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Tone Perception of Cantonese-speaking Children with

Cochlear Implant

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Abstract

This study investigates the ability of Cantonese speaking children with cochlear implant to identify Cantonese tones. It aims at seeing the effect of pitch level and change in pitch form on tone identification. Seventeen subjects aged between four to nine years old were employed in a tone identification task. They were asked to choose between pair of tones upon hearing the word /ji/ with different tones in carrier sentences. The results of the study showed that all the subjects were at about chance level in identifying the six tones. However, there was significant difference between the perception of three tone pairs suggesting that there is less confusion made between high level tone and mid level tone than between mid level tone and low level tone. Results also indicated that subjects are better at differentiating between level tones than between rising tones. Discussion is made on the efficiency of cochlear implant in transmitting tonal information and how the different pitch levels and forms affect tone identification. The fact that a lot of other variables such as age of child, age of implant and postoperative period would also affect performance is also discussed.

Introduction

Cantonese is a tonal language that uses differences in pitch of speaker's voice for lexical purposes. The distinctive tones of a tonal language correspond to the relative differences in fundamental frequency with which words are said (Bauer & Benedict, 1997). There are six contrastive tones in Cantonese which include tone 1: high level (HL), tone 2: high rising (HR), tone 3: mid level (ML), tone 4: low falling (LF), tone 5: low rising (LR) and tone 6: low level (LL). There is also a high falling (HF) tone which does not usually appear in modern Cantonese but is seen more often in Guandzhou Cantonese (Bauer & Benedicy). Besides using descriptive labels, we can also use numbers to represent the different levels of speaker's pitch range, a bigger number representing a higher pitch level. The tone contours for Tone 1: 55, Tone 2: 25, Tone 3: 33, Tone 4: 21, Tone 5: 23 and Tone 6: 22 (Bauer & Benedict, 1997). For example, Tone 2 starts from a relative pitch level of 2 and rise to a relative pitch level of 5. These six tones are differentiated according to their pitch levels/relative heights (high, mid & low) and change in pitch forms/contours of tones (falling, level & rising).

The child development and spontaneous acquisition of spoken language can be affected seriously by deafness (Boothroyd, Geers & Moog, 1991). It is important to provide these children with useful auditory capacity by employing modern hearing aids and suitable training. For profoundly deaf children with little residual hearing who gain no or little benefit from the use of conventional acoustic hearing aid, cochlear implantation may provide further access to audition. Cochlear implant systems electrically stimulate the remaining auditory nerve tissue in the cochlea to induce a sensation of hearing (McCormick, Archbold & Seppard, 1994). A lot of these profoundly deaf children may employ lipreading to aid comprehension. However, to distinguish between different tones on words with the same phonemic structure e g. /ji / meaning 'clothing' and /ji / meaning 'chair', it would be impossible to use lipreading to aid comprehension since they have the same mouth shape. The change of pitch of voice (tone) is related to the frequency of vocal folds vibration and therefore tonal changes would not be visible to lipreading patients (Tang, Luk, Lau, So, Wong, Yiu & Kwok, 1990). Acoustic information on fundamental frequency level and change in its form will be crucial in identifying among tones This acoustic information which is absent in the profoundly hearing impaired must be induced in other forms in order to perceive tones and cochlear implants may provide this information. However, little is know about how well these devices can transmit tonal information.

The current study is intended to investigate the pattern of tone perception in prelingually deaf children using cochlear implant. There are a lot of studies done on speech perception of cochlear implant patients in the West but relatively few have been done on Cantonese patients especially on the issue of tone perception. A study done by Tyler, Parkinson, Bertchy, Lowder, Parkinson, Gantz and Kelsay in 1997 has shown continued improvement of speech perception in prelingually deaf children over a 3-year period. Another study done on consonants and vowels identification by patients using the 6-channel continuous interleaved sampling processor showed that these patients extract sufficient spectral information from speech signals to have performance within the range of normal hearing patients (Dorman & Loizou, 1998). The study done by Tang et al. in Hong Kong in 1990 has shown that adults with cochlear implants performed better in response to warble tones, identification of environmental sounds, word recognition, consonants and vowels identification and tone discrimination than they did when

using hearing aids. This study also did not look at the pattern of tone perception nor look at the confusions made in the tone recognition task. Moreover, in this study the sample size (4 subjects) used was too small to carry out any statistical analysis. It would be an useful question to ask how well the cochlear implant can transmit tonal information to children with cochlear implant and the difficulties and confusions they would encounter in tone identification task.

