in Figure 3.

At the first data point, both CIS and CIL groups produced fricatives /s/ [$F(3, 312) =$

68.720, $p < .05$] and /f/ [$F(3, 312) = 71.183$, $p < .05$] with significant reduced noise frequencies when compared with that of the hearing controls. However, at the second data point, both CIS and CIL produced fricatives /s/ [$F(1, 312) = 6.457$, $p = .012$] and /f/ [$F(1, 312) = 8.717$, $p < .05$] with increased noise frequencies towards the controls.



Note. NH G1 = younger hearing controls group; NH G2 = older hearing controls group;
CI G1 (1) / (2) = cochlear implanted subjects with shorter post-implant hearing experience, at the first and second data point respectively;
CI G2 (1) / (2) = cochlear implanted subjects with longer post-implant hearing experience, at the first and second data point respectively.

Figure 3. Fricative noise centre of gravity for fricatives /s/ and /f/.

The separation in fricative noise centre of gravities between /s/ and /f/ for both CIS and CIL groups (4684-4924 Hz) was narrower than that of the hearing controls (5260-5578

Hz) at the first data point. However, the amplitude of separation widened for both CIS and CIL (4693-5243 Hz) towards the hearing controls at the second data point.

Affricates

Children with cochlear implants produced affricates with longer durations and lower percentage of correct accuracies when compared with the hearing controls. Table 5 and Figures 4-5 presents the summary of results for affricates. Affricates produced by children with cochlear implants showed substitution by stop consonant, substitution by fricative consonant, aspiration (in case of unaspirated /ts/), initial consonant deletion or de-aspiration (in case of aspirated /ts^h/).

Table 5. Percentage accuracies and production patterns of affricates /ts/ and /ts^h/.

				first data point		*second data point*	
		NHS	*NHL*	*CIS*	*CIL*	*CIS*	*CIL*
/ts/	Correct	100%	100%	59%	67.5%	63.6%	72.5%
	Stop	0%	0%	11.4%	10%	9.1%	5%
	Fricative	0%	0%	20.5%	10%	9.1%	5%
	Aspirated	0%	0%	4.6%	10%	9.1%	12.5%
	ICD	0%	0%	4.6%	2.5%	9.1%	5%
/ts^h/	Correct	100%	100%	68.2%	75%	72.7%	80%
	Stop	0%	0%	9.1%	7.5%	11.4%	7.5%
	Fricative	0%	0%	20.5%	10%	15.9%	10%
	De-aspirated	0%	0%	2.3%	7.5%	0%	2.5%

Note. ICD = Initial Consonant Deletion.

When compared between time of measurement, both CIS and CIL groups produced both affricates with slight increases in percentage accuracy from the first to the second data point (/ts/: from 59-67.5% to 63.6-72.5%; and /ts^h/: from 68.2-75% to 72.7-80%). Generally, substitution by fricative (ranging from 5% to 20.5%) occupied the greatest percentage among all the error patterns: substitution by stop, aspiration, de-aspiration and initial consonant deletion ranged under 13% only.

At the first data point, both CIS and CIL groups produced affricates /ts/ [$F(3, 24) = 931.695$, $p < .05$] and /ts^h/ [$F(3, 24) = 98.403$, $p < .05$] with significant longer durations when compared with that of the hearing controls. However, at the second data point, both CIS and CIL produced affricates /ts/ with shorter durations [$F(1, 24) = 120.914$, $p < .05$] towards the hearing controls; while produced /ts^h/ with longer durations [$F(1, 24) = 16.022$, $p < .05$].

