

Consonant Production and Language Skills in Mandarin-Speaking Children With Cochlear Implants

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Objectives: To investigate the phonemic inventories of syllable-initial consonants in Mandarin-speaking children with cochlear implants, assessing the relationship between the children's mastery levels of consonant production and their receptive and expressive language skills.

Design: Descriptive study.

Setting: Chi-Mei Medical Center, Tainan, Taiwan.

Patients: The 30 prelingually deaf children with cochlear implants who participated in the study ranged in age from 6 years to 12 years 6 months, and their age at implantation ranged from 2 years 3 months to 10 years 3 months. The average length of device experience was 3 years 7 months (range, 1 year 7 months to 6 years 5 months). None of the children was identified with concomitant learning disabilities.

Outcome Measures: The 21 Mandarin syllable-initial consonants were elicited using a set of 105 pictures. Two language assessment tools were used to evaluate the children's receptive vocabulary skills as well as their overall receptive and expressive language development.

Results: The mean $\pm$ SD score for correct consonant production was $57.9\% \pm 19.5\%$. Regarding the manner of articulation, plosives received the highest average correct percentage whereas nasals, affricates, fricatives, and the lateral approximant /l/ were less frequently correct. The children's overall percentage of correct scores for consonant production and receptive vocabulary measure were significantly correlated ($r=0.51$; $P=.005$). Additionally, correlation coefficients were significant between the overall score for correct consonant production and both the scores for receptive language measure ($r=0.65$; $P<.001$) and expressive language measure ($r=0.76$; $P<.001$). The participants' consonant production skills were negatively correlated with age at implantation ($r=-0.46$; $P=.01$) and positively correlated with length of experience with cochlear implant ($r=0.45$; $P=.02$).

Conclusions: Mastery levels of Mandarin syllable-initial consonants remained moderately low in prelingually deaf children with cochlear implants. The present results suggest a significant association between consonant production skills and language development in these children.

Arch Otolaryngol Head Neck Surg. 2004;130:592-597

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DURING THE PAST DECADE, cochlear implants (CIs) have been shown to be effective in facilitating the development of speech perception and production in prelingually deaf children with severe to profound sensorineural hearing impairments.¹⁻³ Regardless of the general effectiveness of the device, the following variables may have an impact on children's speech development and language performance after implantation: age at onset of deafness, age at implantation, duration of deafness prior to implantation, duration of CI use, physiological or device-related factors (eg, the number of surviving spiral ganglion cells, electrode placement and insertion depth, electrical

dynamic range, and signal processing strategies), and psychological, educational, and social factors such as a recipient's motivation and level of intelligence.⁴⁻⁶ Specifically, age at implantation and length of CI experience are the historic predictors associated with speech perception and spoken language development in prelingually deaf children.

Prelingually deaf children using CIs and learning English as their first language tend to master certain consonant categories (nasals, stops, glides, and liquids) better than others (fricatives and affricates). It has been suggested that the CI contributes more to voicing and the manner of articulation than to the place of articulation. Research has demonstrated that consonants with more visible

Table 1. Twenty-one Mandarin Syllable-Initial Consonants in the International Phonetic Alphabet by Manner of Articulation, Place of Articulation, Aspiration, and Voicing

Place of Articulation and Voicing (-/+)													
Manner of Articulation	Aspiration	Bilabial		Labiodental		Alveolar		Postalveolar		Palatal		Velar	
		-	+	-	+	-	+	-	+	-	+	-	+
Plosive	-	p				t							k
	+	p ^h				t ^h							k ^h
Nasal			m				n						
Fricative				f		s		ʃ	ʒ	ç			x
Affricate	-					ts		tʃ		tʃ			
	+					ts ^h		tʃ ^h		tʃ ^h			
Lateral approximant							l						

place cues were generally better mastered by these children than those with less visible place cues.⁷⁻⁹

In contrast to the number of studies on the speech and/or language performance of English-speaking children using CIs, few published studies have documented the speech and/or language performance of Mandarin-speaking children using CIs. Since the linguistic structure of Mandarin is very different from that of English, it is of clinical and scientific importance to investigate the extent to which the use of CIs can facilitate the postimplant speech and language development of Mandarin-speaking children. The aim of the present study was to assess the production of syllable-initial consonants and the receptive and expressive language skills of a group of pediatric CI users who were learning Mandarin as their first language. This investigation also serves as a first step toward determining the extent of similarities in speech patterns and language development between Mandarin- and English-speaking CI users.