The questions that this paper would like to address are how the difference in pitch level and change in pitch pattern will affect tone perception of children with cochlear implant. Also which tone/tones and pair of tones will the children with cochlear implant find it most difficult to identify and how comparable this will be to the confusions shown by normal children. In a study done by Ching in 1984, normal hearing children performed best on low falling tone (tone 4) in identification task and made significant confusion between mid level and low level tone (tone 3 and 6) and between low rising and low level tones (tones 5 and 6). The author explained that tone 4 was the easiest to perceive because it is the only falling tone in Cantonese and it has high functional load in Cantonese. Also, confusion between tones was explained in terms of their similarity in pitch pattern. Would the same results be seen in cochlear implant kids and could we use the same argument to explain tone perception pattern of children with cochlear implant? Also, discussion would be made on the efficiency of the cochlear implant in conveying tonal cues/information to the wearer.

The results obtained from this study can show the pattern of tone perception in children with cochlear implant and their performance on each tone of the six tones and tone pair used in the study. This could tell us roughly the difficulty level of each tone and tonal contrast in children with cochlear implant. This data could help in planning the assessment and intervention for these children. For example, the easiest tone or tone pair can be used first during the intervention. Previous research done on perception of tonal languages such as Mandarin (Huang et al., 1995) and Cantonese (Tang et al., 1990) has only been able to show that cochlear implant in profoundly hearing-impaired adults can lead to improvement in tone perception, this study can further provide more precise data on tone perception in children with cochlear implant. This could help in the development of further cochlear implant systems that may be more useful in providing tonal cues.

Method

A. Subjects

Seventeen subjects aged between four to nine year-old were employed in this study. All of these subjects were prelingually deaf children and native speaker of Cantonese. Sixteen of these subjects were using the Nucleus 24-Channel cochlear implant system and one of these subjects were using the Nucleus 22-Channel cochlear implant system. Eleven of these implant systems were employing the SPEAK processing strategy and six of these implant systems were using the ACE speech processing strategy. There were nine females and eight males. Their postoperative period ranged from eleven to forty-one (3 years 5 months) months. Many children as young as two have received cochlear implants since theoretical lower age limit on purely surgical grounds is around 2 years (Cooper, 1991). Only children older than the age of four years were included in this study as the study done by Ching (1984) showed that normal children are unable to recognize isolated lexical tones until age four. According to a study done by Tyler et al. in 1997,

prelingually deaf children using cochlear implant require at least 12 months experience to have performance level of above 50% accuracy in stress recognition task and close-set word recognition test. Thus in this study, subjects were required to have at least eleven months to twelve months postoperative period to participate in this study. These subjects had their implantation done in Queen Elizabeth Hospital or Prince of Wales Hospital or Queen Mary Hospital where they received or were receiving auditory and speech training.

B. Stimuli

Natural stimuli were used because children respond best to natural speech tokens and young children up to about six need speech-like stimuli to make more precise judgements in lexical labeling (Ching, 1984). The word /ji/ is chosen as the target word as it can be represented by simple and concrete lexical labels: Tone 1 /ji / \bar{x} (clothing), Tone 2 /ji / \bar{m} (chair), Tone 3 /ji / $\bar{\Xi}$ (spaghetti), Tone 4 /ji / $\bar{\Omega}$ (child), Tone 5 /ji / Ξ (ear) and Tone 6 /ji / Ξ (two). Two native Cantonese male speakers aged 21 and 22 with no speaking and hearing disability were employed to record the stimuli into a computer. The speakers were young speakers to reduce the chance of any production of high falling tone. Most Hong Kong speakers appear to have lost the high falling tone and replaced it by high level tone, the high falling tone is mostly seen in Guangzhou Cantonese and in the old generation (Bauer & Benedict, 1997). The six lexical items were written on six different cards and these cards were shuffled in random order and the speaker were asked to produce them in the shuffled order in a carrier sentence in a sound proof room. The same procedures were carried out ten times for each speaker. One speaker was perceived to be 'clearer' than the other speaker by native Cantonese speakers. The minimum and maximum excursion of f0 for each syllable of each of the 'clearer' speaker's utterances were measured

representatively. These values were used to calculate the mean and range of variation for each syllable. The syllables with the smallest differences from their respective computed average pitch were used to make a 'most average' sentence. This sentence was designated as the 'context' sentence. Those 6 /ji/ syllables that represented the most extreme difference, in the appropriate direction, from the mean values for /ji/ were identified. For example, the 'best' /ji1/ (high level) syllable was the syllable that had the greatest positive difference in f0 from the mean /ji/ values. The best six syllables for each tone were clipped out of their respective sentence, normalized in amplitude and inserted into the context sentence to make the stimuli sentences. The stimuli was presented in carrier sentences in medial position to prevent the rise or drop of intonation that might affect the perceived tone values (Vance, 1976). The following is an example of the stimuli:

我	會	讀	俾	你	聽
η⊃	wui	t⊃k	 pei	lei	teη

(I will read _____ for you to hear) where ____ will be /ji/ with different tone

The Hyper-Card 2.2 computer program was used to present the stimuli. The following table shows the average fundamental frequency values of the six stimuli used in this study.

