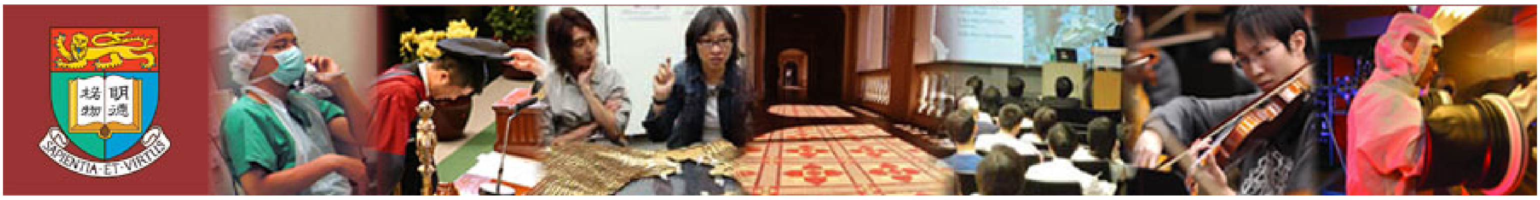

Title	Speech variability and accuracy in Cantonese-speaking children with hearing impairment : comparison with normal-hearing peers
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Speech variability and accuracy in Cantonese-speaking children with hearing impairment: Comparison with normal-hearing peers

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Speech variability and accuracy in Cantonese-speaking children with hearing impairment: Comparison with normal-hearing peers

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Abstract

This study compared speech accuracy and variability between children with hearing impairment and normal-hearing children. Twenty-seven participants were recruited, including nine children with cochlear implants (CI), nine children with hearing aids (HA) and nine normal-hearing children (NH). Participants were asked to name each targets from Cantonese Segmental Phonology Test (CSPT) in three separate trials. Speech accuracy and variability were analyzed in different conditions (i.e. vowels, consonants, tones and whole-words) and in different sets of initial consonants (i.e. set 1, set 2 and set 3). The results showed relatively higher accuracy and lower variability in tones and vowels than in consonants and whole-words, and also in earlier acquired initial consonants than those acquired later. The HA group had higher variability and lower accuracy than the CI and NH groups. It was concluded that, with similar duration of hearing experience, using cochlear implants was more effective than using hearing aids in assisting children with profound hearing impairment in catching up with normal children in speech accuracy and variability. Acquisitional order of phonological features was also found to affect accuracy and variability of speech.

Introduction

Cochlear implantations (CI) and fitting of hearing aids (HA) were the usual managements for restoring hearing ability of children with profound hearing loss. Decision on selecting technology being used was usually determined by different factors, such as the candidacy for cochlear implants, availability of technology and parents' decision. While parents' decision might depend on the extent that their children's hearing ability could be restored, language and social development, quality and intelligibility of speech production after their hearing ability were compensated by the two technologies (Hardonk et al., 2010).

There were researches which had investigated the phonetic inventory or speech accuracy of the hearing-impaired population equipped with either one of the two technologies (Chin & Pisoni, 2000; Dodd & So, 1994; Peng, Weiss, Cheung & Lin, 2004). Law and So (2006) suggested Cantonese-speaking children with hearing impairment usually followed the right track of phonological development but with a slower progress than children with normal hearing. They also found children with cochlear implants usually achieved higher percentage of accuracy in production of consonants and vowels than children with hearing aids (Law & So, 2006). Previous study found that children with CI had better auditory feedback for refining their articulatory gestures (Chin & Pisoni, 2000). Researches on speech production performance of Cantonese-speaking CI-users usually relied on their production accuracy. Yet, few studies had compared between the CI-users and HA-users and there is no study on the time course for Cantonese-speaking children with hearing impairment to achieve consistent and stable speech production.

Apart from analyzing the speech production of people with speech impairment in terms of accuracy of speech or phonological processes employed, "variability" was recently suggested as an early indicator of speech impairment (Holm, Crosbie & Dodd, 2007). The term "variability" was defined as a within-individual difference by making *"repeated* *productions that differ, with the variability attributed to factors described in normal acquisition and use of speech"* (Holm et al., 2007, p.468). If variability could reflect the maturity of phonological acquisition, it could be useful for clinician to evaluate the progress of phonological development of children with speech impairment.

Holm, Crosbie and Dodd (2007) studied on 405 typically developing English-speaking children aged 3 to 6 and concluded that younger children might demonstrate higher variability which attributed to maturational influence.

There were two factors being proposed as affecting the variability of speech production. Firstly, the children's cognitive and linguistic knowledge might attribute to the speech variability. It was proposed that unclear mental representation of words might influence the speech motor movement, which led to different forms of productions of an intended word in different trials (Nip, Green & Marx, 2009). Kent (1992) explained the reason for articulatory errors and inconsistent production of words was unconsolidated phonological and linguistic knowledge. Secondly, some researchers proposed children's control over neuromotor movement for speech production might influence speech variability. The research of Nip et al. (2009) found that, by kinematic measures, spontaneous silent movements of oro-facial movements reduced with words acquisition. That is, with more advanced acquisition of speech and language, children's neuromotor control would be mature with more stable and consistent movements.