Mandarin is a language in which lexical meanings can be distinguished by 4 major tones. The suprasegmental information of these tones is carried primarily by vowel production. The consonant inventory of the language is slightly different from that of English. **Table 1** depicts the 21 Mandarin syllable-initial consonants in the International Phonetic Alphabet. On the basis of the manner of articulation these consonants can be classified into 5 categories, namely, the plosives /p, p^h, t, t^h, k, k^h/; nasals /m, n/, fricatives /f, s, ʃ, z, ç, x/; affricates /ts, tʃ^h, tʃ, tʃ^h, tç, tç^h/; and the lateral approximant /l/. The 21 consonants, which can also be characterized by their place of articulation, form the following subcategories of sounds: bilabial, labio-dental, alveolar, palato-alveolar, palatal, and velar. Unlike in English, aspiration is frequently phonemic in Mandarin; it serves as a phonemic feature that contrasts 12 syllable-initial consonants, 6 plosives, and 6 affricates. Voicing, on the other hand, is phonemic only in that it distinguishes the 2 fricatives /ʃ, ʒ/ (Table 1).

Most Mandarin-speaking children with normal hearing achieve high levels of mastery of consonant production skills by the end of their preschool years.¹⁰⁻¹² In one study, Wang and colleagues¹⁰ investigated consonant production in a group of 3- to 4-year-old children with normal hearing. Except for the 4 retroflex consonants /tʃ, tʃ^h, ʃ, and ʒ/, for which error rates ranged from 15.0% to

19.3%, the percentages of error for the production of consonants were below 5%. Similarly, in another study, Cheung and Hsu¹² indicated that the retroflex consonants /tʃ^h, ʃ, and ʒ/ were the only 3 consonants that remained difficult to produce accurately for children 4 years and older. Taken together, Mandarin-speaking children with normal hearing have been shown to produce accurately most of the syllable-initial consonants before the age of 6 years. The consonants involving complex tongue movements (eg, retroflex sounds) tend to be the ones that are the most difficult for these preschoolers to acquire.

With respect to Mandarin-speaking children with hearing impairments, error productions are most likely to occur in their attempts to produce the consonants /tʃ^h, s, ts, tʃ^h, z, tç^h, and k/. On the other hand, these children are able to produce the consonants /p, p^h, m, and f/ rather accurately.¹³ As Chung¹³ suggested, children with hearing impairments showed delayed patterns in their development of consonant production in comparison with children with normal hearing.

The present study investigated syllable-initial consonant production skills in prelingually deaf Mandarin children using CIs. Specific research questions included the following: (1) What phonemic inventory of consonants do these children have, and, specifically, which categories of consonants tend to be more challenging for them to produce accurately? (2) Is there any relationship between the children's consonant production skills and their development of receptive and expressive language? and (3) What is the relationship between the children's consonant production skills and the 2 time-related variables of age at implantation and length of CI experience?

METHODS

PARTICIPANTS

The participants were 30 prelingually deaf children, 16 boys and 14 girls, who received their implants at the Department of Otolaryngology, Chi-Mei Medical Center, Tainan, Taiwan. Their mean age at test time was 9 years 3 months (range, 6 years to 12 years 6 months). The children had been CI users for 1 year 7 months to 6 years 5 months (mean, 3 years 7 months) at test time. The average age at implantation was 5 years 8 months (range, 2 years 3 months to 10 years 3 months). Among these

Table 2. Correct Consonant Production Results in 30 Children

Consonant*	% Correct		
	Mean	Range	SD
/p/	97.5	75-100	7.63
/p ^h /	78.33	0-100	34.73
/t/	87.5	12.5-100	26.06
/t ^h /	67.5	0-100	40.02
/k/	65.83	0-100	38.55
/k ^h /	70	0-100	35.29
/m/	74.58	0-100	39.73
/n/	60.42	0-100	41.92
/l/	37.50	0-100	40.07
/f/	37.92	0-100	36.77
/x/	65.42	0-100	38.24
/tʃ/	60.42	0-100	41.14
/tʃ ^h /	30.42	0-100	31.09
/s/	50	0-100	40.6
/z/	32.92	0-100	37.5
/ts/	60.83	0-100	41.23
/ts ^h /	32.08	0-100	32.61
/ʃ/	28.33	0-100	36.25
/tʃ/	69.17	0-100	41.23
/tʃ ^h /	48.33	0-100	40.03
/ç/	55.42	0-100	41.87
Mean	57.9	14.88-89.89	19.46