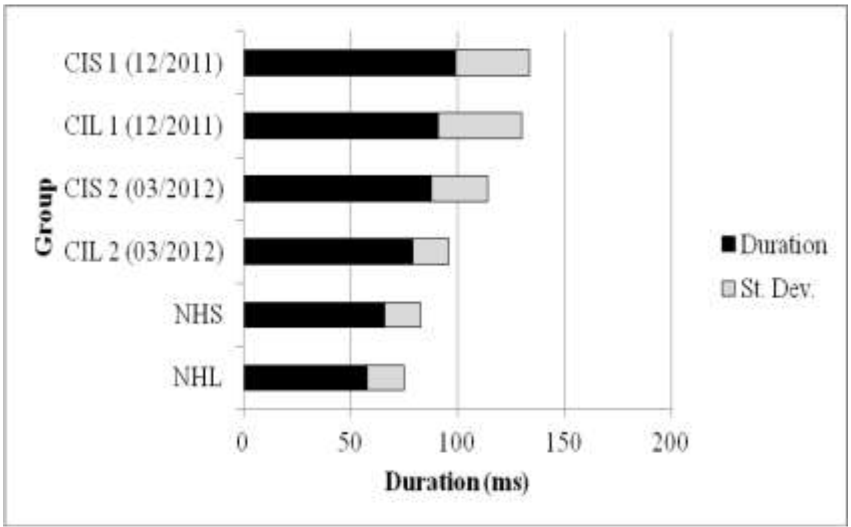


Figure 4. Duration and standard deviation of affricate /ts/.

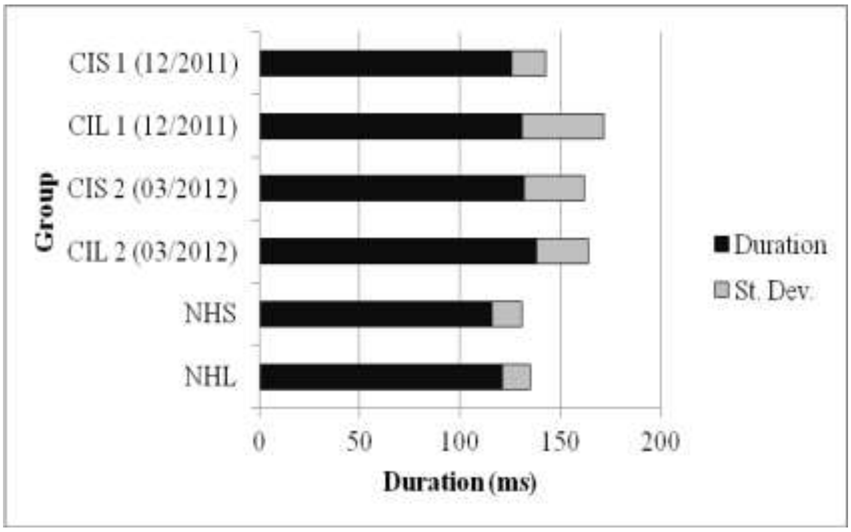


Figure 5. Duration and standard deviation of affricate /ts[h]/.

Discussion

From the above illustrations and statistical results, it was observed that Cantonese-speaking children with cochlear implants on the whole produced all the sound categories with less accurate performance when compared with the hearing controls. However, a general overall improvement could be seen across time of measurement for all the sound categories, although not all of them demonstrated statistically significance.

Comparison with Studies of Alphabetic Languages

The results presented here showed partial agreement and partial confrontation with other researches of alphabetic languages. It was mentioned earlier that interest in investigating Cantonese vowels, fricatives and affricates was inspired by a few studies for Croatian-speaking children with cochlear implants (Mildner & Liker, 2003; Liker et al., 2007; Mildner & Liker, 2008) with longitudinal research designs.

Indications in this study that stood for the Croatian studies included: (a) children with cochlear implants showed a compressed vowel space when compared with the hearing controls; (b) children with cochlear implants produced affricates with longer duration, higher percentage of inaccurate productions and substitutions when compared with the hearing controls; and (c) children with cochlear implants showed a small overall improvement in production accuracy for the three sound categories across time.

Nevertheless, indications in this study that stood against the Croatian studies included: (a) Cantonese-speaking children with cochlear implants showed reduced frontness for vowels /i/ and /ɛ/ but greater frontness for vowels /a/, /ɔ/ and /u/; while Croatian-speaking children with cochlear implants produced vowels with an overall fronted performance; and (b) Cantonese-speaking children with cochlear implants did not show a significant poor distinction between fricatives in terms of noise spectrum; while Croatian-speaking children with cochlear implants produced fricatives with considerable closeness in mean noise centre of gravity and overlapping of noise frequency band.