Ertmer and Goffman (2011) assessed speech production accuracy and variability of children with cochlear implants with two years device usage. They found that children with CI produced lower accuracy and higher variability than age-matched children with normal hearing. The difference in performance between the CI recipients and normal-hearing children might be due to the difference in duration of hearing experience, which led to different progress in speech and language development. Law and So (2006) suggested children with hearing impairment might catch up with normal-hearing peers in phonological development at a later stage while the duration of time needed was not specified. Therefore, it was suspected if hearing experience might be a factor to help the children with hearing impairment to catch up with children with normal hearing in speech accuracy and variability. Apart from the duration of hearing experiences, it was also suspected if different use of hearing devices might lead to difference in speech accuracy and variability.

Therefore, in the current study, it was going to investigate (1) with matched hearing experience, the difference in speech accuracy and variability between children with hearing impairment and their peers with normal hearing (2) with different hearing devices, the difference in speech accuracy and variability between the CI and HA groups.

Ertmer and Goffman (2011) also suggested earlier acquired features might lead to more mature and stable productions. In Cantonese, different phonological units are acquired at different stages. According to So and Dodd (1995), acquisition of tones and vowels would be achieved by age 2 in normal developing children while acquisition of initial consonants would be acquired within a broad range of period, ranging from age 2;0 to 5;0. Therefore, it was suspected phonological features acquired at different stages might show difference in speech accuracy and variability. For example, more accurate and stable productions might be shown in tones as it is acquired earlier than consonants. Thus, in this study, we would like to investigate if order of acquisition might lead to any difference in production accuracy and variability between different conditions (i.e. vowels, consonants, tones and word levels). Also, difference in production accuracy and variability between different sets of initial consonants would also be compared to investigate if order of acquisition might influence the speech accuracy and variability of children with hearing impairment.

According to Schramm, Bohnert and Keilmann (2009), children started their phonological development when they started hearing sound, which is, even before the emergence of canonical babbling. Thus, in this research, all the participants were matched according to their hearing experience. McLeod and Hewett (2008) found variability of speech within individual would be higher between age 2 to 3, variability decreased and accuracy increased when children reached the age of 3. Therefore, participants with about two to three years of hearing experiences were recruited in this study as it would be more sensitive to identify speech variability.

In this research, we predicted the following:

1. Hearing impairment might be a factor to affect speech accuracy and variability. It was hypothesized children with hearing impairment might show lower speech accuracy and higher speech variability than their normal hearing peers. Although it was suggested children with hearing impairment followed the similar track of phonological development as normal children (Law & So, 2006), some study suggested phonological development of children with hearing impairment were at slower progress (Moeller et al., 2007). Therefore, it was hypothesized, with similar hearing experience, children with normal hearing might show better performance than the hearing impaired groups across different conditions.
2. Different usage of devices might affect phonological development and speech production of children with hearing impairment. It was suggested by Osberger (1995) that CI recipients were able to improve their phonological development to a greater extent than HA users. Therefore, it was hypothesized HA group might have higher speech variability and lower accuracy when compared to CI group.
3. Acquisitional order of phonological features might affect the accuracy and variability of speech production. Earlier acquired features might lead to mature acquisition of sounds with more accurate and less variable productions (Ertmer & Goffman, 2011). In Cantonese, tones and vowels were the features that were acquired earlier when compared

to consonants (So & Dodd, 1994).Therefore, it was hypothesized production of tones and vowels might lead to lower speech variability and higher accuracy than production of consonants in all participants. Besides, among different sets of initial consonants, it was hypothesized that earlier acquired initial consonants would be observed with higher accuracy and lower variability than initial consonants that were acquired at a later stage.

Method

Participant

Twenty-seven children who aged between 2;0 and 5;0 were recruited in this study. Nine of the participants were in the cochlear implants (CI) group, nine participants were in the hearing aids (HA) group and nine participants were in the normal-hearing (NH) group with matching hearing experience with the CI and HA groups. They had no other concomitant problems (e.g. ADHD, autism, mental retardation, oral motor impairment, cerebral palsy or other syndromes). They were Hong Kong children with Cantonese as their first language. The participants were recruited from special child care centers for children with hearing impairment and local nurseries. The descriptive information of subject groups can be seen in Table 1.

Table 1. *Descriptive information of subject groups*

Grouping	Number of participants	Age (mean)	Hearing experience (mean)
CI	9	2;5-5;0 (3;10)	2;0-3;2 (2;6)
HA	9	2;8-4;11 (3;9)	2;1-3;0 (2;6)
NH	9	2:0-3;0 (2;6)	N/A

Note. CI = cochlear implant users; HA = hearing aid users; NH = normal hearing participants.