*International Phonetic Alphabet.

children, 19 had received the Nucleus 22 device with the spectral peak (SPEAK) speech-coding strategy (Cochlear, Lane Cove, Australia), and the remaining 11 had received the MED-EL Combi 40 device with the continuous interleaved sampling (CIS) speech-coding strategy (Med-El, Durham, NC). Although neither preimplantation speech and language information nor history of oral rehabilitation were available, no parents indicated concomitant learning disabilities in their children.

SPEECH MATERIALS

The speech protocol used to elicit production of the 21 syllable-initial consonants consisted of 105 laminated pictures measuring 10 × 10 cm. For each of the 21 consonants to be tested, 5 pictures were grouped as a set and each set was placed in an envelope marked with the target consonant. On each of these 5 pictures a specially created cartoon character was depicted. The 5 characters were of similar shape but different color. Each set of pictures was used to elicit the production of the target consonant marked on the envelope. For each set of 5 pictures, 1 picture served as tutorial. The examiner told the child the character's name and then prompted the child to imitatively produce the consonant for the remaining 4 pictures. Each target consonant was in the initial position of either a consonant-vowel (CV) or a consonant-vowel-nasal (CVN) in the syllable structure, in accordance with the phonotactics or sequential constraints of the Mandarin language. These CV(N) syllables were presented in reduplicated forms to elicit multiple productions (ie, up to 8 tokens for each target consonant).

In addition, 2 language assessment tools, the Peabody Picture Vocabulary Test—Mandarin version, Revised Form A (PPVT)¹⁴ and the Assessment of Preschool Language Disorders (APLD)¹⁵ were individually administered to each participant. The PPVT was used to assess the children's word recognition and receptive vocabulary skills. In the PPVT, the words are presented in a hierarchy of increasing linguistic difficulty,

as determined by a population with normal hearing. The APLD was used to evaluate the children's overall receptive and expressive language skills. Although normative data were provided, only the raw scores were used in the present study to evaluate the potential relationships between the participants' consonant production skills and their receptive and expressive language skills.

PROCEDURE

Consonant production skills as well as receptive and expressive language skills were evaluated in an aural rehabilitation room (with noise level at 36 dB SPL [sound pressure level]). The 2 language assessment tools, the PPVT and the APLD, were administered and then the child's production of consonants was elicited. During this task, all envelopes were available to the child, who was asked to choose one. The examiner then opened the envelope and introduced the cartoon character to the child, saying, "This cartoon character has a name, and he is called/pan-pan/," for example. This was repeated a second time. If the child appeared uncertain, the examiner repeated the name until the child showed confidence in the task. The child was then shown the remaining 4 pictures one at a time and asked, "What about this one?" or "What is this person's name?" If the child incorrectly pronounced the target consonant, the examiner pronounced the name of the cartoon character on the next picture and then attempted to elicit the child's imitative consonant productions. The same procedure was repeated for each of the remaining 20 sets of pictures. In total, each reduplicated name was elicited 4 times, and therefore the target consonant productions were probed and recorded 8 times each. Each child completed the consonant production tasks in approximately 1 hour, and the data were recorded on a MiniDisk (MD) using a digital MD recorder (MD-MT831-S; Sharp, Tochigi, Japan) via a stereo condenser microphone (AIWA CM-TS22; now manufactured by Sony Corp, Tokyo, Japan) for further analysis.

SCORING AND RELIABILITY

All speech samples were transcribed by a speech/language pathologist (S.-C.P.) into broad transcriptions. One point was given if the target consonant was accurately produced. The scores were calculated as percentage of correct productions (ie, total correct number/8 × 100). To demonstrate insignificant transcriber bias,¹⁶ intrajudge and interjudge reliability measurements were performed on the production samples of 5 participants, as had been done in an earlier study.¹⁷ The intrajudge reliability across samples ranged from 91.0% to 94.7% (average, 93.0%; SD, 1.5%). Interjudge reliability was completed by having a native speaker of Mandarin judge all samples with regard to the accuracy of the production of a consonant following a training session that used another participant's speech samples. The interjudge agreement ranged from 78.0% to 95.8% across samples (mean ± SD, 90.0% ± 7.5%).

