Title	Perception of vowels and diphthongs by hearing-impaired Cantonese-speaking children with cochlear implants
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Citation	
Issued Date	2010
URL	http://hdl.handle.net/10722/173697
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2006201072

A dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science (Speech and Hearing Sciences),The University of Hong Kong, June 30,2010.

Perception of vowels and diphthongs by hearing-impaired Cantonese-speaking children with cochlear implants.

Chan Kam Wing

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Abstract

This study investigated the perception of vowels and diphthongs perception of congenital profound bilateral hearing impaired children with cochlear implants (CI). The CI children’s age was ranged from 2:04 to 6:01, and 9 CI children were matched with 9 hearing children. A closed-set speech perception task was administrated. High-front vowel was found to be the easiest vowel to be perceived, due to the greatest perception difference in the first 2 formant frequencies. The perception of diphthongs was related to their feature complexity. Diphthongs with feature complexity 1 and 2 were the easiest to be perceived, while diphthongs with feature complexity 3 and 4 were more difficult to be perceived. With 2 year duration of cochlear implantation, CI children could catch up with normal hearing children in their perception of vowels and diphthongs. To conclude, cochlear implants helped children with profound hearing loss in the perception of vowels and diphthongs.

Introduction

Children with profound sensory neural hearing loss always encounter speech production and perception problem. The damage on their hair cell affects the reception of auditory signals. They cannot develop accurate speech production and perception system. They showed phonological error and distorted speech error. Therefore, their speech intelligibility was reduced (Tobey, 1993).

So & Dodd (1994) found that Cantonese-speaking children with profound hearing loss persisted phonological processes in development and non-development way. The introduction of cochlear implants (CI) could retain part of the hearing abilities on children with profound hearing loss. Children with profound hearing loss have damage on either the inner hair cells or the part of the brain for hearing. Multichannel cochlear implants provide electrical stimulation at multiple sites in the cochlea by different electrodes. They could stimulate different nerve fibers in the ear, which bypassed those damaged hair cells. Exploit the place mechanism for coding frequencies.

In the previous English studies, there is limited research done on the development of vowels and diphthongs. Researchers might treat vowels and diphthongs were easy to master when compare to consonants. Vowel has the feature of voicing and high intensity. When produce vowels, the vocal tract usually open, this produce a good resonances and the duration to produce a vowels are long. The formants frequencies provide strong acoustic cues to identify vowels' height and front-back position. On the contrary, most consonants like stops, affricates and fricatives are non-harmonic, aperiodic in nature. The spectral peak for /s/ can be above 4kHz. All these provide evidence that vowels are easier to perceive (Gloria, Katherine & Lawrence, 2007). Actually, vowels are not easy to learn (Davis & MacNeilage,1990). Paschall (1983) found that 20 children aged 16–18 months the produce vowels's accuracy were below 60%. Otomo & Stoel-Gammon (1992) found the mean percentage of correct production of unrounded vowels for children aged 26 months was 63.5%.

Mani & Plunkett (2007) tested children at 15, 18 and 24 month old, and they found that children as young as 15 months could identify the difference between two vowels in monosyllabic word context. Mani, Plunkett & Coleman (2008) found that children at 18 months were more sensitive to vowel's changes in height and back. Wellman et.al. (1931) studied 204 children aged 2 to 6 years old, they found that the diphthongs development of normal children were as follows: /ai/, /Oi/ and /au/ by age 3;0 and the vowels /i, e, Y, u/ appeared at age 4;0. According to Paschall (1983) and Hare(1983), children by age 2 could master /au/, /Oi/, /ai/ and /iu/. However, only four diphthongs had been investigated.

These English studies reveal that children mastered different vowels and diphthongs at different times. Those corner vowels /i,a,u/ are acquired first, followed by mid back and central vowels /o,A/. Front vowels /e,G,I / appeared at the last stage. Hearing children also encountered difficulty in learning vowels and diphthongs; it is needed to see how cochlear implants could help children with profound hearing loss.

Tyler and his colleagues (1997) done several speech perception tests included consonants and vowels, CI children could recognize vowels and consonants features after 2 years of cochlear implant use, with the exception of the place feature. Children with cochlear implants also improved their vowels perception after 36-month implantation (Tyler et al., 1997). Miyamoto and his colleagues (1996) also studied the speech perception for CI children in a longitudinal study. It was found that the CI children have the best performance in the vowel-feature recognition. Their performances were better than children who use conventional hearing aids. These studies showed the perception of vowels and diphthongs for children with profound hearing loss was improved by the cochlear implantation.

