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Sensory Aid and Word Position Effects on Consonant Feature Production by Children with Profound Hearing Impairment[1]

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Abstract. This study examined consonant feature production by pediatric Nucleus 22-channel cochlear implant users (mean PTA = 110 dB) at two intervals: (1) within a few months before or after initial stimulation (mean = 0.36 years after) and (2) after approximately two years of device use. Additionally, the consonant feature production of the cochlear implant users at the later interval was compared with production by tactile aid users (PTA > 110 dB) and two groups of hearing aid users with differing amounts of residual hearing: those with mean PTAs of 93 dB (PTA_{93} hearing aid users) and those with mean PTAs of 104 dB (PTA_{104} hearing aid users). All four groups were had approximately the same average age at testing. All children were administered the *Goldman-Fristoe Test of Articulation*, which was scored in terms of percent correct voicing, place of articulation, and manner of articulation for consonants produced in word-initial, word-medial, and word-final positions. A longitudinal within-group comparison for the cochlear implant users revealed significant improvements in consonant feature production after approximately two years of device use. Consonant feature production for the cochlear implant users at the later interval surpassed that of age-matched tactile aid users and PTA_{104} hearing aid users, although PTA_{93} hearing aid users still outperformed all other groups. Finally, all groups exhibited word-position effects on consonant feature production, so that correct place, manner, and voicing production was highest in word-initial position, reduced in medial position, and lowest in word-final position. The results thus demonstrate the relative usefulness of cochlear implants for promoting appropriate speech production in deaf children, as well as the importance of linguistic variables (e.g., word-position) in assessing speech production performance.

Introduction

The effects of profound deafness on the speech production of postlingually deafened adults are minimal (e.g., Leder & Spitzer, 1990), but the effects on prelingual children can be devastating. Not only is hearing itself affected adversely, but the child's ability to acquire and use a spoken language is severely diminished. Thus, although cochlear implants were first developed for use by postlingually deafened adults, many investigators believe that the patient group that stands to benefit the most from cochlear implants will be "children, particularly young children" (Berliner, Eisenberg, & House, 1985). Such benefits would include, most importantly, provision of the necessary auditory input for the acquisition of target-appropriate speech production and spoken language.

Compared with research on the efficacy of cochlear implants in aiding auditory perception generally and speech perception specifically, the study of speech production by children using cochlear implants is relatively recent. Tobey, Angelette, et al. (1991) examined imitative segmental and nonsegmental characteristics, phonological skills, and intelligibility (following procedures developed by Ling, 1976, and McGarr, 1983) in 61 children who used the Nucleus multichannel cochlear implant. Tobey, Angelette, et al. reported that 79% of the children studied improved on a least one third of the measures. Improvement was most common on tasks assessing imitative segmental characteristics (66.7% of the children), followed by tasks examining intelligibility (62.9%), phonological skills (55.6%), and nonsegmental characteristics (31.1%). Similarly, Tobey and Hasenstab (1991) examined speech production by 78 users of the Nucleus device once preoperatively and up to four times postoperatively. These children demonstrated increases in scores on both segmental and suprasegmental measures postoperatively and with increased device use. Postoperatively, speech intelligibility was higher, but mean length of utterance was not significantly different. Tobey, Pancamo, Staller, Brimacombe, and Beiter (1991) examined consonant production in 29 children before they were fitted with a Nucleus device and again after one year of device use. A greater number of children produced stops, nasals, fricatives, and glides after implantation than before. After implantation, voiced stops were used by more children than were voiceless stops, but voiceless fricatives were produced more than voiced ones. Additionally, consonants with visible places of articulation were used more than those with less visible places.

It should be noted that children without cochlear implants may also show some improvements on the variables just discussed. Ultimately, it would be important to assess the improvement that is due to the implant alone, and not to maturation. To this end, more recent studies have introduced the use of control data from other populations (e.g., children using other sensory devices). Tobey, Geers, and Brenner (1994) analyzed the speech production skills of three groups (users of cochlear implants, tactile aids, and hearing aids) of 13 children matched by age, hearing loss, intelligence, family support, and speech and language skills (Geers & Moog, 1994). All children had better ear PTA thresholds of 100 dB HL or greater[3] and were tested once a year for three years in both imitative and spontaneous speech tasks. In addition, thirteen children with PTAs between 90 and 100 dB HL were tested once at the end of the study for comparison with the other three groups. For imitated speech production, significant differences among groups appeared first at the 24-month interval, when performance by cochlear implant users was better than that of tactile aid and hearing aid users on suprasegmentals and vowels/diphthongs. By the 36-month interval, cochlear implant users showed significantly better performance on most measures. For spontaneous speech, the cochlear implant users also showed significantly greater improvement in the production of both consonants and vowels than did the users of tactile aids and hearing aids. After three years of device use, the cochlear implant group showed similar performance to the children with PTAs between 90 and 100 dB HL.