RESULTS

The mean ± SD score for correct consonant production was 57.9% ± 19.46%. As a group, the participants reached a mastery level of 75% correct for the consonants /p, t, and p^h/; between 50% and 74% for the consonants /m, k^h, tʃ, t^h, k, x, ts, n, tʃ, ç, and ʃ/; and between 28% and 49% for the consonants /tʃ^h, f, l, ç, tʃ^h, tʃ^h, and s/. Table 2 lists the children's percentage of correct consonant production, with range and standard deviation, for the production of each consonant (**Table 2**).

Figure 1 is a box plot illustrating the median, quartiles, and extreme values of correct percentage of production for each consonant category with a different manner of articulation. The mean $\pm$ SD score for correct consonant production was highest for plosives ($77.8\% \pm 21.6\%$) and, in descending order, for nasals ($67.5\% \pm 37.1\%$), affricates ($50.2\% \pm 25.4\%$), fricatives ($45.0\% \pm 27.1\%$), and the lateral approximant ($37.5\% \pm 40.1\%$). Repeated measurements obtained by multivariate analysis of variance using the PROC MIXED procedure (SAS Institute Inc, Cary, NC) showed that the overall difference in the percentages of correct consonant production in the 5 categories was statistically significant ($F_{4,29}=28.9$; $P<.001$). Post hoc Tukey t tests suggested statistically significant differences between the correct production of affricates and plosives ($t_{29}=7.18$; $P<.001$), fricatives and nasals ($t_{29}=3.19$; $P=.003$), fricatives and plosives ($t_{29}=7.95$; $P<.001$), lateral and nasals ($t_{29}=3.06$; $P=.005$), as well as lateral and plosives ($t_{29}=4.88$; $P<.001$). Thus, as a group, the participants' scores for correct consonant production were significantly higher for plosives and nasals than for affricates, fricatives, and the lateral approximant.

Another set of analyses was conducted to examine the relationships between the children's overall scores for correct consonant production and language skills. As a group, the participants' PPVT raw scores ranged from 6 to 104 points (33.2 ± 26.7 points) and the PPVT percentile scores from 1% to 66% ($7.5\% \pm 15.4\%$). With the APLD the raw scores measuring receptive language skills ranged from 7 to 30 points (22.33 ± 6.73 points) and the raw scores measuring expressive language skills ranged from 2 to 30 points (21.4 ± 8.8 points). As revealed by the APLD, there was no significant difference between the raw scores measuring the children's receptive and expressive language skills ($t_{29}=1.1$; $P=.29$).

Controlling for children's age at test time, the partial correlation coefficient between the overall scores of correct consonant production and the PPVT raw scores was statistically significant ($r=0.51$; $P=.005$). **Figure 2** is a scatterplot of the children's overall scores of correct consonant production relative to their PPVT raw scores. Similarly, the partial correlation coefficients were statistically significant between the overall scores for correct consonant production and the scores for receptive skills ($r=0.76$, $P<.001$). **Figure 3** shows the distribution of the children's overall scores of correct consonant production plotted against the raw scores for receptive and expressive language measurements.

The last set of analyses was performed to examine the relationships between the children's ability to produce consonants and the variables of age at implantation and length of device experience. **Figure 4** illustrates the distribution of the children's overall scores for correct consonant production as a function of age at implantation. **Figure 5** shows the distribution of the children's scores for correct consonant production as a function of length of CI experience. The partial correlation coefficient (controlling for age at test time) between the overall scores of correct consonant production and age at implantation achieved statistical significance ($r=-0.46$; $P=.01$). In addition, the par-

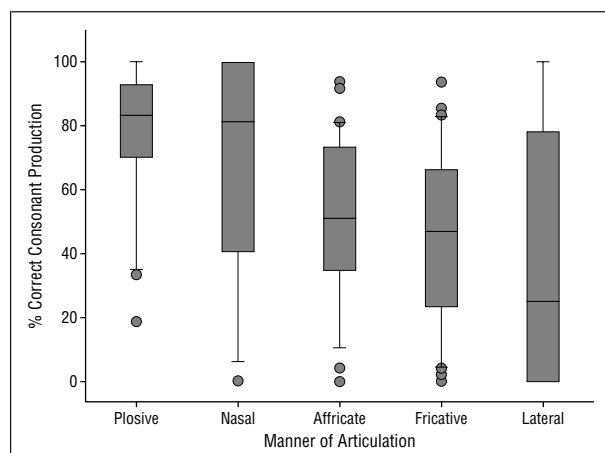


Figure 1. Box plot illustrating the median (line across a box), quartiles (upper and lower bounds of each gray box), and extreme values (gray circles) of the children's correct percentage of the production of each consonant category.