The 18 participants in the CI and HA groups were pre-linguistically hearing impaired with profound sensorineural hearing loss, with pure-tone average thresholds in better ear of 85 dB HL or more at 0.5, 1.0 and 2.0 kHz. In the CI group, there were nine participants having CI alone or both CI and HA. Parents reported they received implantation surgery in Hong Kong. All of the CI participants had received their implantation surgery before age 3. In the HA group, there were nine participants who were wearing one or two hearing aids. Participants in both the CI and HA groups were students of special child care centers where they received auditory-verbal training and pre-school education. Teachers reported they attended school six hours per day, five days a week. The information of participants, unaided/aided pure-tone average, year of speech and auditory training received, and year of experience with the devices are summarized in Table 2.

Table 2. *Descriptive information for participants*

P	CA	Unaided level dB HTL		Aided level dB HTL		Years of training[a]	Years of CI/HA experience
		PTA (R)	PTA (L)	PTA (R)	PTA (L)		
Participants with cochlear implants (CI)							
CI1	4;11	110	120	45	60	2;11	3;2
CI2	2;5	120	115	40	45	1;6	2;2
CI3	3;4	120	120	N/A[b]	40	1;5	2;0
CI4	3;5	90	95	45	50	1;5	2;7
CI5	5;0	120	120	N/A	40	2;5	2;4
CI6	3;6	120	100	N/A	45	2;6	2;10
CI7	4;0	120	120	45	N/A	2;4	2;5
CI8	4;4	110	120	N/A	55	1;8	2;4
CI9	2;11	100	120	40	50	2;0	2;5
Participants with hearing aids (HA)							
HA1	3;8	85	90	45	50	2;0	2;4
HA2	2;8	90	95	40	40	1;10	2;1
HA3	4;9	120	120	N/A	42	2;6	2;8
HA4	4;11	110	110	50	50	2;0	2;3
HA5	2;10	110	120	35	35	2;0	2;2
HA6	3;4	110	100	40	40	2;10	3;0
HA7	3;6	85	90	40	50	2;8	2;10
HA8	5;3	110	110	65	60	2;4	2;8
HA9	3;5	95	120	N/A	45	1;9	3;0

Note. P= participant; CA = chronological age; PTA = pure-tone average of threshold at 500, 1000 and 2000 Hz; HTL = hearing threshold; R = right; L = Left. [a]Training: auditory or/and articulation training.[b]N/A: no hearing device on that side of ear

*refer to Table 1 for the notation of group CI, HA

Speech Materials

Color pictures representing the target words in Cantonese Segmental Phonology Test (CSPT) (So, 1992) were used in this study. The 31 words in CSPT sampled all consonants, vowels and tones while each sound had at least one representation. The pictures were color-printed on a 3 by 4 inch paper cards which were used to elicit the participants' speech production.

Table 3. *Grouping list of initial consonants according to acquisitional milestone*

Set	Age of Acquisition	Initial Consonant
1	2;0 – 3;0	m n ŋ p t j w
2	3;0 – 4;0	h k l p^h t^h k^h
3	> 4;0	f s ts ts^h k^w k^{wh}

The 31 target words in CSPT were further divided into three sets according to their initial consonants for data analysis later. The list of initial consonants in each set is shown in Table 3. According to Olmsted (1971), acquisitional age of phonemes represents the degree of difficulty of articulation (as cited in So & Dodd, 1995, p. 474). Therefore, the initial consonants were divided into three sets. Grouping criterion followed the proposed acquisitional age range in 90% criterion of normal children by So and Dodd (1995). Set 1 included nasals /m, n, ŋ/, bilabial and alveolar stops /p, t/ and glides /j, w/. Set 2 included aspirated plosives / p^h, t^h, $k^{h/}$, velar stop /k/, fricative /h/ and one lateral /l/. Set 3 included fricatives /f, s/, affricates /ts, $ts^{h/}$ and labialized velar stops / k^w, k^{wh}/.

Procedures

Participants were assessed individually in a quiet room in the special child-care centers or the nurseries. The first five minutes were spent on building rapport with the participant. Then, each participant was asked to name the pictures, which represented the target words in CSPT. Each target word was named in three separate trials. If the participant was unable to name the picture, he/she would be asked to imitate the clinician's production. If the participant imitated the clinician's production in the first trial, imitation would also be required in the second and third of that target syllable. Similarly, if the participant imitated the clinician's production in the second trial of that target word, imitation would also be required in the third trial. All productions were recorded using a Sony ICD-MX20 audio recorder placed within five inches of the children's mouth. Digitalized signals of 93 trials from each participant were then stored on a PC computer for later analysis.

Data analysis

The speech samples of the participants were recorded and online transcribed using International Phonetic Alphabet (International Phonetic Alphabet [IPA], 1999) by the author who had received previous training in phonetic transcription.