Table 1. The fundamental frequency of the six tonal stimuli used in this study

Tone	HL	HR	ML	LF	LR	LL
Fundamental	142.962	145.824	123.876	123.876	153.785	123.592
Frequency (Hz)						

The six stimuli were grouped into eight pairs as seen below Each pair was presented four times. Suppose the two tones in the pair were A and B. Then the order AB and BA were each presented two times (left and right order of responses) to balance the left and right target responses. In each of the 2AB and 2BA presentations, A and B were each presented once as the target responses. Thus in one block there were thirty-two stimuli. The following are the eight pairs of the stimuli that were used in this study. Pairs A, B and C were used to investigate the effect of the three pitch levels (high, mid & low) on tone perception. If we refer to the tone contours, we can see that Tone 2, 4, 5 & 6 all have the same initial relative pitch level but different final relative pitch differences. Thus pairs D, E, F & G were used to see any effect of the endpoint pitch rise on tone perception. Similarly, the last pair, H, was used to see the any effect of initial pitch difference on tone perception.

Α.	HL (55) vs ML (33) - Tone 1 & 3	E.	LR (23) vs LL (22) - Tone 5 & 6
B.	HL (55) vs LL (22) - Tone 1 & 6	F.	LF (21) vs LR (23) - Tone 4 & 5
C.	ML (33) vs LL (22) - Tone 3 & 6	G.	LF (21) vs LL (22) - Tone - 4 & 6
D.	HR (25) vs LR (23) - Tone 2 & 5	H.	HL (55) vs HR (25) - Tone 1 & 2

C. Procedures

A computer (Power Machintosh 7100 / 80 AV) was placed outside the sound proof room and the pictures from the monitor were projected onto a screen placed in the sound proof room. The stimuli were randomized by the computer and presented through an audiometer (Madsen 0B822) to a speaker (Westra LAB-501) in a sound proof room. The noise level of the stimuli inside the sound proof room was measured with a sound-level meter (Bryel & Kjaer Type 1625) and was at 60dB SPL. One clinician sat inside the sound proof room while the another sat at the computer outside the sound proof room. Before carrying out the actual test, all the subjects were familiarized with all the lexical items used for labeling to make sure that the children knew all the six words. Subjects sat one meter away facing the speaker in the sound proof room with a clinician beside him/her. Before the actual testing, all the subjects were given 10 -15 practice trials. They were given practices with the actual test materials and given feedback on their responses. Subjects were tested individually. Each subject had to do four blocks, each block consisting of 32 stimuli. They were given the following instruction: 'You will hear each word once, then you should point to one of the two pictures to tell me which word you have heard'. The subjects responded by pointing to one of the two pictures on the screen and a clinician outside the sound proof room click that picture. The subjects were encouraged to guess if they were not sure about the correct response. No feedback was given to the subject on their performance after each presentation. Subjects were allowed to take a short break during which they played with the clinician or went out to the washroom when they felt tired.

This study was carried together with another study that involved tone discrimination and tone identification tasks. Subjects were tested in the order of (a) I-D-I or (b) *I*-D-I where *I* is the tone identification task of this study and D & I are the tone discrimination task and the tone identification task of the other study. Nine subjects were tested in order a and eight subjects were tested in the order b. This were to balance any possible learning effect due to the different tasks.

A pilot study employing a moderately haring-impaired six-year-six-month old boy with hearing aid was done before testing the cochlear implant subjects.

Results

Performance on Tone Pair

For the tone identification task, refer to Table 2 and Figure 1. Table 2 displays the individual percent correct scores on each of the tone pair and Figure 1 displays the percent mean correct scores and standard deviation of each tone pair. From Table 2, it can be seen that individual percent correct scores range from 47% to 66% Eighty-two percentage of the total subjects obtained a score at or above chance level. From Figure 1, It can be seen that the average correct scores for each tone pair range from 50% to 61%. The highest and the only score above 60% was obtained for Pair A (Tone 1 & Tone 3) suggesting that subjects made least confusions between HL (Tone 1) and ML (Tone 2) tones. The tones in Pair C (Tone 3 & Tone 6) and Pair D (Tone 2 & 5) were the least well identified, both yielding a mean correct score of 50%. A one-way repeated ANOVA was carried out to see if there was any significant difference in identifying tones in the eight pairs. The results of ANOVA confirmed significant difference in identifying the different tone pairs, F (7,112) = 2.707, p = .012. A post-hoc Tukey HSD test analysis showed significant difference between Pairs A & C, p = .047 and between Pairs A and D, p = .035.