In Cantonese, many studies have been done on the tone perception of CI children. (Lee, van Hasselt, Chiu and Cheung, 2002; Ciocca, Francis, Aisha & Wong 2002) .They found that cochlear implanted children performed worse than normal children in identifying and perceiving the six lexical tones. But their performance was better than those who wear hearing aids. Law & So (2006) identified the phonological error of children with cochlear implants on their production of consonants. They didn’t report the error in vowel production.

The above studies focused on tone and phonological ability of CI children. The research focus mainly concern their speech production, tonal error. But limited researches have been done on the perception of vowels and diphthongs in children with cochlear implant. Wei and his colleges (2002) investigated 28 prelingually deaf children with cochlear implantation. They found that CI children show significant improved consonant and vowel identification, after 24 months implantation and rehabilitation training, but the error pattern of those CI children was not reported. Since speech production and perception has a close linkage, the studies on vowels and diphthong's production could provide some useful information on how children perceive vowels and diphthongs.

In the study of Stokes and Wong (2002), they investigated the vowel and diphthongs development in Cantonese speaking children, and found that normal children's developments were related to feature complexity and ambient frequency. They found that the vowel development follow the trends as: /a/→/ε/→/i/→/O/→/A/→/Y/→/y/→/u/, this was more or less follow the feature complexity and the ambient frequency in Cantonese. For diphthongs, they questioned the tongue height and tongue's horizontal movement might contribute the development of the diphthongs. CI children definitely have a different auditory system to assists their speech perception and production. It will be meaningful to see whether their vowels and diphthongs' development would follow the trends of hearing children.

Therefore, it would be interesting to study the vowel and diphthong perception of CI children. This not only gave a more complete picture about CI children's phonological ability, but also good to see whether CI children's vowels and diphthongs perception also affected by factors like feature complexity and vowel space.

To give a more objective analysis, acoustic analysis will be used in the present study. Formant frequency was defined as resonances of the vocal tract (Lawrence, Gloria, & Katherine, 2007). The first three formant frequencies are most related to the vocal tract's spacing and the movement of the tongue. Therefore, different vowels can be characterized by their formant frequency. And this provides an additional perspective to look at the perception of vowels and diphthongs of CI children.

For CI children, since they have delayed exposure to the auditory signals, it would be interesting to see whether their vowel and diphthongs development follow normal children's pattern. And their perception of vowels and diphthongs might give a clearer picture of their phonological error.

Cantonese vowels and diphthongs

Cantonese is regarded as a tonal language. Cantonese vowels could be defined by articulatory and acoustic basis. According to the tongue height, vowels can be defined as high, mid and low vowels. From the perspective of tongue's front-back position, vowels can be classified as front, central and low features. According to Zee (1999), Cantonese has seven long vowels [i,y,□□e,Y,C, O, u]and four short vowels [I,B,A,u]. There are eleven diphthongs in Cantonese, they are: /iu, iu, ai, au, ai, eu, ei, ou, Ai,Au, BEy/ (Zee, 1999). Diphthongs are a combination of vowels but with a gradual changes in the articulator production (Bernthal & Bankson,1998). It contains a nuclear vowel and an ending vowel. /eu/ will be excluded as it is not a common phoneme in Cantonese**.** The features complexity of diphthongs can be analyzed by the composite vowels.

Feature complexity of vowels and diphthongs

Vowels can be defined as from its height, front-back position, tenseness and roundness. Zee(1999) defined the vowels' feature as shown in Figure 1:

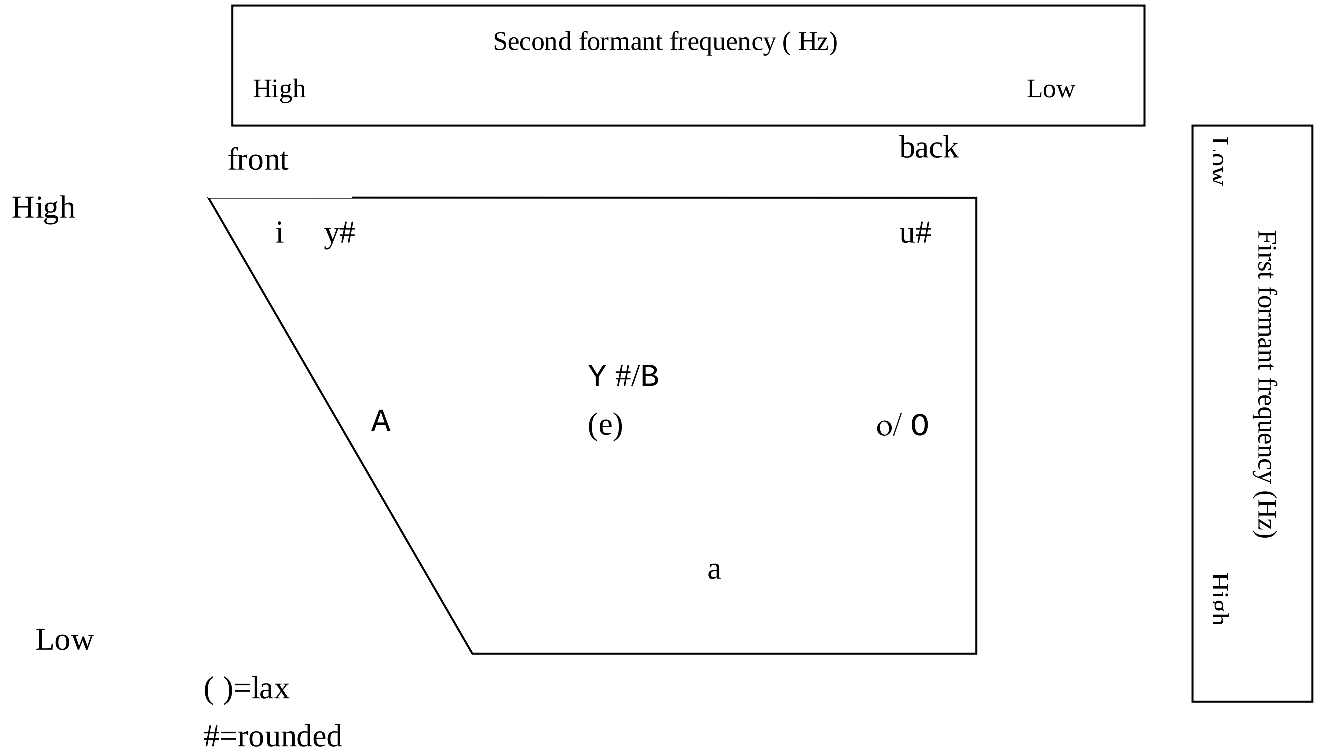

Figure 1. Feature of Cantonese vowels.

For diphthongs, they have two root nodes (Bernhardt, 1992). Therefore, their feature complexity also depends on the conjugate pair's feature difference.

The feature complexity depends on four features: tenseness, roundness, height, and anteriority. Comparing the two conjugate vowels in a diphthong, any movement in terms of the anteriority was rated a value of 1. For example, the two conjugate vowels move from [central] to [front] is rated as a complexity value of 1. The same rule applies to the height dimension. Any difference of the two conjugate vowels in terms of their height was rated a value of 1. For example, movement from [middle] to [high] is rated as a complexity value of 1. The [round] contrast is also weighted as 1, as is the [tense] contrast. For example, the constituent vowels of the diphthong /Jy/ are characterized as [mid], [central], [round] and [high], [front], [round] respectively, and therefore, it has a rating of 2. Table 1 summarized the diphthong's feature complexity and their levels coded as 1.2.3.4

Table 1

Level of Feature complexity of Cantonese Diphthongs

Diphthongs	ei	ou	Jy	ai	ui	iu	Oi	au	Ai	Au
Level of feature complexity.	1	1	1	2	2	2	3	3	3	4

Purpose of the study

1: To determine whether the tongue's height, front-back position has any effect on the perception of vowels of CI children.

2: To determine whether feature complexity affect the perception of diphthongs in children with cochlear implant.

3: To determine whether CI children will perform as well as hearing children with similar hearing experience.

Method

Subject

A total of 35 subjects, all are Cantonese-speaking children. Nineteen subjects had congenitally, bilateral profound hearing loss, they have received cochlear implantation (CI). The 19 CI children's age ranged from 2:04 to 6:01. Their mean age equals to 3:08 (*SD* =1;01). They recruited from the Special Child Care Centre of the Hong Kong Society for the Deaf. They received rehabilitation ranged from 0:04 to 4:03 years (*M*=1;10). All of them had at least one year's CI experience. They had no known disorders other than deafness. Table 3 showed the subject's information, including their unaided and unaided hearing threshold of both ears. The degree of their aided hearing level at 250Hz was also recorded, which is the average fundamental frequency for Cantonese speakers. (Ching,1984). Another 16 children are children with normal hearing. They were recruited from nursery school. Their age ranged from 2:02 to 5:04. Their mean age equaled to 3:05,(*SD*= 0;11). Among the 16 hearing children, nine CI children were matched with nine hearing children by their hearing age. The hearing ages of all children were at least 2 years old. The hearing age ranged from 2:02 to 4:06. Questionnaires were sent to parents or teachers to confirm that the children have normal intelligence and hearing ability. They were recruited from mainstream nursery or kindergarten. Table 2 summarized the CI children's information.