Kirk, Diefendorf, Riley, and Osberger (1995) compared consonant feature production in CV syllables by 24 multichannel cochlear implant users at two intervals and further compared this with production by two groups of hearing aid users (16 children whose mean unaided PTA was 103 dB HL and 16 children whose mean unaided PTA was 94 dB HL). Cochlear implant users demonstrated significant improvements in the production of voicing, place, and manner features after approximately 2.6 years of device use. Additionally, both cochlear implant users and hearing aid users with a mean PTA of 94 showed significantly better place and voicing scores than did hearing aid users with a mean PTA of 103.

Two recent studies have compared the production of cochlear implant users and vibrotactile aid users. Ertmer, Kirk, Sehgal, Riley, and Osberger (1997) examined longitudinal changes in imitative vowel and diphthong production in 10 children using cochlear implants and 10 children using tactile aids. Production was evaluated at two intervals: (1) before children received a cochlear implant or tactile aid and (2) after at least one year of using the sensory aid (M = 1.8 years). From the earlier interval to the later interval, cochlear implant users showed significant improvement on seven of nine vowel and diphthong production measures, whereas the tactile aid users significantly increased performance on only one measure. Additionally, at the postdevice interval, cochlear implant users had significantly higher scores than the tactile aid users on eight of the nine measures. Sehgal, Kirk, Svirsky, Ertmer, and Osberger (1998) examined consonant feature production in CV syllables by cochlear implant users and vibrotactile aid users. Both groups were tested before receiving their devices and again approximately 1.5 years after receiving their devices. Users of both cochlear implants and tactile aids showed relatively poor production

[3] Cochlear implant users had an average unaided threshold of 118 dB HL; both tactile aid and hearing aid users had an average unaided threshold of 110 dB HL.

of voicing, place, and manner features at the predevice interval. Both showed improved production postdevice, but the improvement demonstrated by the cochlear implant users was significantly greater than that of the vibrotactile aid users. Cochlear implant users improved performance on one place feature and all of the manner features.

Previous research has provided strong evidence that cochlear implants benefit the acquisition of certain aspects of speech production and spoken language in young children with prelingual profound hearing impairments. However, previous studies have either (1) relied exclusively on imitative production tasks or (2) limited sampling to consonants in restricted phonological environments or (3) lacked comparison with other groups of children. The present study examined elicited consonant feature production in pediatric cochlear implant users at two intervals and compared production at the later interval with production by age-matched tactile aid users and two groups of conventional hearing aid users. Speech samples were collected using the *Goldman-Fristoe Test of Articulation* (GFTA; Goldman & Fristoe, 1972), a standard instrument used in assessing articulation disorders and articulation development. Using these speech materials, consonant feature production was compared longitudinally for the cochlear implant users (early vs. late interval), as well as cross-sectionally among the late-interval cochlear implant users and the users of tactile aids and conventional hearing aids. Finally, productions of consonant features located in various word positions were compared in the various groups of children.

Method

Subjects

Subjects for this study were nine pediatric users of the Nucleus-22 multichannel cochlear implant (Patrick & Clark, 1991). Age at onset of deafness ranged from 0.0 years to 1.3 years (M = 0.41 years, SD = 0.56). Age at fitting with the cochlear implant ranged from 3.1 to 8.5 years (M = 5.38 years, SD = 1.52), so that the length of auditory deprivation ranged from 1.8 to 7.2 years (M = 4.97 years, SD = 1.43).

Consonant feature production of these children with cochlear implants was examined (see below) at two intervals: (1) Early interval: either immediately prior to implantation or within several months after implantation (years of device use: M = 0.36 years, SD = 0.25 years), and (2) Late interval: between 1.5 years and 2.6 years after implantation (M = 2.1 years, SD = 0.5 years) (late interval). For the nine cochlear implant users, the early interval occurred before implantation for three of the children, and within 0.6 years after implantation for the remaining six. Of the six children whose early interval occurred after implantation, five used the MPEAK strategy implemented on the MSP (mini speech processor) and one used the F0/F1/F2 strategy implemented on the WSP (wearable speech processor). Also for these six, the number of active electrodes ranged from 9 to 20, with five children using 12 or more active electrodes. At the late interval, eight of the children used the MPEAK strategy and one the F0/F1/F2 strategy. For these nine children, the number of active electrodes ranged from 5 to 20, with seven children using 12 or more active electrodes. Two of the children with cochlear implants used Oral Communication, and the remaining seven used Total Communication.