Table 2. the (a) individual scores of each tone pair, (b) individual average of the tone identification task, (c) average of all the subjects on each tone pair and (d) standard deviation of each tone pair.

Subject Pair	A(HL-ML)	B (HL-LL)	C (ML-LL)	D (HR-LR)	E(LL-LR)	F (HL-HR)	G(LL-LF)	H (LR-LF)	average
1	0.60	0.50	0.56	0.55	0,46	0.45	0.56	0.54	0.53
2	(0.70)	0.40	0,65	0.35	0.43	0,65	0.45	0.50	0.52
3	0,50	0.45	0.35	0.50	0.55	0.60	0.45	0,45	0.48
4	0.40	0.50	0.40	.0.50	0.70	0.60	0.45	0.50	0.51
5	0.55	0.55	0.50	0.50	0,50	0,45	0.55	0.50	0.51
6	0.45	0.60	0.44	0.40	0,35	0.45	0.55	0.54	0.47
2	0.75	0.38	0.55	0.50	0,50	/0/56	0.50	0.67	0.53
8	0.70	0.65	0.45	0.50	0.55	0.65	0.50	0.49	0,56
9	0.42	0.56	0.69	0.69	0.69	0.25	0.63	0.44	0:54
10	0.50	0.44	0.38	0.44	0.44	0.69	0,44	0.44	0,47
11	0.75	0.56	0.50	0.56	0.31	0.63	0.56	0.50	0.55
12	0.88	0.88	0.56	0.50	0.56	0.81	0.50	0.50	0.65
13	0.69	-0.63	0.50	0.55	0.56	0.50	0.50	0.56	0.56
14	0.69	0,38	0.63	0.31	0.69	0.56	0,63	0.53	0.55
15	0.69	0.75	0.50	0.56	0.63	1.00	.0.56	0:56	0,66
16	0.44	0.69	0.44	0.44	0.44	0.63	0.56	0.50	0.52
17	0.75	0.69	0.38	0,56	0.44	0.50	0.56	0.63	0.56
Average	0.61	0.56	0.50	0.50	0.52	0.59	0.53	0.52	
SD	0.091	0.090	0.076	0.072	0.081	0,098	0.059	0.060	



Figure 1, showing the mean scores and standard deviation of each tone pair

Performance on Individual Tone

The identifiability of each of the six tones was calculated by counting the total number of times each tone appears as the target response in the tone pairs and the number of times each tone was identified correctly. These scores were used to calculate the percentage correct responses for each tone. Referring to Table 3 and Figure 2 that display the individual correct scores on each tone and mean correct scores & standard deviation for each tone respectively. It can be seen that the scores ranged from 48% accuracy to 59% accuracy suggesting that all of the subjects performed at chance level or slightly above chance level. The highest and lowest mean correct scores were obtained for the HR tone (Tone 4) and the LL tone (Tone 6) respectively. A one-way repeated ANOVA confirmed no significance of the main effect of the six tones, F(5,80) = 1.291 and p = .276.

Table 3, showing the (a) individual scores of each tone, (b) individual average of each tone, (c) average of all the subjects on each tone and (d) standard deviation of each tone.

ubject/Pair	HL.	MI.	LI.	HR	L.R	Γh	Average
1	0.43	0.55	0,62	0.65	0.46	0.45	0.53
2	0.70	0.60	0.40	0:40	0.57	0.45	0.52
3	0.33	0,60	0.48	0.55	0.47	0.55	0.50
4	0.63	0.30	0.48	0.60	0.50	0.50	0,50
3	0.67	0.50	0.18	0.55	0.67	0,70	0.54
6	0.50	0,40	0.43	0.25	0.67	0.45	0.45
7	0.50	0.88	0.34	0.56	0.58	0.75	0.60
8	0.57	0.70	0.45	0.60	0.60	0.60	0.59
9	0,46	0.50	0.66	0.44	0.58	0.50	0.52
1.0	0.54	0.44	0.47	0.50	0.46	0.38	(0.46
11	0.63	0,69	0.34	0.69	0.54	0,56	0.57
12	0.79	0.88	0.53	0.88	0.75	0,06	0.65
13	0,58	0.56	0.59	0.56	0.50	0.50	0.55
14	0.50	0.69	0.53	0.56	0.42	0.63	0.55
15	0.96	0.50	0.50	0.81	0.63	0.56	0.66
16	0.54	0.38	0.50	0.56	0.50	0.63	0.52
17	0.33	0.63	0.72	0.81	0:42	0.50	0.52
Average	0.57	0.58	0.48	0.59	0.55	0.52	
SD	0.0261	0.097	0.087	0.095	0.075	0.094	





It is worth mentioning that the moderately hearing impaired child who participated in the pilot study performed much better than the children with cochlear implant in this study. His percent average correct score on the tone identification task was 91%. His performance for all the eight minimal pairs and six tones was over 90% accuracy except for Pair D (58%) and Tone 5, the low rising tone, (72%). Table 4 display the performance of the hearing impaired child on the tone identification task.