Table 2.

Subjects with cochlear implant's information

			Unaided Level dBHTL		Aided Level dBHTL				
S*	CA**	Sex	PTA*** (R)	PTA(L)	PTA(R)	PTA(L)	250Hz	Training year	CI experience
A	2:04	M	115	115	N/A	40	45	0;04	1;00
B	2:05	M	97	117	(Binural)	45	50	0;05	1;03
C	2:07	F	100	100	(Binural)	40	50	0;05	1;00
D	3:00	M	110	100	35	N/A	45	0;11	1;06
E	3:01	M	115	115	(Binural)	50	50	0:06	1:05
F	3:03	M	110	115	(Binural)	45	60	1;03	2;03
G	3:10	F	100	100	70	71	60	2;09	2;03
H	4:00	F	95	100	(Binural)	45	50	1;11	1;08
I	4:00	M	115	115	(Binural)	47	55	1;03	1;03
J	4:01	F	125	125	(Binural)	45	50	1;04	1:00
K	4:03	M	100	110	N/A	50	50	2;02	2;11

L	4:05	F	110	110	(Binural)	41	55	2;04	2;02
M	4:06	F	100	95	N/A	50	50	1;05	1;05
N	4:08	M	125	125	52	N/A	55	2;04	1;02
O	4:10	M	111	115	(Binural)	45	60	2;04	2;03
P	5:05	M	115	105	40	N/A	45	3;04	4;05
Q	5:08	M	125	125	40	N/A	50	4;03	3;09
R	6:0	M	115	115	35	N/A	35	3;05	4;06
S	6:01	M	110	100	N/A	45	45	3;05	2;06

*S:Subject

**CA: Chronological Age

***PTA: Pure tone average of thresholds at 500, 1000 and 2000 Hz

Materials

The perception of vowels was assessed in the form of spoken word-picture matching. The task was a closed-set design. Each set had three pictures. All the pictures represented a monosyllabic word with CV/CVV structure. Seven long vowels and ten diphthongs were included in the test. For each set of words, the tone and consonants was the same. Each vowel and diphthong was tested. There are a total 56 tested items in the speech perception test. For vowel's perception, the three picture cards included the target stimuli, one acoustic distracter and one unrelated distracter. The target stimuli and the acoustic distracter was different from their vowel's height or front-back position.(.i.e. high versus low, high versus middle, low versus middle, front versus back, front versus central, central versus back.). For diphthong's perception, the three picture cards included the target stimuli, one feature complexity distracter and one unrelated distracter. The target stimuli and the feature complexity distracter were different from their level of feature complexity. (i.e. 1 versus 2, 1 versus 3. 1versus 4, 2 versus 3, 2 versus 4).

Procedure

Children were assessed in a quiet room in the Child Care Centre. Background noise was below 45 dB HL level in the room. This was to make sure that the children could perform at their normal level. The researcher built up rapport with the subject for 5 minutes. Then, each child was asked to name all the pictures once. If they could not name the picture, researchers would name the picture once. This was to make sure that they could comprehend all the pictures and the words that each picture represents. Then, the researcher presented auditory stimuli of the pictures in any set, the child was asked to point to the picture they had heard. The researcher presented the target stimulus through live voice with the instruction : 邊幅係 ______. The loudness level was above 65 dB. The test administrator sat on the side of the child's ear with cochlear implant.

Results

General result

Non-parametric statistics were used to evaluate the differences among the groups. An alpha level of .05(2-tailed) was adopted for all statistical tests.

The mean percentage correctness of vowels and diphthongs perception was 87.1% and 81.4% respectively. Regarding the perception of vowels contrast in height, the mean percentage correctness was 93.7% for high vowels, 82.3% for middle vowels, 77.9% for low vowels and the overall correctness are 84.6%. With respect to the perception of vowels contrast in front-back position, the mean perception correctness was 94.7% for front vowels, 84.2% for central vowels, 89.5% for back vowels and the overall correctness are 89.5%. Table 3 showed the accuracy of CI children in their performance on vowels perception.