Accuracy measurement

Accuracy of speech production was examined through calculating the percentage of productions of consonants, vowels and tones that were perceptually judged to be accurate during the three productions of each target syllable while whole word accuracy was measured by dividing the number of accurate phonological units by total number of phonological units within the target syllable. For example, in three different trials of production of /wun^{35}/(碗), the participant produced [wu^{35}], [wun^{35}] and [wuk^{55}]. The percentage of accuracy of consonant would be 67% (4 out of 6 correct productions of initial and final consonants in 3 trials), vowels would be 100% (3/3), and tones would be 67% (2/3) while the percentage of accuracy of whole-words is 75% (9/12).

Variability measurement

Variability measurement was a method derived from the research of Ertmer and Goffman (2011), in which a scoring system was proposed for measuring speech variability. In this scoring approach, variability scores was used as an indicator by assigning a higher variability score to more variable productions and lower variability score to less variable productions. Regardless of the accuracy, a score of 1.0 would be given if the three attempts were identical, 2.0 would be given if two different productions were identified in three attempts and 3.0 would be given if all three attempts were different. Therefore, it was expected a mature speaker or a speaker with more stable speech production would have a generally high accuracy and low variability score across all conditions (i.e. vowels, consonants, tones and whole-words) and sets of initial consonants (i.e. set 1, set 2, and set 3). For example, in the production of /wun^{35}/(碗), variability score of vowel would be 1.0(because only one form of vowel was made),consonant would be 2.0 (within 3 trials, 4 different productions were made in 2 phonemes), tone would be 2.0 and whole-word would be 3.0.

<u>Reliability Measurement</u>

Ten percent of the data was re-transcribed again by the author about one week after the first transcription to obtain the intra-rater reliability. Ten percent of the data was transcribed by another trained transcriber independently to evaluate the inter-rater reliability. The intra-rater and inter-rater reliabilities were 81% and 79% respectively. The reliability was calculated by dividing the total number of agreements on the participant's speech production by the total number of target sounds and multiplying by 100.

Results

In order to determine if the three groups performed differently between different conditions and sets of initial consonants, separate analysis of variance (ANOVA) analysis were done. Significant level was set at 0.05. Significant interactions were further examined through post-hoc (Tukey HSD) testing.

Comparison of groups' variability scores for vowels, consonants, tones and whole-words

The means and standard deviations of percentage accuracy for vowels, consonants, tones and whole-words were shown in Table 4. The variability scores in four conditions (i.e. vowels, consonants, tones, whole-words) among three groups (i.e. CI, HA, NH) were compared.

A 3 x4 (group x condition) two-way repeated-measures ANOVA was conducted. The interaction between groups and conditions was statistically significant, *F* (6, 72) = 5.73, *p*<.01. The analysis also identified statistically significant main effect of Group, *F* (2, 24) = 26.17, *p*<.01 and significant main effect of condition, *F* (3, 72) = 74.58, *p*<.01. To examine the interaction effect, simple main effect of condition at each of the three groups and simple main effect of group at each of the four conditions were further analyzed by one-way ANOVA.

Table 4. *Mean Score and Standard Deviations (SD) of Speech Production Variability (n=27)*

Group	Vowel		Consonant		Tone		Whole-word	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CI	1.09	0.07	1.17	0.11	1.02	0.03	1.30	0.12
HA	1.34	0.12	1.33	0.15	1.18	0.14	1.78	0.17
NH	1.12	0.09	1.17	0.12	1.02	0.54	1.35	0.20

Note. Values are mean scores on a 3-point scale (1=least variable; 3=most variable)

Simple main effects of condition and group were evaluated by separate one-way ANOVAs. Among three groups, there were significant simple main effects of vowels, *F* (2, 26) = 18.21, *p*<.01, consonants, *F* (2, 26) = 4.73, *p* = 0.019, tones, *F* (2, 26) = 10.04, *p* = 0.001 and whole-words, *F* (2, 26) = 23.83, *p*<.01. Post-hoc testing found that, the CI group had significantly better performance (i.e. significantly lower variability scores) than the HA group as lower variability scores were achieved in each of the four conditions and the NH group also performed significantly better than the HA group by having lower variability score in each of the four measures. However, no significant difference was noted between performance of the CI and NH groups within the four conditions.

Separate one-way ANOVAs were conducted to compare the performance among different conditions within each group. First, within the CI group, difference in variability scores among vowels, consonants, tones and whole-words was statistically significant, *F* (3, 24) =

20.05, *p*<.01.Post-hoc testing found the variability score in tones production of the CI group was significantly lower than that of consonants and whole-words and variability score in vowels and consonants were lower than that of whole-words. Second, within the HA group, statistically significant difference between different conditions was identified, *F* (3, 24) = 36.86, *p*<.01, revealing the HA group's performance in whole-words was significantly with higher variability than all the other three conditions. Third, within the NH group, the difference among conditions was also found to be statistically significant as well, *F* (3, 24) = 24.19, *p*<.01, revealing variability in vowel productions was significantly lower than that of consonants and whole-words while variability of tone was significantly lower than that of vowels productions.