Pair	Correct Score	Tone	Correct Score
Α	0.92	1	0 89
В	1.00	2	1 00
С	1.00	3	0.96
D	0.58	4	0.92
E	0.92	5	0.72
F	0.92	6	1 00
G	1.00	/	/
Н	0.93	/	/
Average	0.91	Average	0.91

Table 4. The correct score of the hearing impaired children on the tone identification task.

Discussion

Overall Pattern of Identification of Tones

Referring to Table 2 and Table 3, it can be seen that the average correct percentage for each tone pair and each tone for the tone identification task mostly lies between 50% to 60%. This suggests that all of the six tones in Cantonese are identified at around chance level by children with cochlear implant and the results of the ANOVA demonstrated that there is no significant difference in identification for these six tones. From the results on mean correct scores on identification of the six tones, referring to Figure 2, there is a tendency that tones in the relative higher frequency region (HL, HR, ML) are better identified than tones in the relatively lower frequency region (LL, LR, LF). However, as mentioned before, there is no significant difference between their identification. Still, it is worth noticing this trend. If we look at the confusions that subjects made for the eight minimal pairs, we can notice some significant difference among these pairs. This will be discussed in the later section.

If we look at the acquisition pattern of lexical tone of normal children (Ching, 1984), LF tone (Tone 4) are the first to be acquired and LR tone (Tone 5) and LL tone (Tone 6) are the latest to be acquired. The LF tone was best identified among the other tones in the responses of all age groups in the Ching's study. However, children with cochlear implant did not performed best on the LF tone nor worst on LR and LL tone among the other tones. An explanation for this situation is that normal children use acoustic stimulation to process tonal information and children with cochlear implant use electrical stimulation to process tonal information. The different in the nature and of stimulation may results in different tonal perception for normal children and children with cochlear implant. Hence, children with cochlear implant may not be showing similar tone acquisition pattern as normal children More extensive research is needed on the implant to explain exactly how different is the nature of stimulation and tone perception for these children from normal children.

Effect of Pitch Level on Tone Perception

From the results on performance on different tone pairs, it can be seen that subjects performed significantly better on Pair A (HL & ML) than on Pair C (ML & LL). Comparing Pair A & C, we can see that all of them are level tones but they are in relative different frequency range, Pair A in relative higher frequency range and Pair C in relatively lower frequency range. We can hypothesize that subjects were better at distinguishing between tones at relatively higher frequency range than at relatively lower frequency range. The mean correct score for Pair F (HL

& HR) was 59% which was the second highest score. This can further support that subjects performed better at higher frequency range. Although there is no significant difference between the identification of the individual tones, there is a similar trend found in the results. The grand mean correct scores for Tone 1, 2 & 3 (HL, HR & ML) is 58% which is higher than grand mean correct scores for Tone 3, 4 & 6 (LF, LR & LL) which is 51.7%.

According to a study done on lexical tone learning pattern in normal Cantonese speaking children by Ching (1984), it was found that children made most confusion between Tone 3 & 6 (ML & LL). The same situation was found in the performance of children with cochlear implant on these tones in this study, supporting the fact tones with relative lower pitch are more difficult to perceive. This can be explained in terms of similar pitch patterns and small difference in frequency level between these two tones. Both the ML and HL tone are level tone thus having same pitch contour and their average f0 are very close in values, refer to Table 1.

Effect of Contours on Tone Perception

Referring to the results, it can be seen that there was significant difference, p = .012, in identification of tones in Pair A (HL & ML) and Pair D (HR & LR). The confusion occurring for Pair D was significantly more than the confusion occurring for Pair A. This may suggest that subjects are better at distinguishing between change in pitch between level tones than between rising tones. To support this proposed hypothesis, we have to explain why performance on Pair B was not significantly better than performance on Pair D since both of the tones in Pair B are also level tones. The presence of the LL tone would have affected the subjects' performance on Pair B adversely since we had hypothesize that subjects are better at distinguishing tones in relative

higher frequency region than tones in relative lower frequency region. The LL tone occurs in relatively lower frequency region and subjects' performance in identifying LL tone in Pair B would not be as good as identifying ML tone in Pair A since ML tone are in relative higher frequency level. Thus, performance on Pair B was not as good as performance on Pair A and was not significantly better than performance on Pair D.