Table 3.

Mean percentage correctness of vowels perception.

Testing Conditions	Contrast in height			Contrast in front-back position		
	High	Middle	Low	Front	Central	Back
Mean percentage of correctness	93.7%	82.3%	77.9%	94.7%	84.2%	89.5%
Overall correctness	84.6%			89.5%		

For the tested diphthongs, the mean percentage correctness for perception of diphthongs with feature complexity 1 was 87.7%, 85.6% for diphthongs with feature complexity 2, 78.4% for diphthongs with feature complexity 3 and 74.2% for diphthongs with feature complexity 4.

The tested diphthongs were analysis in terms of their feature complexity. Table 4 showed the accuracy of CI children in their performance on diphthongs perception.

Table 4.

Mean percentage correctness of diphthongs perception.

Feature complexity	1	2	3	4
Mean percentage of correctness	87.7%	85.6%	78.4%	74.2%

Comparison of CI children on perception of vowels and diphthongs.

In the speech perception task, the mean percentage of correct response for vowels and diphthongs were 87.1% and 81.3% respectively. To test whether the two results differenced significantly, Wilcoxon Signed Ranks Test was carried out. The result revealed that the performance on the vowels and diphthongs was significantly different, $p = 0.001$. It was suggested that the performance of CI children on the perception of vowels and diphthongs were significantly different. CI children had a better perception on vowels.

Vowels with contrast in height and front-back position.

In the speech perception task, the stimuli for vowels were different from either their vowel's height or front-back position. For the stimuli different in vowels' height, the mean percentage accuracy was 84.6%. For the stimuli different in vowels' front-back position, the mean percentage accuracy was 89.5%. Wilcoxon Signed Ranks Test was carried out on the percentage of correct response in these two set of stimuli. The difference was significant as $p = 0.02$. This indicated that children with cochlear implants had better perception in vowels with distracters different in the vowel's front-back position than that in vowel's height.

In the speech perception task, part of the stimuli for vowels perception was characterized by their vowel's height contrast. The Friedman analysis was conducted to relationship of CI children's perception between vowels different in height. The Friedman test analyzed their mean percentage, and showed a significant difference for perception of vowels not in the same height (Chi-Square=20.4, df=2, $p<0.001$). Further Wilcoxon signed ranks test was done to determine which height level's perception correctness were significant different from the others. It was found that the mean percentage correctness of middle vowel was significantly lower from high vowel, as p=0.001. The mean percentage correctness of low vowel was also significantly lower from high vowel, as p=0.001. There was no significant different between the mean percentage correctness of low vowel and middle vowel as p=0.253.

Another part of the stimuli for vowels perception were paired by their vowel's front-back position. The Friedman analysis was conducted to evaluate the relationship of CI children's perception between vowels different in front back position. The Friedman test analyzed their mean percentage, and showed a significant difference for perceptions of vowels not in the same front-back position (Chi-Square=10, *df*=2, *p*=0.007). Further Wilcoxon signed ranks test was done to determine which type of vowels perception correctness were significantly different from others. It was found that the mean percentage correctness of the front vowels was significantly higher than central vowels and back vowels as *p*=0.023 and *p*=0.046 respectively. The mean percentage correctness of back vowels were significantly higher than central vowels (*p*=0.046)

Perception of diphthongs with contrast in feature complexity.

In the speech perception task, parts of the stimuli are tested for diphthongs perception with contrast by their feature complexity. The Friedman analysis was conducted to evaluate the relationship of CI children's perception accuracy between diphthongs with different levels of feature complexity. The Friedman test analyzed the mean percentages of the diphthongs perception showed a significant difference in perception of diphthongs of different feature complexity (Chi-Square=19, *df*=3, *p*=0.008). Further Wilcoxon signed ranks test was done to determine which type of diphthongs were significant different from the others. It was found that the mean correct percentages for diphthongs with feature complexity 3 and 4 were significantly lower than diphthongs with feature complexity 1 as *p*=0.026 and 0.005 with respectively. The mean correct percentages of diphthongs with feature complexity 3 and 4 were also significantly lower than diphthongs with feature complexity 2 as p=0.044 and p=0.014 respectively. However, there was significant difference in between the mean percentage correctness of diphthongs with feature complexity 1 and 2 as p=0.645. The same is true for diphthongs with feature complexity 3 and 4 as p=0.167.

Children with cochlear implant and hearing children on perception of vowels and diphthongs.