Comparison of groups' percentage accuracy for vowels, consonants, tones and whole-words

The means and standard deviations of percentage accuracy for vowels, consonants, tones and whole-words were shown in Table 5.

Table 5. *Means and Standard Deviations (SD) of Percentage of Speech Production Accuracy (n=27)*

Group	Vowel		Consonant		Tone		Whole-word	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CI	92.6	6.0	68.1	13.3	97.2	3. 9	84.1	6.5
HA	75.9	18.3)	57.6	15.9	85.0	13.2	71.2	14.1
NH	89.4	8.4	76.1	10.3	98.5	2.6	86.8	4.8

The percentage accuracy in the four different conditions between three groups was compared by a 3 x 4 (group x condition) two-way repeated-measures ANOVA. A statistically significant main effect of group was noted, *F* (2, 24) = 6.45, *p* = 0.006, revealing higher accuracy in the CI group than the HA group (p=0.023) and higher accuracy in the NH group than the HA group (p=0.008) across the four conditions. Statistical significant main effect of condition was also identified, *F* (3, 72) = 62.24, *p*<.01, revealing significantly higher accuracy achieved in vowels than tones (p=0.018), whole-words (p=0.044), consonants (p<.01), significantly higher accuracy in tone than whole-words (p<.01) and consonants (p<.01) and significantly higher accuracy in consonants than whole-words (p<.01) However, no significant interaction between groups and conditions was found, F (6, 72) = 0.954, p=0.462.

Comparison of hearing impaired groups' variability score for initial consonants

The means and standard deviations of variability score in different sets of initial consonants between CI and HA groups were listed in Table 6.

Table 6. *Means and Standard Deviations (SD) of Variability Scores in Different Sets of Initial Consonants (n=18)*

Group	Set 1		Set 2		Set 3	
	Means	SD	Means	SD	Means	SD
CI	1.08	0.06	1.28	0.21	1.40	0.32
HA	1.15	0.11	1.39	0.29	1.59	0.33

A 2 x 3 2-way repeated measures ANOVA revealed there was significant main effect of sets, F (2, 32) = 12.82, p <.01, revealing significantly lower variability score in set 1 than set 2 (p = 0.011) and set 3 (p = 0.001). No significance between set 2 and set 3 initial consonants was found (p = 0.179). However, no significant main effect of group, F (1, 16) = 2.63, p = 0.12, and no interaction between group and set, F (2, 32) = 0.23, p = 0.78 was found.

Comparison of hearing impaired groups' percentage accuracy for initial consonants

Table 7 showed the means and standard deviations of percentage accuracy in different sets of initial consonants between CI and HA groups. To compare the percentage accuracy in difference sets of initial consonants (i.e. set 1, set 2 and set 3) and performance between groups (i.e. CI and HA groups), a 2 x 3 2-way repeated-measures ANOVA was conducted. A statistical significant main effect of set, F (2, 32) = 78.58, p <.01 was confirmed with the above observations. In post-hoc analysis, it showed that within both groups, percentage accuracy achieved in set 1 was significantly higher than set 2 (p<.01) and set 3 (p<.01); while percentage accuracy of set 2 was significantly higher than set 3 (p<.01). However, no significant main effect of group, F (1, 16) = 0.429, p = 0.522 was found and interaction between groups and sets of initial consonants, F (2, 32) = 0.38, p = 0.963 was insignificant.

Table 7. *Means and Standard Deviations (SD) of Percentage of Accuracy in Different Sets of Initial Consonants (n=18)*

Group	Set 1		Set 2		Set 3	
	Means	SD	Means	SD	Means	SD
CI	91.0	8.3	69.9	20.6	32.8	32.0
HA	87.0	8.7	64.8	22.7	26.2	20.9

DISCUSSION

Overall performance

In the study of Law and So (2006), the mean percentage accuracy of vowels and consonants by CI recipients were 98.2% and 73.4% respectively, which were close to the results in the present study. In the current research, both the CI and HA groups had relatively higher accuracy in tone productions when compared to the study of Law and So (2006), which were 86.6% and 78.1% respectively.

On the whole, the results of the current research showed the CI recipients gained substantial improvement in speech accuracy and variability as a function of implant use. Performance of the HA users had significantly lower accuracy and higher variability in speech when compared to the NH and CI groups. The result matched with findings of pervious researches which showed children with cochlear implants had their phonological development improved to a greater extent than children with hearing aids (Law & So, 2006; Osberger, 1995). Therefore, the outcome supported previous hypothesis that, with similar duration of hearing device usage, use of cochlear implants was more feasible for children with hearing impairment to achieve faster progress in phonological development when compared to use of hearing aids. The current outcome could not imply if the HA users were able to achieve similar level of phonological development with a longer duration of device usage. It is suggested future research could look into the duration of HA device usage required for achieving compatible speech accuracy and variability with CI usage.