There was no significant difference observed for other pairs suggesting that there is no effect of initial pitch differences and final pitch rise on tone perception for children with cochlear implant.

Effects of Other Variables on Tone Perception

If we look at the average correct score of each subject on the tone identification task, Table 1, right-most column, we can see that there is some variation, ranging from 47% accuracy to 66% accuracy. There are a number of factors that could be affecting individual performance and they include etiology of deafness, age of the child, age of implant, postoperative period, type of cochlear implant, frequency and quality of speech and auditory training, motivation and learning ability of the child and practice at home. For this study, all of the children were prelingually deaf and sixteen of the subjects were using the Nucleus 24 cochlear implant system and only one children, subject 10, was using the Nucleus 22 cochlear implant system. All the subjects have received or were receiving at least one hour of speech and auditory training by speech therapists in their first two years of implantation in the hospital where they had the implantation. Since the range for age of child, age of implant and postoperative period for the children with cochlear implant is quite big, it is worth looking whether there is any relationship between age of child and tone perception, between age of implant and tone perception and between postoperative period and tone perception for these subjects. Figure 3, Figure 4 and Figure 5 display the relationships of tone perception with age of child, age of implant and postoperative period respectively



Figure 3, showing how the performance on tone perception changes with age of child

It can be seen that there is no specific relationship between the age of the subjects and their ability to perceive tones. It is not the case that older subjects performed better than younger children. Unlike normal children whose ability to perceive tone increases with age, the ability to perceive tone for children with cochlear implant may depend more on their experience with the cochlear implant than their chronological age. Furthermore, older children are more advanced in terms of their cognitive and learning abilities which could benefit them in their postsurgical training



Figure 4, showing how the performance on tone perception changes with postoperative period

From Figure 4, it can seen that again, the ability to perceive tones does not necessarily increase with the postoperative period. However it is worth noticing that the two highest scores 65% accuracy and 66% accuracy occur for children with at least 18 months of postoperative period. However, one of the lowest score, 47% accuracy also occurs for the subject with the longest postoperative period. The postoperative may not be a good reflection of the actual length of use of the cochlear implant since subjects may choose not to wear the implant after the implantation. Thus, a better measurement may be the amount of daily use of the implant.





From Figure 5, we can see that there is no particular trend between the age of implant and performance on tone identification task. The two peak scores occur at age 3;05 and 4,11. However, there does not appear to be a particular age limit before or after which implantation gives better tone recognition ability to the subjects. Again, it is difficult to see how the age of implantation influences tone identification ability of the children since the subjects in this study did not have the same postoperative period and same training and these factors also affect performances.

Efficiency of the Cochlear Implant in Transmitting Tonal Information

Research done by Huang (1995) has shown that adult implantees with the Nucleus 22channel cochlear mini system were able to perceive Mandarin tones with 67.8% accuracy compared to 34.5% accuracy preoperatively in an Mandarin tone perception test which involves ten four-alternatives forced choice trials. Huang (1995) had claimed that the acoustic cues of fundamental frequency of the four Mandarin tones can be extracted by the speech-coding strategy of the 22-channel cochlear implant system and stimulate the auditory nerve where they are perceived as pitch (Huang, 1995, Clark, 1987). Another study (Tang et al., 1990) done in Hong Kong on four adults with House/3M single-channel cochlear implant found that the mean correct score on tone recognition task for theses patients was 32% only. For the present study, 82% of the subjects achieved a mean correct score from 51% to 66% for the tone identification task. This suggests most of the subjects performed slightly above chance level

Comparing to the Mandarin speaking implantees in the previous studies that used Nucleus cochlear implant, children with the Nucleus 24 cochlear implant system in the present study did not do as well in the tone perception. There can be several reasons for the poorer performance of the subjects in this study. First, the subjects in the previous studies are adults and they may have pre-existing auditory and phonological knowledge before the implantation, and they are being able to take more immediate benefit from the auditory capacity provided by the implant (Boothroyd et al., 1991). The children in this study are all prelingually deaf and they have no or very little auditory experience before the implantation and may therefore be less able to take immediate advantage of auditory capacity provided by the implant Secondly, adults are cognitively better than the young children in the present study and this may benefit them in making decision in the tone identification task. Thirdly, Cantonese tones are more difficult than Mandarin tones as there are six contrastive tones for Cantonese but there are only four contrastive tones for Mandarin and children acquire Cantonese tones later than Mandarin tones (Lee, Vakoch & Wurn, 1996). This may help explain the fact that Mandarin speaking adults with cochlear implant performed better than Cantonese speaking children with cochlear implant on tone perception.

