Tone Perception of Cantonese-speaking prelingually Hearing-Impaired Children using Cochlear Implants

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ABSTRACT

Objective: To evaluate tone perception performance in Cantonese-speaking prelingually hearing-impaired children using cochlear implants (CI).

Study Design and Setting: The ability to discriminate and identify Cantonese tones was evaluated on 17 native Cantonese-speaking prelingually hearing impaired children. Performance was correlated to factors like age of implantation and general communication ability.

Results: Subjects' performance in discrimination and identification tasks was slightly above chance level. Although variations in the contour fundamental frequency of the tones provided some cues for tone discrimination, these distinctions proved insufficient for subjects to perform well. Tone 6 (low level tone) was the most difficult to identify. Subjects' performance did not correlate with gender, age of implantation, duration of implant use, frequency of auditory training session, or general communication ability.

Conclusion: Although some children were able to discrimination and/or identify Cantonese tones, their performance was poor. Further studies are needed to understand how tone perception relate to daily speech understanding.

Significance: Cochlear implant speech coding strategies may need modification to optimize tone perception.

A primary benefit of cochlear implantation (CI) is improving communication ability. Many profoundly hearing-impaired children using CI acquires speech and language faster than those using vibrotactile devices or hearing aids. Phoneme, word and phrase recognition are improved.[1-3] These studies hold for children who acquire English as a first language and cannot be simply assumed to those hearing-impaired children exposed to tonal languages, say Cantonese, Yoruba or Thai.

In a tonal language, like Cantonese, tonal contrasts among syllables are phonemic. There are six contrastive Cantonese tones (Table 1 and Figure 1). Tone changes correspond to variations in fundamental frequencies (F0) and have three dimensions: contour, direction and height.[4] “Contour” refers to the slope of fundamental frequency patterns that distinguishes level tones (Tones 1, 3, 6) from gliding tones (Tones 2, 4, 5), accordingly frequency changes. The fundamental frequencies of level tones are quite stable over time; and vary for gliding tones. “Direction” distinguishes rising (Tones 2, 5) from falling (Tone 4) tones. “Height” is determined by the average fundamental frequency: high (Tones 1 and 2), mid (Tone 3) and low (tones 4, 5 and 6). Cantonese tones are differentiated mainly by F0 contour and height[5]. Tone height may be more important in tone perception than tone contour.[6] Tonal contrasts do not affect lip movement so that tone perception relies entirely on listening. For speech in a tonal language to be intelligible to anybody hearing it tonal information must be available, whether naturally or through devices such as CI.

Research on tone perception in cochlear implant users is scarce. A few studies on hearing-impaired Mandarin speakers suggest enhanced speech perception and auditory abilities.[7-9] Adults with CI were able to perceive most Mandarin phonemes including the four distinct tones.[8,9] Tang et al.[10] showed four postlingually impaired Cantonese speaking adults who had single channel CI and hearing aids had tone recognition scores above chance levels. Another study on Cantonese speaking postlingually impaired adults demonstrated better tone perception scores using CI than hearing aids.[11] High tones tended to be better perceived than low tones: scores were relatively high for Tones 1, 2 and 4; Tone 5 scores were lowest. While Barry et al found Cantonese children being able to discriminate nonsense syllables[12], Ciocca found very few Cantonese-speaking children using CI were able to identify tones.[13] The present study examines the tone perception performance of prelingually impaired children using CI. Relationships between performance in tone perception task and gender, age of implantation, length of implant use, type of coding strategies and frequency of auditory training were evaluated. Tone perception performance was compared with the children's general communication abilities.

METHODS

Subjects

A total of 17 native Cantonese-speaking children using Nucleus multichannel CI participated in the study. There were nine females and eight males. Subjects were between 4 to 9 years of age (M 6.39, SD 1.23). Children older than 4 years of age were evaluated because normal hearing children of younger age might not be able to reliably recognize lexical tones.[14] All participants were implanted with the Nucleus CI24M except one child who used the Nucleus CI22M device. Eleven participants used the SPEAK coding strategy while the remaining six used the ACE. A pulse rate of 250 Hz was employed for all SPEAK users. Three different pulse rates were used by the ACE users: 720 Hz (one participant), 900 Hz (six participants), and 1200 Hz (four participants). All participants had 20 to 22 active electrodes. These children had used implants for at least one year prior to the study (M1.87, SD 0.60, range 1.17-3.25). Subjects were identified with hearing loss at birth to 30 months of age (M 1.01, SD 0.77). These children were receiving auditory training about once to eight times per month (M 4.0, SD 2.08). They had been in training for an average of 2.53 years (SD 1.94; range 1-7.67). Participants were implanted at Prince of Wales Hospital (n=9), Queen Elizabeth Hospital (n=7) and Queen Mary Hospital (n=1).