The performance of the CI group was close to the NH group, which was different from the hypothesis made at the beginning of this passage. In the study of Ertmer and Goffman (2011), they found that performance of the CI recipients were poorer than their age-matched normal hearing peers in terms of speech accuracy and variability. The current study showed, when all participants had their duration of hearing experience matched, use of cochlear implants was effective in assisting children with hearing impairment to catch up with normal hearing peers in terms of speech accuracy and variability.

The participants' speech accuracy and variability in vowels, tones, consonants, and whole-words level were also compared and discussed separately as follow:

(1) Vowels

The current research reflected the CI and NH groups had more maturely acquired vowels according to their close to ceiling level accuracy and relatively lower variability, which were relatively better than other conditions (e.g. consonants). According to So and Dodd (1995), acquisition of vowels should be achieved prior to that of consonants and to be achieved by Cantonese-speaking children by age 2. Considering the suggestion that earlier acquired sound features might lead to more consistent productions (Ertmer & Goffman, 2011), the result also followed the above findings as higher accuracy and lower variability were observed in vowels productions.

The percentage of accuracy in vowel productions among the HA group was 75.9%, which was lower than that in the study of Law and So (2006), which was 97.0%. Besides, significant difference in the variability scores of vowel productions between the HA and NH groups was found, revealing participants with hearing aids in this study had significantly less accurate and more variable vowel productions. This implied, apart from the duration of hearing experience, it was suspected if there might be other factors affecting HA users' vowel production accuracy and variability. According to Osberger (1995), cochlear implantation was more effective in restoring auditory perception to a greater extent than hearing aids. HA users might rely on auditory feedback, which might be deprived or distorted by the use of HA. As proposed in research of Baudonck, Lierde, Dhooge and Corthals (2011), due to the lacking of adequate auditory feedback, children with hearing impairment might attempt to compensate the auditory feedback by proprioreceptive feedback during articulatory maneuvers, which might in turn lead to inconsistent and unstable control over articulators and higher variability of speech production. Therefore, it might be due to the reason that production of vowels relied more on kinesthetic feedback which might be influenced or deteriorated by usage of HA.

(2) Tone

With a mean hearing experience of 30 months among the participants, the percentage of accuracy was high and variability score was low across three groups. The highest percentage of accuracy and lowest variability scores were achieved in all three groups when compared to other conditions, revealing more mature acquisition and stabilized productions in tones. One possible explanation suggested by So and Dodd (1995) was the heavy functional load of tones in Cantonese might enhance the tone perception and production, which should be acquired by age 2.0 in normal developing children. It was proposed children who had more consolidated phonological ability mighty lead to less variable productions as their low speech production variability reflected their phonological knowledge (Kent, 1992). Therefore, the current study supported the hypothesis that earlier acquired features would show high percentage of accuracy and low variability.

In the study of Lee, van Hasselt and Tong (2010) on Cantonese-speaking children, children who received cochlear implantation by age 4 might lead to faster progress in tone acquisition. The present study followed their findings as all CI participants were reported to have their implantation by age 3.This might explain for the approximation in production accuracy and variability of tone between the CI group and the NH group.

(3) Consonants

In the study of Ertmer and Goffman (2011), significant difference in production accuracy and variability were found between the subjects with cochlear implants and their age-matched normal hearing peers. Past studies revealed that children using cochlear implants showed significant difference in production accuracy of consonants from children using hearing aids (Baudonck, Dhooge, D' haeseleer and Van Lierde, 2010). The present study followed the previous finding as significant difference among the participants was noted in accuracy and variability of consonants production. Yet, only the performance of the HA group was found to be significantly different from the other two groups while the CI group showed no significant difference from the NH group in consonant production.

Besides, it is observed the variability score of consonant productions was relatively higher than other phonological features (i.e. tones and vowels). According to So and Dodd (1995), acquisition of tones and vowels usually came earlier than that of consonants, which were usually acquired at age 2;0-5;0. With an average of 2.5 years of hearing experiences, it was suspected all the participants were at emerging stage of consonants acquisition with developing phonological ability in consonants. Their lack of phonological knowledge on consonants might lead to more variable speech productions (Stoel-Gammon, 2004). Therefore, the outcome supported the hypothesis that less maturely acquired features might lead to more variable productions.

There were two suggestions made in order to increase the sensitivity in identifying difference in variability scores between productions of different consonants. First, position of consonants within a syllable might be a contributing factor. In the study of Byrd, Lee, Riggs and Adams (2005), they found children's production of consonants varied between different syllabic positions. According to Byrd et al. (2005), articulation time for final consonants was shorter than that of initial consonants. Thus, they suggested children who had less phonological awareness on final consonants and weaker control on neuromotor for articulation might not have enough time for preparation of their articulation. However, the current research did not look into the difference of variability between initial and final consonants. Therefore, it would be interesting for future study to investigate if position of consonants within a syllable could be a factor to affect speech variability in children with hearing impairment.