The consonant feature production of cochlear implant users at the late interval was compared with that of children using either tactile aids or conventional hearing aids. The nine children who used a tactile aid (Tactaid 7; see Franklin, 1991) were prelingually profoundly deaf and had PTAs > 110 at the time of testing. The hearing aid users were divided into two groups according to their unaided thresholds at 500, 1000, and 2000 Hz (Miyamoto, Osberger, Todd, & Robbins, 1994; Osberger, Maso, & Sam, 1993). Nine children who used hearing aids demonstrated hearing levels of 90-100 dB HL at two of the three frequencies with none of the thresholds higher than 105 dB HL; mean PTA for this group was 93 dB HL. These children were designated as the PTA_{93} hearing aid group. Nine children who used hearing aids demonstrated hearing levels of 101-110 dB HL at two of the three frequencies; mean PTA was 104 dB HL. These children were designated as the PTA_{104} group. Summary information for all five groups (cochlear implant users at the early interval, the same children at the late interval, tactile aid users, PTA_{93} hearing aid users, and PTA_{104} hearing aid users) is shown in Table 1.

Table 1: Subject Characteristics

	Cochlear Implant Users	Tactile Aid Users	Hearing Aid Users	
			PTA_{93}	PTA_{104}
Subjects	*n* = 9	n = 9	*n* = 9	*n* = 9
Mean unaided pure tone average, dB HL	111	>110	93	104
Mean age at onset of deafness, years	0.41	0.53	0.13	0.14
Mean age fit with sensory aid, years	5.38	5.78	1.81	1.04
Mean years deaf	4.97	5.24	1.68	.90
Mean age at time of testing, years				
Early interval	5.67	n/a	n/a	n/a
Late interval	7.51	7.61	7.78	7.47
Mean duration of device use, years	2.13	1.83	5.97	6.42

Speech Materials and Analysis

Consonant production was elicited by administration of the Sounds-in-Words Subtest of the *Goldman-Fristoe Test of Articulation* (Goldman & Fristoe, 1972; hereinafter GFTA), a standard instrument used for assessing articulation disorders and articulation development in children. In addition to its widespread use with various pediatric clinical populations (including children with hearing impairments; see Osberger, Robbins, Lybolt, Kent, & Peters, 1986), the GFTA also has the advantage of using actual words and of probing sound segments in different word-positions (word-initial, -medial, and -final). The test consists of 44 words containing all English consonants (except [ʒ]) that can occur in word-initial and most in word-medial and word-final position. Stimulus materials consist of colored drawings on card stock.

The GFTA is part of a battery of speech perception, speech production, and language tests routinely administered to all participants (including control subjects) in sensory aid studies in the Department of Otolaryngology–Head and Neck Surgery at the Indiana University School of Medicine.

All productions elicited in the GFTA were recorded on audiotape and later transcribed phonetically by a speech-language pathologist with experience hearing and transcribing the speech of deaf children. Transcriptions were entered into the Logical International Phonetics Programs (LIPP 1.40; Intelligent Hearing Systems, Miami, Florida), a computerized transcription and phonetic/phonological analysis program. With this program, a user enters a phonetically transcribed target form and a segment-aligned phonetic transcription of the corresponding production. LIPP subsequently performs a number of segment-by-segment analyses, including analyses of feature and segment correctness. For the present study, the program generated percent correct production scores for the segments, features, and feature classes listed in Table 2.[4]

Table 2: LIPP Output

Feature Class	Feature	Segments
Voicing	Voiced	b d g v ð z dʒ m n w l
	Voiceless	p t k f θ s ʃ tʃ h
Place of Articulation	Bilabial	p b m
	Dental	θ ð
	Alveolar	t d n l s z
	Velar	k g
Manner of Articulation	Stop	p b t d k g
	Fricative	f v θ ð s z ʃ h
	Affricate	tʃ dʒ
	Nasal	m n
	Glide	w l

[4] To facilitate analysis, LIPP was programmed with the following settings: (1) only singletons (not clusters) were included in the analysis; (2) four places of articulation were included in the analysis: bilabial, interdental, alveolar, and velar; (3) glides were limited to [w] and [l] and were not included in the Correct Manner score; (3) the velar nasal [ŋ] was not included in the

Results

Development of Consonant Feature Production in Cochlear Implant Users

Figure 1 shows mean percent correct scores for voicing, place of articulation, and manner of articulation for cochlear implant users at both the early interval and the late interval. As this figure shows, mean scores (collapsed across word positions) at the late interval were higher for all three feature classes than at the early interval.