To evaluate the effect of duration of CI experience on vowels and diphthongs perception, Mann-Whitney test was done to determine whether the CI children and hearing children showed significant difference from each other in the perception task. It is found that the mean percentage for perception of vowels and diphthongs were no significant difference as p= 0.133 and p=0.139 respectively.

Discussion

Vowels and diphthongs

The overall performance showed that CI children perceived vowels better than diphthongs. In the perception of vowels, one vowel sound was involved. However, in the perception of diphthongs, two vowels need to be decoded at a time, so CI children should encounter more difficulty in diphthongs perception than in vowels perception. Acoustically, the formant frequency signals of vowels were steadier than diphthongs, as diphthongs involve formant frequency of two vowels and formant transition from one vowel to another (Lawrence, Gloria, & Katherine, 2007). It definitely increases the difficulty for CI children to perceive and distinguish the diphthongs signals. The vowel-inherent spectral changes (VISC), which are the slow changes in formant frequencies in any speech context, exist in both vowels and diphthongs. But the VISC are a secondary cue for vowel perception but are an essential for diphthongs perception (Rosner & Pickering, 1994).These acoustic features showed that the perception of diphthongs was more difficult than that of vowels. It explained why children with CI in this study performed worse in diphthongs perception than in vowels perception.

Vowel perception and formant frequency.

The closed-set perception task showed that CI children's performance were better, as the task stimuli differed by their vowel's front back position, instead of the vowels differed in tongue's height. The difference could be related to formant frequency. The perception of vowels relied on formant frequency cues, especially first formant frequency (F1) and second formanct frequency (F2) (Nelson & Freyman, 1987). F1 were corresponding to the volume of pharyngeal cavity, which means the tongue's height will affect F1. For the F2, it is correlated to the size of oral cavity, and therefore it reflects the tongue's front-back position during phonation.

The result of CI children showed that they may extract acoustic information of F2 better than F1, as they scored higher when the stimuli showed difference in F2. Another study on CI users also found that some of them are likely to use F2 information in the recognition of speech (Tyler et al, 1989). But this result deviated from the study by Tyler and his colleagues (1992). They tested the perception of vowels of 10 subjects with cochlear implants in a 9-choice vowel-recognition task. The result showed that the subjects mainly used F1 to distinguish the vowels. But individual variation might exist in the dependence on different formant frequencies. In a single case study by Dorman and his colleagues (1988), the vowel stimuli presented with F1 along could not help the CI user to recognize all the vowels. F2 is involved to help the perception of vowels. Therefore, it could be concluded that both F1 and F2 play an important role in the vowel perception. And the CI children in this study could extract F2 information better than F1.

Following the result shown above, further analysis found that CI children perceived high vowels better than low vowels and middle vowels. They also had a better perception on the front vowels than back vowels and central vowels. If the two results were combined, it could be said that high front vowels was the easiest vowels to perceive. As shown in figure 1, it could be observed that the frequency difference between F1 and F2 is the greatest for high front vowels, and for other vowels like low back vowels, the frequency difference between the F1 and F2 is relatively close. This affected the perception of vowels by CI children. Therefore, the larger the difference between F1 and F2, the easier would be the perception of vowels.

Diphthongs and feature complexity

Children with CI's correctness in diphthongs perception is ranked as 4≈3<2≈1 in terms of their feature complexity. The feature complexity rating was related to the tongue movement, and the manner of articulation of the conjugate pair of vowels. It could be said that the higher the feature complexity, the higher the variation in the acoustic signals. Figure 2 showed the transition of diphthongs from the nuclear vowel to the ending vowel (Robert & Paul , 1997).