Second, different manners and articulatory positions of consonants might be another factor affecting speech accuracy and variability. It was suspected if consonants acquired at an earlier stage might lead to a lower variability and higher accuracy in speech. Thus, a comparison of performance in different sets of initial consonants between the two hearing-impaired groups was made. The result revealed that children with hearing impairment showed different speech accuracy and variability across different sets of initial consonants. It was observed better performance in set 1 than the other two sets. Previous findings also support the result. Law and So (2006) found that, among children with hearing impairment, initial consonants in set 3, including fricatives, affricates and labialized velar stops were always missed in the phonetic inventory of children with around two years of hearing experiences. In the study of Ertmer and Goffman (2011) on children with cochlear implants, they found that consonants acquired at a later stage (e.g. fricatives and affricates) had a generally higher variability and lower accuracy than earlier acquired phonemes (e.g.

labial stops). Stoel-Gammon (2004) suggested that children with more acquired understanding of phonological rules and mature phonological knowledge might produce more consistent speech productions. Thus, such observations supported the hypothesis that mature acquisition of phonological features was shown by relatively more stable and more accurate speech productions between different conditions and different sets of initial consonants.

Yet, one interesting finding was that, in both accuracy and variability, no significant difference on their performance between different sets of initial consonants was found between the CI and HA groups. Although in general consonants productions (i.e. both initial and final consonants), CI group did achieve a higher accuracy and lower variability than HA group, the result revealed that at the emerging stage of acquiring initial consonants, the CI group was not significantly different from the HA group. It might be due to the short duration of hearing experience of the participants with hearing impairment (i.e. mean hearing experience was 2.5 years). And with this duration of device usage, both the CI and HA groups were at the emerging stage of initial consonants acquisition, thus they did not differ significantly from each other. Osberger (1995) suggested use of cochlear implants would be more effective than use of hearing aids in achieving close to normal phonological development. It was suspected whether the CI and HA groups would significantly different from each other in variability of initial consonant productions with a longer duration of hearing experiences. Thus, further study on the duration of time needed for children with hearing impairment to achieve stable productions of initial consonants would be suggested.

(4) Whole-word productions

In whole-word productions, HA group showed significantly greater variability and lower accuracy than the other two groups. Two factors were suggested to attribute to such difference in performance. Firstly, constrained phonological ability might be the first factor affecting one’s speech accuracy and variability (Leonard, Rowan, Morris, & Fey, 1982). In the present study, the HA group showed relatively poorer performance in accuracy and variability across all three phonological features (tones, vowels and consonants), reflecting the phonological ability of the HA group was constraining their ability to maintain accurate and consistent speech productions.

Secondly, immature neuromotor control might also attribute to the speech inconsistency (Smith & Zelaznik, 2004). Hearing impairing children might attempt to obtain more proprioreceptive feedback in order to compensate the distorted auditory input, thus leading to inconsistent and variable productions as observed in the current study. Yet, such variability was not observed in CI group, which might attribute to difference in auditory input by difference of hearing device. However, the methodology of the current research did not investigate the factor of maturity of neuro-motor control. Therefore, as a suggestion for future studies, acoustic and kinematic measurements could be used to investigate if there might be any difference in speech variability between children with normal hearing and children with hearing impairment.

Limitation

Only a relatively small number of subjects were studied, which might lead to a limited generalizability of the study findings. Only a limited exploration on the difference of speech stability between three groups was achieved. It might not be able to represent the whole population of children with impaired hearing ability and children with normal hearing ability.

Despite the hearing experience of the two groups (i.e. children with hearing aids and children with cochlear implants) was controlled, the length of participation in auditory and articulation training was not controlled as provision of auditory and articulation training might lead to variation in speech performance among subjects.

In the present study, only the performance on single word picture-naming was considered and discussed, to look into more information on the speech variability of hearing impaired children, study on speech variability of continuous speech production was needed.

Conclusion

Among the participants with hearing impairment, it was found that only the HA group performed significantly different from their normal-hearing peers. The HA group had lower accuracy and higher variability in speech productions while the CI group did perform similarly with the NH group across different conditions. Besides, it was also revealed the CI group performed significantly better than the HA group in accuracy and variability of vowels, consonants, tones and whole-word productions. Such difference in performance revealed that, when compared to normal hearing peers with similar duration of hearing experiences, the CI recipients were able to achieve better progress in phonological development than the HA users. Whether children using hearing aids were able to performe similarly with hearing experience matched normal peer and the length of time needed to do so were worthwhile to be further investigated.

Second, among phonological features in Cantonese, it was found that earlier acquired features usually led to more accurate and less variable speech productions. This was implied in the significant difference in performance in vowels and tones productions across the three groups. Also, among the CI and HA groups, initial consonants acquired at earlier stage (i.e. nasals and stops in set 1) were also found to be more accurately and consistently produced. This implied maturity of phonological features acquisition could be observed from speech variability as well. The finding provided clinical implication that apart from evaluating the rate of accuracy, variability of speech production could also be another indicator for clinicians to evaluate the progress in phonological acquisition and also to determine priorities and selections of treatment targets.