Insert Figure 1 about here

To determine if the improvements demonstrated by the cochlear implant users were significant, a separate paired *t* test was computed for each feature class (voicing, place or articulation, manner of articulation) with interval as the independent variable and percent correct score as the dependent variable. For these cochlear implant users, percent correct scores for voicing ranged from 0 to 85% ($M = 30.6$, $SD = 22.9$) at the early interval and from 6 to 94% ($M = 52.5$, $SD = 20.6$) at the late interval. A paired t test showed the difference in mean correct percent between the two intervals to represent a significant improvement in production of correct voicing ($t = -6.39$, $p < .001$). Similarly, percent correct scores for place of articulation ranged from 0 to 55% ($M = 21.1$, $SD = 19.2$) at the early interval and from 6 to 94% ($M = 47.8$, $SD = 23.1$) at the late interval, a significant increase ($t = -7.62$, $p < .0001$). Finally, percent correct scores for manner of articulation ranged from 0 to 55% ($M = 19.1$, $SD = 17.6$) at the early interval and from 0 to 94% ($M = 40.3$, $SD = 24.0$) at the late interval; this increase was also significant ($t = -5.78$, $p < .0001$). Table 3 summarizes the results of the paired *t* tests.

Table 3: Paired *t* test results: Early vs. Late Interval Percent Correct Production of Voicing, Place, and Manner Features by Cochlear Implant Users

	Percent correct				
Feature Class	Early Interval, *M*	Late Interval, *M*	Difference (Late - Early)	*SEM* of paired differences	*t*
Voicing	30.6	52.5	21.9	3.4	6.39*
Place	21.1	47.8	26.7	3.5	7.62**
Manner	19.1	40.3	21.2	3.7	5.78*

*$p < .001$; **$p < .0001$

For the nine cochlear implant users, then, production improved significantly from the early interval to the late interval for all three feature classes examined in this study: voicing, place of articulation, and manner of articulation.

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analysis. Additionally, production of target initial [tʃ] was assessed from the word *chicken*, rather than from *church*, the former having been found to be more familiar to children.