As vowels are mostly distinguished by tongue height and tongue frontness, it is often difficult for the therapists to perform perfect exaggerated visual demonstrations by themselves and judge whether the client has performed the desired tongue configuration. Studies of alphabetic languages (Mildner & Liker, 2003; Liker et al., 2007; Mildner & Liker, 2008) reported that there was a tendency for therapists, family and children themselves to make articulatory gestures to where it could be more visible, i.e. towards the front of the lips. However, the trend of frontal tongue movement towards the lips is not commonly observed in Cantonese-speaking population because Chinese traditional thinking believes that keeping the tongue within oral cavity during actions, speech actions as well, is a virtue of politeness.

Therefore, results in this study do not agree with the pattern of vowel production presented by Mildner & Liker (2003), Liker et al. (2007) and Mildner & Liker (2008). It is still expected that the vowel space in Cantonese-speaking children with cochlear implants to further expand with increased reliance on hearing experience brought by prolonged use of cochlear implants. This notion was advocated by Moeller et al. (2007) and other authors (Calmels et al., 2004; Eisenberg, 2007; Flipsen, 2008), who suggested that auditory experience was crucial for accurate acquisition of speech sounds.

The absence of overlapping of fricatives' noise frequency bands in this study could be explained by the longer post-implant experience of the subjects recruited. The hearing experiences of subjects with cochlear implants in the Croatian research (Mildner & Liker, 2008) ranged between 4;03-9;08 years; while that in this study ranged between 6;03-15;07 years. However, this study supported the results of the Croatian research that the separation between fricatives in terms of noise centre of gravity widened with prolonged hearing experience brought by cochlear implants. This indicated a direction towards successful perceptual and articulatory separation between the fricatives.

Affricate is the most difficult sound category for children with cochlear implants. This sound class is the last one to be acquired accurately due to its complexity of articulatory combinations and control of timing. Results of affricates' performance in this study agreed with that of the Croatian researches. The slight increment in accuracy, decrease in percentage of substitutions and shortening of duration for /ts/ could be explained by the better mastery of stop-fricative combination. The slight increment in accuracy and lengthening of duration for /ts^h/ could be explained by a "speed-and-accuracy" tradeoff, as production of aspirated affricate required higher degree of coordination between stop-fricative components and airstream projection. Increased time would be required for children with cochlear implants to perform the articulatory gestures that involved in the production of this complex consonant.

Lastly, Being a tonal language, an accurate tone production in Cantonese is essential for conveying the most-wanted lexical meaning and making phonological contrasts. Cochlear implant could not provide adequate tonal information for its users. Consequently, children with cochlear implants were subjected to difficulty in tonal lexical comprehension (Tse & So, 2012). Tone errors in word productions by subjects with cochlear implants were observed in this study (alternation from rising to level tone). Distortion in tone representation could lead to a totally different lexical meaning.

General Discussion

Children with cochlear implants do not perceive speech sounds with high quality acoustic signals when compared with the hearing peers, their auditory input are hence deprived and distorted. Besides, researchers (Tye-Murrary et al., 1995) had proven that speech perception skills were correlated with speech production skills in cochlear implant users. Hence, significant differences in production patterns between children with cochlear implants and hearing children could be explained.

Although auditory inputs in children with cochlear implants are deprived and their perceived acoustic signals are distorted, they can still acquire articulatory gestures through visual input. Campbell et al. (1998) reported that hearing impaired people could identify 61-80% word correctly through speech-reading. As a result, verbal productions along with exaggerated articulatory movements are always demonstrated by therapists when they communicate with children with hearing impairment.

Clinical Implication and Conclusion

The current research provides insights into how production of vowels, fricatives and affricates were performed by children with cochlear implants acoustically across time of measurement. Results in this study partially agree and partially disagree with that of researches of alphabetic languages. Acoustic performance of all the sound classes produced by children with cochlear implants showed deviations from the hearing peers. However, by the second data point, children with cochlear implants demonstrated a small and overall improvement for all the three sound classes towards the hearing controls.

The outcomes are encouraging. Cochlear implantation is further advocated as a promising therapeutic option for people with deprived auditory experience. Subjects recruited in this study included both "early" and "late" implantees with age at implantation ranging between 1;10 and 11;05 years, no specific conclusion of the effect of age of implantation could be made. The Croatian studies (Mildner & Liker, 2003; Liker et al., 2007; Mildner & Liker, 2008) and other reports (Dowell et al., 2002; Mildner et al., 2002) considered duration of therapy, not essentially early age at implantation, strongly correlated with the rehabilitative outcome. But other authors (Govaerts et al., 2002; Tomblin et al., 2005 Connor et al., 2006; Nicholas & Geers, 2006; Tait et al., 2007) stressed the advantages of early implantation.