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Appendix A - *Word list of Cantonese Segmental Phonology Test*

No.	Stimuli	IPA
1	眼	ŋan^{23}
2	襪	mɐt^{2}
3	脷	lei^{22}
4	鈕	nɐu^{35}
5	餅	pɛŋ^{35}
6	水	sɵi^{35}
7	琴	k^{h}ɐm^{21}
8	碗	wun^{35}
9	蕉	tsiu^{55}
10	雞	kɐi^{55}
11	檯	t^{h}ɔi^{35}
12	裙	k^{wh}ɐn^{21}
13	花	fa^{55}
14	蘋	p^{h}iŋ^{21}
	果	kwɔ^{35}
15	西	sɐi^{55}
	瓜	k^{w}a^{55}
16	刀	tou^{55}
17	貓	mau^{55}
18	魚	jy^{35}
19	床	ts^{h}ɔŋ^{21}
20	巴	pa^{55}
	士	si^{35}
21	鴨	ap^{3}
22	龜	k^{w}ɐi^{55}
23	筷	fai^{33}
	子	tsi^{35}
24	鞋	hai^{21}
25	電	tin^{22}
	話	wa^{35}
26	糖	t^{h}ɔŋ^{35}
27	腳	kœk^{3}
	板	pan^{35}
28	杯	pui^{55}
29	洗	sɐi^{35}
	面	min^{22}
30	粥	tsʊk^{5}
31	耳	ji^{23}

Appendix B – *Letter for recruiting participants*

(Date)

Dear Principal,

Asking for assistance in recruiting participants for research

I am a year four student in the Division of Speech and Hearing Sciences of the University of Hong Kong. I am writing to ask for your assistance in recruiting participants for my final year research.

The title of my research project is "***Speech variability and accuracy in Cantonese-speaking children with hearing impairment: Comparison with normal-hearing peers***". My study aims at evaluating the speech accuracy and variability of hearing-impaired children with cochlear implants in order to provide some elementary information and support for the speech therapists on their intervention of the hearing-impaired students. I would like to investigate if speech variability can be used an early indicator of speech maturity of children who have early cochlear implantation.

In order to purse my study, I am now looking for 20 native Cantonese-speaking children aged from2;0 to 5;0 with prelingual profound hearing impairment and fitted with cochlear implants before age 3 or with hearing aids. They should have normal intelligence with no known visual, emotional, behavioral, physical, cognitive, and neurologic impairments.

The subjects will be required to attend a 45-minute session individually in a quiet room in the school. Each subject will be asked to name pictures under a playing context. Audio-recording will be made during the sessions. The time and the date of the session are negotiable. All information will be kept confidential and in no way the students will be identifiable from the results recorded. Participants and their parents are allowed to withdraw from the research at any time without prejudice.

For further details of my research or reply, please feel free to contact me (tel. 61508723) or my supervisor Dr. Lydia So (lydiaso@hkucc.hku.hk). If you have questions about your rights as a research participant, contact Dr. Estella Ma, Chairperson of the Faculty of Education Research Ethics Committee (tel. 2859 0594). Thank you for your attention and assistance. I am looking forward to hearing from you soon.

I would be grateful if you could help passing this message to the members of your association. Enclosed includes a parent consent form for my research in which you are free to distribute it to the possible candidates.

Yours sincerely,

LEE PUI SZE

Division of Speech and Hearing Sciences

University of Hong Kong

I agree to the procedures set out above to facilitate Lee Pui Sze to conduct the research project in my school.

Endorsed by: Date:

[Name of Principal]

Principal

[School name]

Appendix C - *Parent consent form*

(日期)

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部四年級學生，將進行一項關於弱聽兒童和正常兒童語音發展的學術研究，對象為兩歲至五歲的兒童。研究旨在探討弱聽兒童的言語準確性及變化性。因是項研究將有助言語治療師理解學童在這方面的發展及特性，以協助釐定合適的評估方案。

參與是項研究的同學只需按老師的安排，在上課期間單獨參與一節約四十五分鐘的評估。過程中， 貴子弟將會被要求讀出圖片咭上的圖片。為了把所得資料作詳細分析，評估過程將會被錄音，並需要 閣下提供 貴子弟的個人資料。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。

是次參與純屬自願性質，您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，請與本人聯絡(6150-8723)。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

貴家長

香港大學言語及聽覺科學部四年級學生

李珮鍶謹啓

（日期）

家長回條

學生姓名：___________________________ 性別：______________

出生日期：____／______／______（日／月／年）

接受人工耳蝸及啟用日期:____／______／______（日／月／年）

開始佩帶助聽器日期：____／______／______（日／月／年）

班別：__________

本人 ＊＊同意／不同意 子弟參與是項研究。

（＊＊請刪去不適用者）

家長姓名：________________

家長簽署：________________

日期：____________________