Materials

Tone discrimination and tone identification tests were adapted from Cochlear Implant Speech Perception Evaluation Manual for Adults.[15] Two tests from the Manual were used for this study. Although these two tests were created for the adult population, the stimuli used and the mode of testing was appropriate for the subjects that are of interest in this study. Moderately hearing-impaired children with age similar to those in this study are able to perform these tests without much difficulty.

1. Tone discrimination test: Using a same/different paradigm and stimuli with the same root phoneme /wai/, 15 contrastive and 15 identical tone pairs were presented. Each subject was presented these tone pairs in one of five random sequences. Subjects responded by pointing to either of the two cards showing the Chinese characters of “same” and “different”. This base phoneme was used because it is one of the few phonemes that are associated with six contrastive tones.
2. Tone identification test: Participants had to identify the target word among four choices with the same root phoneme /ji/. The /ji/ root phoneme was used because the six contrastive tones associated with it can be easily represented using pictures and they are readily understood by children of age four years and above.[14] Pictures of the test stimulus and three randomly selected foils accompanied each presentation. Each tone was presented six times so that there were a total of 36 trials.

Besides the above tone discrimination and identification tests, the Categories of Auditory Performance (CAP) was adopted to assess general auditory development level.[16] The CAP evaluates auditory abilities as a hierarchy of eight descriptions ranging from “no awareness of environmental sound” to “talking on telephone with familiar talker”.

This study was carried out in conjunction with another study that employed a different tone identification task.[13] Eight subjects were tested first with the tasks in this study, and nine subjects with the task involved in the other study.

Apparatus

The 12 Test stimuli were spoken by a male native Cantonese speaker and recorded using a SONY Digital Audio Tape system. The peak amplitudes of stimuli were equalized using Sound Edit 16 Version 2 software. The stimuli were randomly selected and played back by a personal computer connected to a Madsen OB822 audiometer. The loudspeaker was situated at 0 degree azimuth about 1 meter away from the child. The output of the loudspeaker was calibrated to 65 dB A. Response cards were shown on a computer screen after presentation of test stimuli.

Procedure

Ethics approval were obtained and informed consent were sought from the parents of the subjects. For the discrimination and identification tasks, all test trials were administered in a sound-treated booth. Prior to each test, the children received some training. For the discrimination task, subjects were first asked to identify whether a pair of stimuli were the same or different. If subjects did not respond correctly, feedback was given, the stimulus pair was presented again and subjects were instructed to listen and trial once more. To make sure the participants know the test stimuli for the identification task, participants were asked to name all pictures prior to the practice run. To indicate a response for the identification task, participants pointed to the computer screen that depicted the presented stimulus and three foils. The practice for each test continued until subjects understood the task and each participant received at least five practice trials before actual testing began. For the actual testing, half of the children had the tone discrimination test first and the other half the tone identification test. The order of test items was randomized. No feedback to the correctness of response was given. The CAP was distributed by mail to the speech therapists of each participant and 15 questionnaires were returned.

RESULTS

Subjects were able to discriminate an average of 59.2% (SD 11.15, range 43.4-83.3%) of test stimuli. The mean score for the identical pairs was 57.2% (SD 17.80, range 33.3-93.3%);

and for the contrastive pairs was 61.1% (SD 8.89, range 40.0-73.3%). Individual scores are shown in Figure 2 suggesting 13 of the 17 subjects were performing above chance level (50%). However, except one subject, their scores were not high (below 73.3%). Table 3 shows performance at chance level and subjects were confusing most tone pairs. To examine whether the number of correct response to any tone pair was significantly above chance level, binomial distribution analyses were conducted for each tone pair. Number of correct responses for the tone pairs 3-3, 6-6, 4-5 was significantly above chance level ($ps < .05$). In general, subjects had difficulty discriminating both identical and different tone pairs.