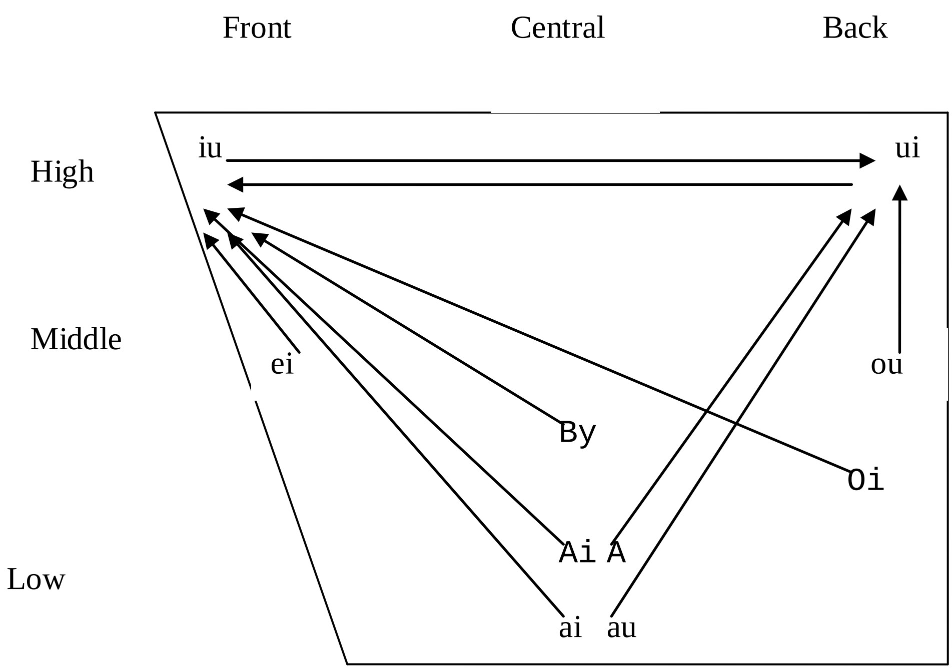

Figure 2 Transition of diphthongs from nuclear vowel to the ending vowel.

When comparing the feature complexity of /iu/ and /ai/, /iu/ is rated as 2 and /ai/ as 3 in term of their feature complexity. From Figure 2, it can be seen that /iu/'s transition is horizontal. It means that the transition of /i/ to /u/ mainly varies in F1, while F2 is relatively steady. However, for the diphthong /ai/, the transition is found to be slanting, which represented a change in both the F1 and F2 of /ai/. The more the changes in the feature complexity, the more acoustic information will be needed to be decoded by the CI children. This may be the possible reasons to explain why CI children have more difficulty to perceive diphthongs with higher feature complexity.

On the other hand, diphthongs with feature complexity 1 and 2 had no significant difference in their perception result. The perception correctness for diphthongs with feature complexity 3 and 4 also showed no significant difference. It can be observed that for diphthongs with feature complexity 1 and 2, their transition within the conjugate vowels results in either a change of height or front-back position. Therefore, CI children encountered similar difficulty in perceiving diphthongs with feature complexity 1 and 2. For diphthongs with feature complexity 3 and 4, the conjugate vowels are transit, involving both the height and front-back position. This means that they have a similar degree of variation in their formant transition, so CI children had similar difficulty in perceiving diphthongs with feature complexity 3 and 4.

Effect of CI experiences on vowel perception.

The perception task result showed that children with CI and hearing children with at least two year hearing age performed more or less the same. These suggested CI children could catch up with normal children in the perception of vowels and diphthongs. As perception should develop precede production, it can be predicted that these CI children should have good vowel production in the later time. The study of Law and So (2006) agreed the prediction, they found that Cantonese children with cochlear implants at age 5 to 6 years old had complete vowel inventory.

The result also matched with another study of Mandarin speaking children. Jiunn and Hui (2003) investigated the age effect on cochlear implantation of Mandarin speaking children; they found that the vowel perception improved significantly after two year of implantation. This implies that cochlear implantation did help children with profound hearing loss in their vowels and diphthongs perception. Therefore, it is not a surprise to find that CI children with enough CI experience could catch up with the normal peers in their vowels and diphthongs perception.

General Summary

In the present study, it is found that children with profound hearing loss could benefit from cochlear implants in the perception of vowels and diphthongs. CI children's performance was better on the perception of vowels, when compared to diphthongs. The perception of diphthongs was more complex as children need to decode more acoustic information of them. Moreover, the formant frequency might affect the perception of vowels. It was found that a larger difference in between the F1 and F2 could enhance the perception of vowels. CI children perceived high front vowels best in this study. In the perception of diphthongs, the feature complexity could be a reference for the level of perception in diphthongs. Finally, cochlear implants could help children to catch up with normal hearing peers in the perception of vowels and diphtongs, with two year hearing experience.

Clinical Implication

The perception ability of CI children in vowel and diphthongs was investigated in this study. The current findings, based on the tongue position and feature complexity, provided a level of hierarchy in perceiving vowel and diphthongs. The study on hearing age of CI also provided an insight on how the hearing experience related to their phonological development, when compare to hearing children.

All these findings provide some insight and sugest that clinicians need to take into account, when choosing appropriate treatment target in aural rehabilitation for CI children.