While researchers showed non-identical views for the effect of age at implantation; many other factors may also influence the rehabilitative outcome. Several endogenous and exogenous factors, such as children's cognitive styles, pre-verbal and non-verbal competencies, family support and expectations, play vital roles in determining a successful outcome as had been suggested by a number of authors (Pisoni, 2000; Nikolopoulos et al., 2004; Vlahovic´& Sˇindija; 2004).

Undoubtedly, there are still lots of rooms for improvement in speech intelligibility in children with cochlear implants. Contextual cues facilitate caregivers and teachers to comprehend what speeches of children with cochlear implants are intended to convey rather than by their exact wordings. Even though children's productions in this way are understood, their productions remain to be inaccurate and unintelligibility. Children with cochlear implants would fail to appreciate the importance of consistent accuracy in word productions contributing to higher speech intelligibility. Therefore, caregivers and teachers should be encouraged to promote a communicative environment that requires a high articulatory consistency and accuracy, which is important in enhancing speech intelligibility without many contextual supports (Dodd et al., 1994).

Lastly, future research directions could be extending the present understandings of speech performance by Cantonese-speaking children with cochlear implants by different means that were proposed in some recent studies. For examples, to investigate tongue movement by employing Electromagnetic Articulometry (EMA; Neumeyer et al., 2010) or to investigate the role of Audiovisual presentation for speech perception (Bergeson et al., 2005).

Acknowledgements

I would like to express my gratitude to Dr. Lydia So for her great supports and resourceful advice throughout the course of this dissertation. I would also like to thank all the participants and their families for their willingness to participate in this research. Special thanks are given to Dr. Lawrence Ng and Dr. Nyan for advising the procedures of acoustic analysis; and Ms. Kaman Cheung for her generous help in the research process.

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Appendix A

Word list of stimuli for speech sample recordings.

Sound Class	*Stimuli*			
Alveolar Fricative /s/	3	4	10	獅
Labio-dental Fricative /f/	飛	筷	花	褲
Unaspirated Affricate /ts/	足	蕉	豬	紫
Aspirated Affricate /ts^h/	7	車	叉	橙

Appendix B

THE UNIVERSITY OF HONG KONG
Faculty of Education

November 28, 2011

Dear Principal,

Fricatives, affricates, and vowels in Cantonese-speaking school-age children with cochlear implants: an acoustic study

As part of the final year B.Sc. (SPEECH) programme, I am required to conduct a small-scale research. This will involve participating students to produce five word combinations- /pipa/, /pɛpa/, /papa/, /pɔpa/, /pupa/ and name pictures of daily objects which consist of fricatives and affricates consonants. Students' speech samples will be audio-recorded individually by a computer with microphone at school. Speech samples collected will be stored in the computer for future analysis. Each sampling will take for around 5 minutes. Each student participant is hoped to take part in the research for once only. There are no potential risks involved. Students' participation can contribute new knowledge to the academic research and clinical field for Cantonese population.

According to the University's policy on the ethical conduct of research, I am writing to ask your consent for these procedures.

I will make sure that the information students provide will be treated with the utmost confidentiality and anonymity. Students' participation is voluntary. They have the right not to be included in my analysis, and if I find out that a student does not wish to be included, I will act according to that wish and not include the student. They can also choose to withdraw from the study at any time without negative consequences. As the procedures will be audio-taped, the participants have the right to review and erase the tapes. The information collected will only be used for the dissertation and will be destroyed after the dissertation grade has been approved. The computer storing the collected data will be locked in cabinet in the Division of Speech and Hearing Sciences of the University of Hong Kong.

If you agree to these procedures, please sign one copy of this letter and return it to me. If concerns arise about this aspect of my work, please feel free to contact me (tel. 6202-7914), or Dr. Lydia So (tel. 2859-0595). If you have questions about your rights as a research participant, please contact the Human Research Ethics Committee for Non-Clinical Faculties, HKU (tel.2241-5267).