In the tone identification test, subjects were performing slightly above the chance level of 25%. A mean score of 31.2% was obtained (SD 12.29, range 16.6-63.8%). Figure 2 showed that most subjects (10 out of 17) were performing above chance level, however, their scores were not better than 40%. Those performing well in discrimination tasks did not necessarily do well in identification task, and vice versa. Percent correct score for each tone is shown in bold in Table 4. The level of significance was determined using a formula proposed by Fok Chan (pp. 61)[5]:

$$\frac{N - n}{5} + 1.96 \sqrt{\frac{N - n}{5}\left(1 - \frac{N - n}{5N}\right)}$$

Where n = number of correct identifications and

N = total number of responses or 102 in this case

The formula was derived based on the rationale that if the confusion of tones was made by chance, and if n out of N presentations was correct, than the remaining score should be distributed evenly over the other five tones (or cells in a column in Table 4). The expected number in each cell should then be N-n and the standard deviation should be $\sqrt{\frac{N - n}{5}\left(1 - \frac{N - n}{5N}\right)}$ For the confusion to be significant at the 5% level, with a normal distribution of responses, th value in the cell must be 1.96 times the standard deviation above the expected number.

Data in Table 4 revealed that errors made on high and mid tones (Tones 1, 2 and 3) were distributed evenly over other tones. Tone 5 was confused with Tone 4 21.6% of the time ($p < .05$), Tones 5 and 6 were confused with Tone 2 20.6% ($p < .05$) and 24.5% ($p < .05$) of the time, respectively. Results also showed Tone 6 was the most difficult to identify (20.6% correct, $p < .05$).

Spearman rho correlation did not show a significant relationship between tone perception performance and gender, type of speech coding strategies, age at implantation, and length of implantation ($p < .05$). Frequency of training correlated somewhat with tone discrimination scores but a level of significance was not reached ($\rho = 47$, $p = .06$).

A modal rating of Category 5 (M 5.29, SD = 1.64) was obtained using CAP, suggesting subjects were able to understand common phrases without lipreading. Eleven of the 15 subjects whose speech pathologists returned the CAP were able to understand or converse without speechreading. Three other subjects were only able to discriminate two sounds. Scores on the CAP did not correlate significantly with performance in discrimination and identification tasks.

DISCUSSION

The present study aimed at evaluating the tone perception performance of prelingually impaired children with CI and poor results were obtained. Although more than half of the children in the study were able to discriminate the tone pairs above chance level, the score was not very high (below 73.3%) except for one child. Participants were not able to discriminate most tone pairs whether they were the same of different. Similarly, on average, these children were able to identify tones slightly above chance level, most scores were quite low (below 40%). Thus, although these children were able to perceive some aspects of Cantonese tones, they could not consistently distinguish the tones. Results from this study are poorer than the findings from Lee et al.[11] in which postlingually impaired adults were evaluated. It seemed that prelingually impaired children may not perceive tones as well as those who have acquired language prior to onset of hearing loss. Results in this study are also slightly poorer than the findings on Mandarin-speaking children using cochlear implants.[7,9] The difference may be related to the fact that Cantonese tones are more difficult to identify than Mandarin ones.[17] Greater number[17] and the particular characteristics of Cantonese tones, which for example, second language learners find more difficult to master than they do Mandarin ones, may be contributing factors. While Mandarin speakers were able to use temporal envelope cues for tone recognition[18], these information do not normally aid Cantonese tone perception.[13]

In this study, tone pair 4-5 was the easiest to discriminate among all others. Disconcertingly, the same pair was found hardest to discriminate in another study.[12] The difference may be related to the type of stimuli and test paradigm. While this study employed a test paradigm of "same/different" in the discrimination of meaningful words; Barry et al.[12]used a "change/no change" task on discriminating nonsense syllables. Although tone pairs (Tone pairs 1-2, 4-5 and 2-6) that are distinct in contour and direction at first sight would suggest their being easier to discriminate than other tone pairs, these distinctions did not aid the discrimination of other contrastive tone pairs (e.g., Tone pairs 1-5, 2-4). In fact, subjects had difficulty recognizing identical tone pairs. Theoretically, higher unresolved harmonics could cue tone identification in normal hearing listeners[13,19], these information are not strong enough to be useful. This phenomenon holds not only for those using lower pulse rates (the SPEAK users) but also the ACE users utilizing higher pulse rates. Similar findings were reported in another study using different test stimuli and test paradigm on the same subjects.[13] Employing nonsense stimuli in a tone discrimination task, Barry et al[6] did not find a difference in performance between ACE and SPEAK users. They concluded that although ACE allows better discrimination of tone contour than SPEAK but because ACE provides less information about pitch height, users of these coding strategies do not perform superior to each other. Overall, these subjects were not perceiving or utilizing sufficient cues through their implants to discriminate tone pairs.