Limitation

There were 19 CI subjects participating in this study, which was relatively small in terms of subject size. More CI children's participation would enhance the generality of this study. Besides, children with hearing aids were not included in this study. However, the speech perception ability of children who wear hearing aids was also an important area to be investigated. It helped to compare how the cochlear implantation and the fitting of hearing aids could help children with hearing impairment in vowel perception, and gave further insight on the ability in speech perception of these two hearing enhancement tools.

The investigation on how the vowel length affects vowel perception would be also worth while to explore, given that acoustic signals duration played an important role in speech perception

Acknowledgements

I would like to express my sincere gratitude to Dr. Lydia So for her guidance, spiritual and knowledge support during this study.

I am deeply grateful to all the subjects participated in this study. I would also like to show my appreciation to the principals, staffs and educationist in the Bradbury Special Child Care Centre, the Sheung Tak Child Care Centre and the HKSPC Sze Wu Shu Min Nursery School for their help and arrangement, so that the data collection process can be smoothly done.

The last but not the least, I thank my family, friends and all the fellow colleagues, especially Etta, Irene for their inspiration and valuable opinions contributed to my dissertation.

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Appendix A

Test stimuli in the speech perception task

1	獅/si/	沙/sa/	錶/piu/
2	車/tsHe/	叉/tsHa/	手/sau/
3	梳/sO/	沙/sa/	雞/kAi/
4	豬/tsy/	遮/tse/	梨/lei/
5	虎/fu/	火/fa/□	笑/siu/
6	書/sy/	梳/sO/	杯/pui/
7	車/tsHe/	叉/tsHa/	錶/piu/
8	加/ga/	菇/gu/	笑/siu/
9	煲/pou/	錶/piu/	沙/sa/

10	梨/lei/	鈕/lau/	車/tsHe/
11	煲/pou/	飽/pau/	梳/sO/
12	咀/tsJy/	爪/tsau/	獅/si/
13	笑/siu/	瘦/sau/	叉/tsHa/
14	蟻/NAi/	咬/Nau/	沙/sa/
15	杯/pui/	飽/pau/	書/sy/

16	洗/sAi/	手/sau/	車/tsHe/
17	梯/tHAi/	呔/tHai/	遮/tse/
18	高/gou/	雞/gAi/	遮/tse/
19	推/tHJy/	呔/tHai/	書/sy/

20	女/nJy/	奶/nai/	叉/tsHa/
21	豬/tsy/	遮/tse/	杯/pui/
22	書/sy/	沙/sa/	蟻/NAi/
23	獅/si/	梳/sO/	咀/tsJy/
24	鋸/kJ/□	嫁/ka/	四/sei/

25	書/sy/	沙/sa/	鈕/lau/
26	菇/gu/	加/ga/	女/nJy/
27	書/sy/	梳/sO/	呔/tHai/
28	四/sei/	細/sAi/	豬/tsy/
29	獅/si/	沙/sa/	錶/piu/
30	菇/gu/	加/ga/	女/nJy/
31	虎/fu/	火/fa/□	笑/siu/
32	書/sy/	沙/sa/	蟻/NAi/
33	車/tsHe/	叉/tsHa/	錶/piu/
34	加/ga/	菇/gu/	笑/siu/
35	獅/si/	梳/sO/	咀/tsJy/
36	高/gou/	雞/gAi/	遮/tse/
37	四/sei/	細/sAi/	豬/tsy/

38	梨/lei/	鈕/lau/	車/tsHe/
39	書/sy/	梳/sO/	杯/pui/
40	梯/tHAi/	呔/tHai/	遮/tse/
41	杯/pui/	飽/pau/	書/sy/

42	蟻/NAi/	咬/Nau/	沙/sa/
43	洗/sAi/	手/sau/	車/tsHe/

44	笑/siu/	瘦/sau/	叉/tsHa/
45	豬/tsy/	遮/tse/	杯/pui/
46	女/nJy/	奶/nai/	叉/tsHa/
47	推/tHJy/	呔/tHai/	書/sy/
48	梳/sO/	沙/sa/	雞/kAi/
49	豬/tsy/	遮/tse/	梨/lei/
50	車/tsHe/	叉/tsHa/	手/sau/
51	書/sy/	沙/sa/	鈕/lau/
52	書/sy/	梳/sO/	呔/tHai/

53	煲/pou/	錶/piu/	沙/sa/
54	煲/pou/	飽/pau/	梳/sO/
55	咀/tsJy/	爪/tsau/	獅/si/
56	鋸/kJ/	嫁/ka/	四/sei/