Yours sincerely,

Hui Chun Kit, Gibson
Division of Speech and Hearing Sciences
Faculty of Education
The University of Hong Kong

Appendix C

香港大學

「使用人工耳蝸適齡兒童的粵語摩擦音、塞擦音和元音：聲學研究」

父母/監護人同意書

敬啓者：

本人是香港大學言語及聽覺科學系四年級學生，將在真鐸學校進行一項研究，題為「使用人工耳蝸適齡兒童的粵語摩擦音、塞擦音和元音：聲學研究」，對象為中一至中六年級佩帶人工耳蝸的學生。研究旨在以聲學方法分析使用人工耳蝸中學生的粵語語音。是項研究將有助促進新知識予使用人工耳蝸的粵語人口的學術研究和臨床領域。

參與此研究的同學只需按老師及言語治療師的安排，在放學後抽出約五分鐘到課室讀出五句粵語組合以及讀出幾張圖卡上物件名稱。為了把所得資料作詳細分析，過程將會被錄音，並需要　閣下提供　貴子弟的個人資料及聽力數據。參與此研究的同學需在十二月初及來年三月尾進行共兩次同樣的錄音。是項行動並不含任何潛在風險，所收集的資料只作研究用途。由於過程涉及錄音，　閣下有權審查和刪除有關錄音。收集到的錄音會被儲存於電腦內，並只用於此項研究之用。當論文成績一經被批核，所有資料將會被銷毀。存儲所收集數據的電腦將被鎖在香港大學言語及聽覺科學部的儲存閣內。

本人確保 閣下所提供的資料將絕對保密和以匿名形式處理。是次參與純屬自願性質，　閣下可隨時終止參與是項行動，有關決定將不會引致任何不良後果。希望　閣下能對此研究給予支持，讓　貴子弟參與其中。請 閣下填妥以下回條，以表示　閣下是否同意　貴子弟參與是項研究。如 閣下對是項研究有任何查詢，請與本人(6202-7914)或 蘇博士(2859-0595)聯絡。如 閣下想知道更多有關研究參與者的權益，請聯絡香港大學非臨床研究操守委員會(2241-5267)。

此致

真鐸學校家長

香港大學言語及聽覺科學系四年級學生

許俊傑謹啟

二零一一年十一月二十八日

Appendix D

香港大學

「使用人工耳蝸適齡兒童的粵語摩擦音、塞擦音和元音：聲學研究」

學生須知及同意書

各位同學：

本人是香港大學言語及聽覺科學系四年級學生，將在真鐸學校進行一項研究，題為「使用人工耳蝸適齡兒童的粵語摩擦音、塞擦音和元音：聲學研究」，對象為中一至中六年級佩帶人工耳蝸的學生。研究旨在以聲學方法分析使用人工耳蝸中學生的粵語語音。是項研究將有助促進新知識予使用人工耳蝸的粵語人口的學術研究和臨床領域。

本人早前已得到你父母／監護人的同意讓你參與這個活動，但你的決定對本人也很重要。參與此研究的同學只需按老師及言語治療師的安排，在放學後抽出約五分鐘到課室讀出五句廣東話語音組合以及讀出幾張圖卡上物件名稱。為了把所得資料作詳細分析，過程將會被錄音。參與此研究的同學需在十二月初及來年三月尾進行共兩次同樣的錄音。是項行動並不含任何潛在風險，所收集的資料只作研究用途。由於過程涉及錄音，你有權審查和刪除有關錄音。收集到的錄音會被儲存於電腦內，並只用於此項研究之用。當論文成績一經被批核，所有資料將會被銷毀。存儲所收集數據的電腦將被鎖在香港大學言語及聽覺科學部的儲存閣內。

本人確保你所提供的資料將絕對保密和以匿名形式處理。是次參與純屬自願性質，你可隨時終止參與是項行動，有關決定將不會引致任何不良後果。希望你能對此研究給予支持，參與其中。請你填妥以下回條，以表示你是否同意參與是項研究。如你對是項研究有任何查詢，請與本人(6202-7914)或 蘇博士(2859-0595)聯絡。如你想知道更多有關研究參與者的權益，請聯絡香港大學非臨床研究操守委員會(2241-5267)。

此致

真鐸學校學生

香港大學言語及聽覺科學系四年級學生

許俊傑謹啟

二零一一年十一月二十八日