Comparing the performance of the Cantonese speaking children in this study with the Cantonese speaking adults in the study done by Tang et al., 1990, the children in this study did much better on tone identification task achieving an average correct score of 54% whereas the adults in the previous study achieved an average correct score of 32%. One of the main contributing factor for this difference may be the different type of cochlear implant system used in these two studies. In the previous study, the patients were using the 3M/House single channel device whereas in this study, the patients were using the Nucleus 24 multi-channel device. Thus we can at least hypothesize that multi-channel device may be better at discriminating fundamental frequency than single channel device.

Looking at the performance of the subjects in this study, it is possible that the Nucleus 24 cochlear implant system is able to extract the relevant fundamental frequency of tones to stimulate the auditory nerve and this helps in the transmission of tonal information in Cantonese. However, the efficiency of the implant for this fundamental frequency extraction and tonal transmission processes does not appear to be equivalent to normal hearing. From the performance of the seventeen prelingually deaf children, we can see that the efficiency is quite low, as subjects only performed around chance level in a two-choice forced task. Thus their performance is similar to guessing the responses. There were two subjects who were able to perform at 65% and 66% accuracy for tone identification and this suggest that some individuals who were profoundly deaf are able to identify tones well above chance level after implantation. It is important to note that beside the efficiency of the implant in processing tonal information, individual differences such as motivation, learning ability and length of implant use also affect performance. Also, from the performance of the children with cochlear implant on the tone

identification task, we can suggest that there is a tendency that the Nucleus device may be better at extracting higher fundamental frequency component of the signal, thus facilitating the identification of tones with relative higher pitch. However, there is only a weak support for this suggestion and more data would be needed to support this for any definite conclusion

Both the SPEAK and ACE speech processing strategies use the roving strategy that stimulates many sites to provide a richly detailed representation of the sound by selecting from 20 electrodes. They differ only in the rate of stimulation, SPEAK stimulate at moderate rate whereas ACE (which is a combination of SPEAK and CIS, CIS is a high rate strategy) can stimulate at a moderate or high rate. Although manufacturers claim that the strength of SPEAK roving strategy is that it can provide detailed pitch information of natural sound as it can select different electrodes for different sounds. However, from the results of this study suggest that the Nucleus 24-Channel cochlear implant system is not very efficient in providing tonal information. One suggested reason for this may be that both the SPEAK and ACE selects six to ten maxima (loudest sounds) from each sound input to stimulate the respective electrodes along the electrode array. However, the exact fundamental frequency information of the tone may not be included in the selected maxima, thus making the transmission of tonal information inefficient.

Clinical Implication

The present study has shown that children with cochlear implant tend to perform at chance or slightly above chance level for all of the six tones. However, there is a tendency that they made less confusion between tones with relative higher fundamental frequency. One conclusion that may be drawn from this is that, in the postoperative training for children with cochlear implant, it would be a good idea to start with words that have tones with relative higher pitch such as HL tone, ML tone or HR tone and train discrimination between these tones before introducing other tones.

The findings of the present study proved that subjects' performance was only at about chance level. This suggests to the manufacturers of these cochlear implant systems that improvement should be made in the speech processing system to further improve transmission of tonal information.

Limitation of Present Study

The results of the present study may only represent a limited estimate of tone perception ability of children with cochlear plant. Since the subjects used in this study all used the same type of cochlear implant and it may be impossible to generalize the findings of the present to other types of cochlear implant system which may be using different coding strategies.

There is large intergroup variability that created a lot of individual differences among subjects. Subjects in this study received postoperative training in different places, their length of use of the device may not be the same and their parents' educational level and effort put in doing practice with the child at home may not be identical. All these could affect the children's performance on the tasks in this study and were not take into consideration in this study.

Lastly, this study used identical carrier sentences to present the stimuli in a neutral context. However, this may not be a good reflection of their ability to perceive tone in reality. In

the natural environment, we seldom need to perceive tone in isolation. Instead they typically appear in sentences and/or occurs in multisyllabic words where there are rich contextual cues. Thus, performance in this experiment may not reflect the true performance of the subjects in a natural speech context. It may be the case that, these subjects are able to make use of contextual cues to comprehend words that are only differentiated by tones.

Direction for Further Research

It is suggested to carry out more indepth investigation to explain how the speech processing strategy of the cochlear implant system aid and how insufficient it is in transmitting tonal information for Cantonese could provide more functional information for the manufacturers to modify their device for better tonal transmission.

The subjects in this study were using the same type of device However, there are a number of different types of cochlear implant systems with different speech processing strategies used currently in Hong Kong, It would be useful to compare the performance of the different types of cochlear implant systems on tone perception.