Errors in identification of high and mid tones (Tones 1, 2 and 3) were distributed quite evenly over other non-stimulus tones suggesting that subjects were making random errors. In the tone identification task, Tone 6 (low level) was confused with other tones especially with Tone 2 (high rising) although they differ in contour, direction and height. Tone 6 (low level) was also the hardest to identify, a finding that concurs with Ching's reports on hearing-impaired children's tone perception and accords with Tone 6 was acquired later than other tones in the language acquisition of children hearing Cantonese.[20] Ching also reported confusion of Tone 5 (low rising) with Tone 2 (high rising) was common even among secondary school with normal hearing students. These tones are similar in contour and direction, differ in pitch only at the end of the contour so that they are easily confused if only the initial segment of the tone is heard or attended to. Tones 4 (low falling) and 5 (low rising) differ in their direction but share the same height at the beginning of sound production. Disconcertingly, subjects confused these tones in the identification task but were somewhat better able to discriminate them. Similarly, subjects who did well in tone discrimination could not identify tones (e.g., subject number 9). These differences are attributed to differences in the type of auditory skills involved in these tasks.

Overall results and the findings on confusion of tones in discrimination and identification tasks and the poor performance suggest that these prelingually hearing-impaired children were only able to utilize cues from CI to aid tone perception in a limited way. Lack of linguistic experience prior to onset of hearing loss may adversely affect this process.

Performance in tone discrimination and identification tasks was not congruent with general speech perception ability reported by subjects' speech therapists. With most subjects conversing without speechreading, performance on tone perception tasks was expected to be better than has been demonstrated. This phenomenon suggests that aspects other than tone information are providing important cues for speech intelligibility. Whether improving tone perception will enhance overall speech understanding of CI users will benefit from further studies.

Age of implantation did not relate to tone perception abilities. These results are consistent with findings from Fryauf- Bertschy et al.[21] Although previous studies reported improved performance over time,[21,22] this study failed to establish the point. The poor performance of subjects might have reduced the significance of its relationship with other factors. Due to large variations in individual performance, we suspect that a cross-sectional study like the present one may not show an improvement on subjects with different duration of implant use. A within-subject comparison in a longitudinal study may be more efficient in establishing such relationships.

CONCLUSION

The present study on prelingually hearing-impaired children with CI showed poor performance in tone perception. Many subjects were able to understand speech well despite this poor performance. Further studies are needed to fully understand what information most contributes to tone perception and whether improving tone perception would aid speech understanding by CI users with prelingual hearing impairment.

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LEGENDS FOR FIGURES

Figure 1. Fundamental frequency tracing for the six Cantonese tones

Figure 2. Percent correct scores in tone discrimination and tone identification tests (results arranged in ascending order of tone discrimination scores).

Table 1. Desrcription and examples of six contrastive tones in Cantonese.

Tone number	**Description**	**Examples**
Tone1	High level	Clothes
Tone2	High rise	Chair
Tone3	Mid level	Spaghetti
Tone4	Low fall	Child
Tone5	Low rise	Ear
Tone6	Low level	Two

Table 2. Demographic Characteristics of subjects.

Child No.	Gender	Age (years)	Coding strategies	Age loss identified (years)	Age implanted (years)	Duration of implantation (years)	Number of training per month	Number of years in training
1	F	4.67	ACE	0.00	2.67	2.00	2	1.83
2	M	4.58	ACE	1.50	3.42	1.17	4	1.00
3	M	6.25	SPEAK	0.50	4.92	1.33	4	1.08
4	F	4.50	SPEAK	1.00	3.00	1.50	4	1.58
5	M	6.58	ACE	2.50	4.17	2.42	1	2.33
6	F	6.17	SPEAK	0.50	4.83	1.33	4	1.00
7	M	6.67	SPEAK	1.00	5.25	1.42	4	1.33
8	M	5.42	ACE	2.00	3.33	2.08	2	1.92
9	F	7.58	SPEAK	0.50	6.17	1.42	4	1.33
10	F	8.00	SPEAK	1.75	4.75	3.25	1	
11	F	6.50	ACE	0.42	3.92	2.58	8	5.42
12	M	6.50	SPEAK	2.00	5.00	1.50	8	4.42
13	M	8.92	SPEAK	0.50	7.42	1.50	4	1.33
14	M	8.25	SPEAK	0.25	6.42	1.83	4	1.92
15	M	6.00	SPEAK	0.83	3.42	2.58	8	5.17
16	F	6.50	SPEAK	2.00	3.92	2.58	4	7.67
17	F	5.50	ACE	0.00	4.25	1.25	4	1.17
Mean		6.39		1.01	4.52	1.87	4	2.53
SD		1.23		0.77	1.24	0.60	2.08	1.94
Range		4.5-8.92		0-2.5	2.67-7.42	1.17-3.25	1-8	1.00-7.67