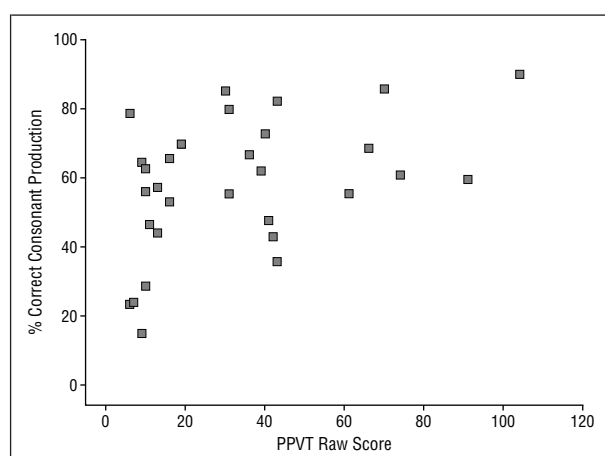


Figure 2. Overall percentages of correct consonant production against Peabody Picture Vocabulary Test—Mandarin Version, Revised Form A (PPVT) raw scores.

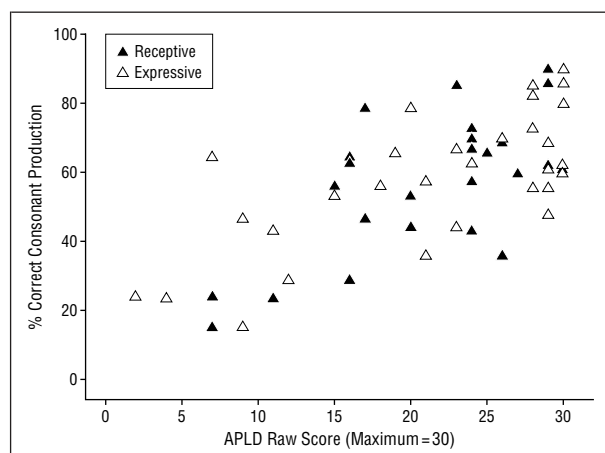


Figure 3. Overall scores of correct consonant production against Assessment of Preschool Language Disorders (APLD) raw scores of receptive and expressive language measurements.

tial correlation coefficient between the overall scores of correct production and length of CI experience was statistically significant ($r=0.45$; $P=.02$).

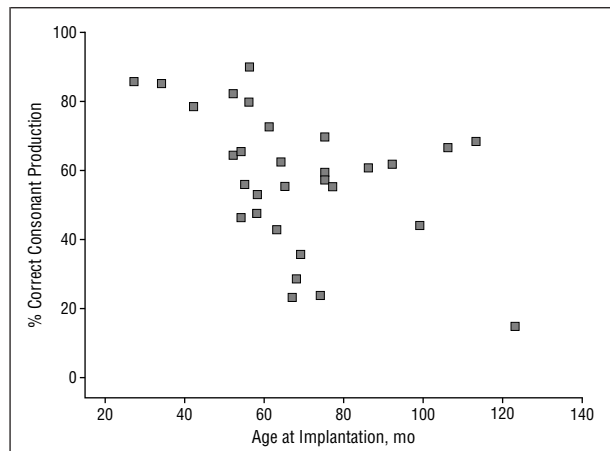


Figure 4. Distribution of correct consonant production scores as a function of age at implantation.

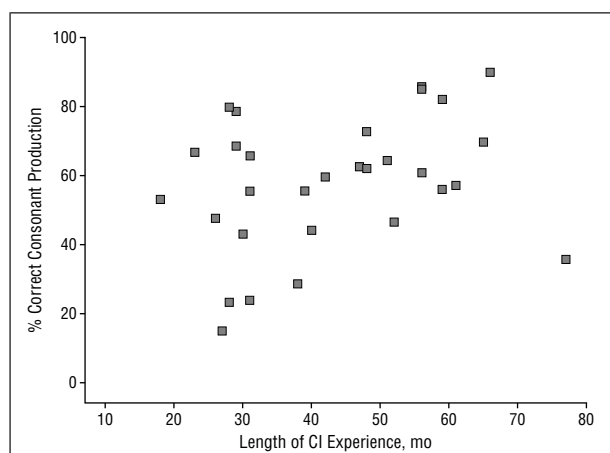


Figure 5. Distribution of correct consonant production scores as a function of length of cochlear implant (CI) experience.