Conclusion

The present study shows that (a) 82% of the prelingually deaf children with Nucleus cochlear implant are able to identify Cantonese tones at about chance level (b) children with cochlear implant are better at identifying tones with relative higher fundamental frequencies, such as HL tone, ML tone and HR tone (c) less confusions were made between level tones with relatively higher pitch (HL & ML) then between rising tones by the children with cochlear implant and (d) the Nucleus 24 cochlear implant system can not extract accurate pitch information to transmit tonal information

Acknowledgement

I wish to take this opportunity to thank Dr Alexander Francis, Dr. Valter Ciocca and Miss Lena Wong for their valuable suggestions, comments and support on this project. I would also like to give special thanks to the speakers and the children who participated in this study Lastly, a word of appreciation should also go to the technicians of this department for their technical support during the study

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http://www.cochlear.com./



<u>Appendix</u>

各位家長,

此致

•earing assessment 第刀,則驗 首先謝謝你們對這項研究的參與,我們盼望透過這項研究能更多了解兒童用了人工耳蝸內植後對語言的分辦能方。由於這項研究是由兩部份組成(一部份使用電腦,另一部份使明 畫卡)所以我們附上兩份同意書,盼你們閱後能對研究內容有 初步了解,並且同意你的小孩參與研究,如有任何問題可向;"" 試員詢問。

hearing aids 助聽器驗配

expert advice 冪業意見 黃麗娜 助理教授

research 學術研究

education 專業教育



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敬啓者:

本人現於香港大學言語及聽覺科學系修讀學士學位課程,現正進行一項關 於人工電子耳蝸對兒童之聲調理解的研究。

這項研究約時六十分鐘,期間貴子女只須聆聽及作出反應,例如選擇正確 答案。此項研究對貴子女絕無不良影響。而整個過程將會被錄音,以作記錄。 所有錄音記錄只作爲學術研究之用途。參與者的個人資料絕對保密。 倘若閣下批准貴子女參予是項研究,請填妥以下回條。 本人承蒙閣下合作,深表謝意。

此致

貴家長

Aisha Rani 香港大學言語及聽覺科學系 四年班學生

家長同意書

本人同意兒子/女兒_____(學生姓名)參與上述研究。

本人亦同意整個過程被錄音記錄,以作研究。而本子弟之個人資將受到絕對保密。

家長答署

日期

Subject's Information Sheet

Name:	_(Eng)	(Chi)
Age / Sex:		
Date of Birth:	(D/M/Y)	
Grade:		
Mother-Tongue:		
Name of School:		
Home Address:		
Etiology of Deafness:		
Family History of Hearing Proble	ems:	
Onset of Deafness:	(Age)	
Experience with Hearing Aids: _		
Postsurgical Period:		(Month & Year of Implantation)
Date of Switch On:		(date/month/year)
Type of Cochlear Implant:		-
Coding Strategy:		
Hospital where implantation was	done:	
Frequency of Therapy:		(hr/week)

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Information sheet for the participants

Tone perception in Cantonese speaking children with cochlear implant

We wish to invite you to participate in a project which aims to see the pattern of tone perception in Cantonese speaking children with cochlear implant. This study can improve our understanding of tone perception which may contribute to the development of better cochlear implant system and improve the effectivness of speech training given to implantees.

The study will involve hearing some sentences and then pointing to the correct response. The whole study will take about 60 minutes depending on individual response times. This study will take place around Jan, 2000.

Information regarding the participant's medical history will be released to investigators but the information will not be disclosed to any other people. The results of the study if published will not reveal the identity of the participants.

Participants in this project will face no hazard to their health.

We thank you for your interest and support. If you would like to ask further question, please contact one of the investigators listed below.

Dr. Valter Cioccca, Department of Speech and Hearing, The University of Hong Kong, 28590581.

Dr. Alexander Francis, Department of Speech and Hearing. The University of Hong Kong, 28590561.

Ms. Lena Wong, Department of Speech and Hearing, The University of Hong Kong, 2850590.

Ms. Aisha Rani, HKU fourth year speech and hearing student, 9701575.

2 2 MAR 2006

Consent Form:

Please fill in the following form if you agree to participate in the study

I (Name)

(Address)

hereby consent my son/daughter _____ (name) to participate in the study entitled " Tone perception in Cantonese-speaking children with cochlear implant "

I have read/understand the information about this study I understand that the purpose of this study is to find out the ability of Cantonese speaking children with cochlear implant in identifying tones I understand that my child has to attend an one hour session to undergo a test of tone identification

I have been given the opportunity to ask question about this study and they have been answered to my satisfaction

I consent my son/daughter to participate in this study and understand that I have the right to withdraw at any time

Parent's signature

Date

Parent's name in block letter