Table 3. Distribution of errors in tone discrimination test.

Tone pairs		Correct response (%)	Incorrect response (%)
Identical Pairs	**1/1**	58.8	41.2
	2/2	52.9	47.1
	3/3	69.7	33.3 *
	4/4	60.8	39.2
	5/5	66.7	36.4
	6/6	69.7	33.3 *
Different Pairs	**1/2**	70.6	29.4
	1/3	52.9	47.1
	1/4	58.8	41.2
	1/5	41.2	58.8
	1/6	64.7	35.3
	2/3	58.8	41.2
	2/4	47.1	52.9
	2/5	52.9	47.1
	2/6	70.6	29.4
	3/4	52.9	47.1
	3/5	47.1	52.9
	3/6	64.7	35.3
	4/5	76.5	23.5 *
	4/6	58.8	41.2
	5/6	41.2	58.8

Note. * $p < .05$

Table 4. Confusion matrix of responses in tone identification task. (Numbers in each column represent percentage of response of each tone in relation to the total number of stimuli presented for the tone specified in column heading. Number in last column represent the percentage of time each tone was mistaken for other tones in relation to the total number of stimuli presented or 612 in this case).

	Target Stimuli (Tones)					
Response	**1**	**2**	**3**	**4**	**5**	**6**
1	31*	16	13	12	22	29
2	29	36*	29	18	31*	37*
3	24	22	33*	19	24	19
4	21	22	25	35*	24	25
5	18	25	21	32*	30*	24
6	25	21	26	27	16	21

Note. * = $p < .05$ using Fok Chan's formula[5].

Numbers in bold = number of correct responses = n

N = 102

Figure 1. Fundamental frequency tracing for the six Cantonese tones

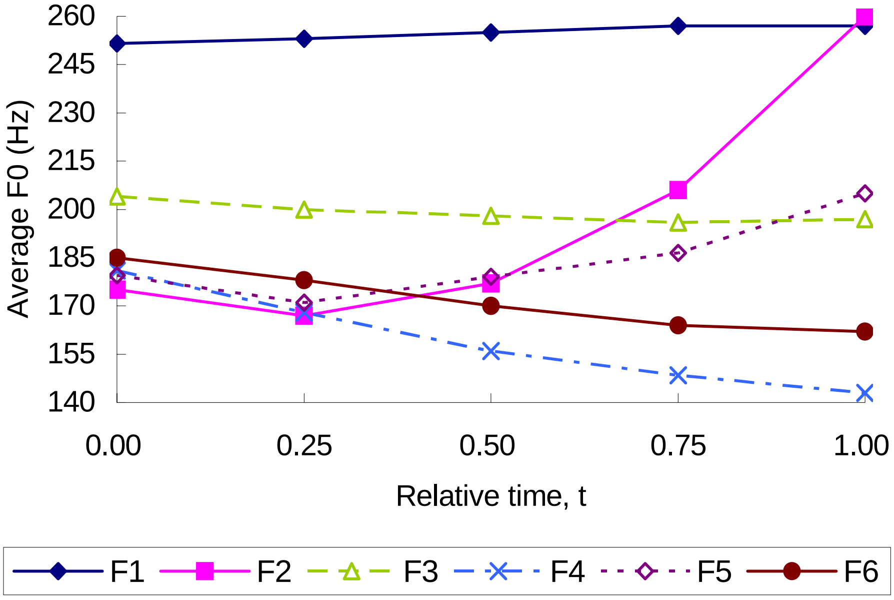

Figure 2. Percent correct scores in tone discrimination and tone identification tests.