COMMENT

Group performance showed that, on average, the participants' mastery levels of the Mandarin syllable-initial consonants were 75% or higher for only 3 plosives. The average mastery levels were within the range of 50% to 74% for 11 of the 21 consonants and below 50% for the remaining consonants. Compared with the consonant production skills of children with normal hearing who were learning Mandarin as their first language, the participants' mastery levels of syllable-initial consonants lagged behind. Their performance levels, however, exhibited a wide variability.

Regarding the manner of articulation, the participants' mastery levels of Mandarin consonants varied across the different categories of consonants. The children were able to produce the plosive and nasal consonants more accurately than consonants from the other categories, namely, affricates and the lateral approximant. In general, the present results are consistent with findings in previous studies that investigated the postimplant consonant production skills of pediatric English-speaking CI recipients. For instance, Serry and colleagues^{7,8} indicated that fricatives and affricates

tended to be the most challenging categories for their participants to accurately produce. However, results from the present study showed that the lateral approximant was among the most challenging consonants for Mandarin-speaking children to produce accurately. This result is very dissimilar to that of Serry and colleagues,⁷ in which the lateral approximants did not appear to be as challenging as fricatives and affricates for prelingually deaf children who learn English as their first language. In fact, our participants' 2 most common erroneous patterns of production involved 2 phonological processes: the substitution of /l/ with the nasal /n/ and the nasalization of /l/ as [l̃]. It is very likely that the children treated the 2 consonants /l/ and /n/ as 2 variants of a single phoneme, and therefore did not consistently differentiate them when producing words containing these phonemes.

The present results indicate that the participants' mean scores for correct consonant production were significantly positively correlated with the raw scores of their receptive vocabulary as well as with their overall receptive and expressive language skills as assessed by the PPVT and APLD. Moreover, the average percentile score was as low as 7.5% (range, 1%-66%), which suggested that children using CIs tended to have a limited vocabulary in comparison with children of the same age with normal hearing. Nevertheless, the results suggest that speech production skills, specifically the correct production of syllable-initial consonants, were positively correlated with receptive and expressive language skills.

Although information about each participant's involvement in aural rehabilitation was not available, it was known that the children all communicated orally and received training from a similar educational setting, specifically, the public elementary school. The present results suggest that higher scores of correct consonant production were associated with younger age at implantation and longer length of CI use. This is consistent with the major trend of findings in the literature, that younger age at implantation and longer device experience can facilitate the postimplant speech and spoken language development of pediatric CI recipients. Our study participants, as a group, did not achieve a high mastery level of many of the Mandarin syllable-initial consonants. Their delayed ability to produce consonants may be related to the fact that they tended to have an average of less than 4 years (specifically, 43 months) of device use. Given the positive correlation between mastery levels of consonant production and length of CI experience already observed, it is likely that the children's consonant production skills will continue to improve with the length of their experience.

CONCLUSIONS

Our participants' average mastery levels of most of the Mandarin syllable-initial consonants remained low, between 28% and 74%. The children were able to produce consonants of certain categories (eg, plosives and nasals) more accurately than others (eg, affricates, fri-

catives, and lateral approximant). The comparison of each participant's percentage of correctly pronounced consonants with language test results revealed that consonant production profiles were positively correlated with both receptive and expressive language skills. Thus, the children with more sophisticated receptive and expressive language skills also had better consonant production skills. Finally, higher percentages of correctly produced consonant were also closely associated with younger age at implantation as well as longer length of CI experience.

Submitted for publication September 16, 2003; final revision received December 8, 2003; accepted January 16, 2004.

An earlier version of the manuscript was presented at the Ninth Symposium on Cochlear Implants in Children; April 25, 2003; Washington, DC.

We thank the 30 participating children and their parents. We also thank the audiologists of the Chi-Mei Medical Center Department of Otolaryngology for their assistance in data collection; Lih-Sheue Wang for the preparation of the speech materials; and the manuscript reviewers for their most useful suggestions and comments.

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Reprints are available from Ms Shu-Chen Peng.

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