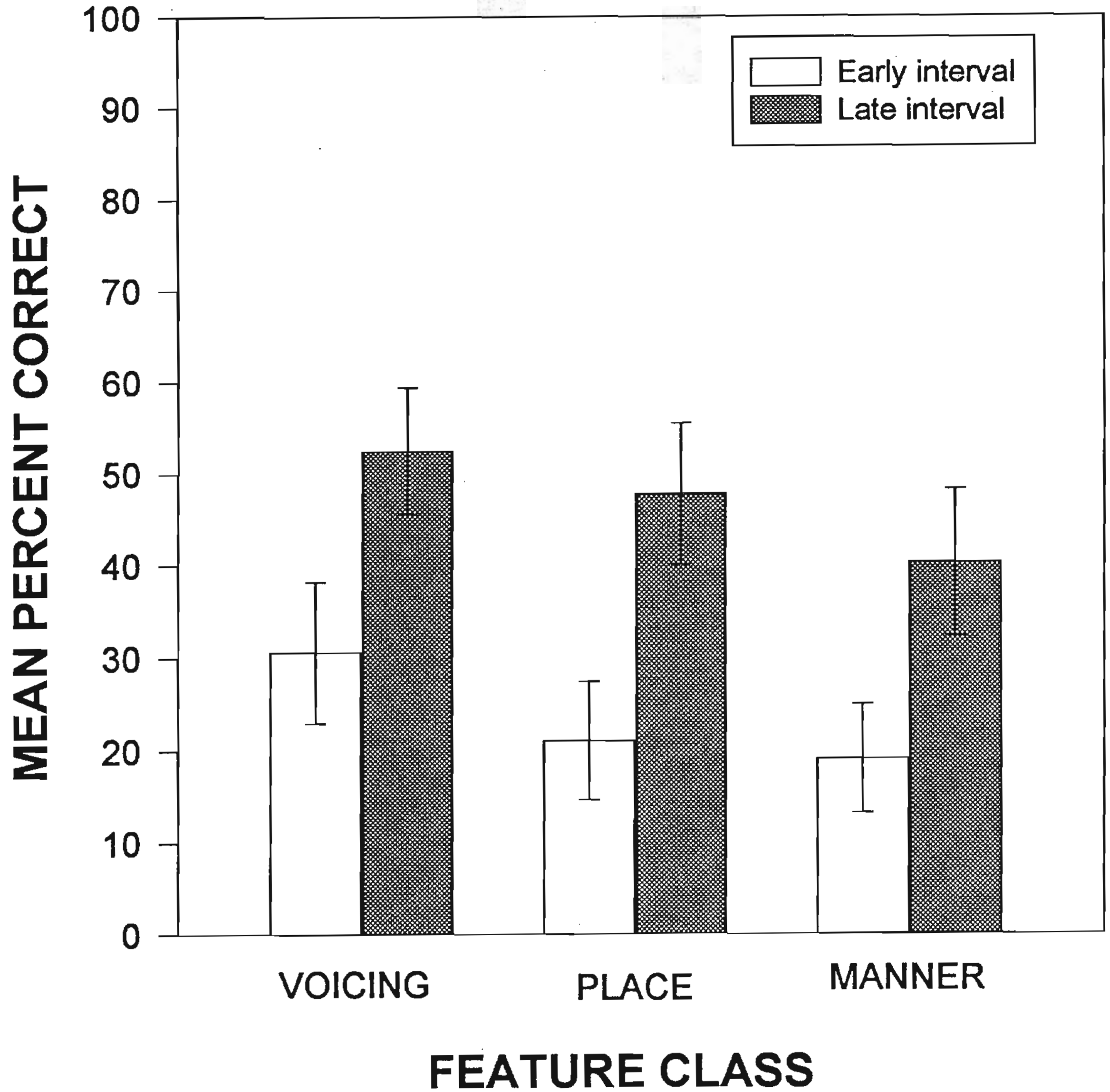

Figure 1: Cochlear implant users' mean percent correct production by feature class and interval. Error bars indicate standard errors of means.

Sensory Aid Effects on Consonant Feature Production

Figure 2 shows mean percent correct scores achieved by PTA_{93} hearing aid users, cochlear implant users at the late interval, PTA_{104} hearing aid users, and tactile aid users for the feature classes voicing, place of articulation, and manner of articulation. As this figure shows, scores for PTA_{93} hearing aid users were consistently higher than scores from the other device groups, but cochlear implant users also consistently outperformed both PTA_{104} hearing aid users and tactile aid users on correct production of all three types of features.

Insert Figure 2 about here

Across word positions, percent correct scores for PTA_{93} hearing aid users ranged from 18 to 100% (M = 77.9, SD = 13.6) for voicing, from 22 to 100% (M = 71.8, SD = 15.9) for place of articulation, and from 17 to 95% (M = 64.1, SD = 17.9) for manner of articulation. For cochlear implant users at the Late interval, scores ranged from 6 to 94% (M = 52.5, SD = 20.6) for voicing, from 6 to 94% (M = 47.8, SD = 23.1) for place of articulation, and from 0 to 94% (M = 40.3, SD = 24.0) for manner of articulation. For PTA_{104} hearing aid users, percent correct scores ranged from 0 to 80% (M = 40.9, SD = 20.0) for voicing, from 0 to 78% (M = 35.1, SD = 22.1) for place of articulation, and from 0 to 65% (M = 32.2, SD = 20.3) for manner of articulation. Finally, for tactile aid users, percent correct scores ranged from 0 to 75% (M = 34.2, SD = 17.4) for voicing, from 0 to 95% (M = 33.6, SD = 25.3) for place of articulation, and from 0 to 90% (M = 31.2, SD = 25.2) for manner of articulation.

To determine the statistical significance of differences among the device groups, a separate one-way ANOVA was computed for each feature class, using device group as the independent variable and feature class score as the dependent variable. These revealed a significant main effect of device on percent correct production of voicing ($p < .001$), place ($p < .001$), and manner ($p = .001$) features. Post-hoc analyses (Student-Newman-Keuls method) revealed PTA_{93} hearing aid users' performance to be significantly higher than that of the three other groups on all three feature classes. There were no significant differences between the performance of the cochlear implant users and the PTA_{104} hearing aid and tactile aid users, except that performance by the cochlear implant users on voicing feature production was significantly higher ($p < .05$) than that of the tactile aid users.

Word-Position Effects on Consonant Feature Production

A two-way RMANOVA was computed to determine the effects of device group and word position (word-initial, -medial, and -final) on feature class scores. This indicated a significant main effect of word position on feature production scores [$F_{2,64} = 62.86$, $p < .0001$]. Figure 3 displays percent feature production scores as a function of device group and word position.

Insert Figure 3 about here

As Figure 3 shows, there was a consistent pattern across devices, such that correct feature production was highest in initial position, followed by medial position, with features in final position produced least correctly. All device groups showed a significant ($p < .05$) difference between initial and final position.

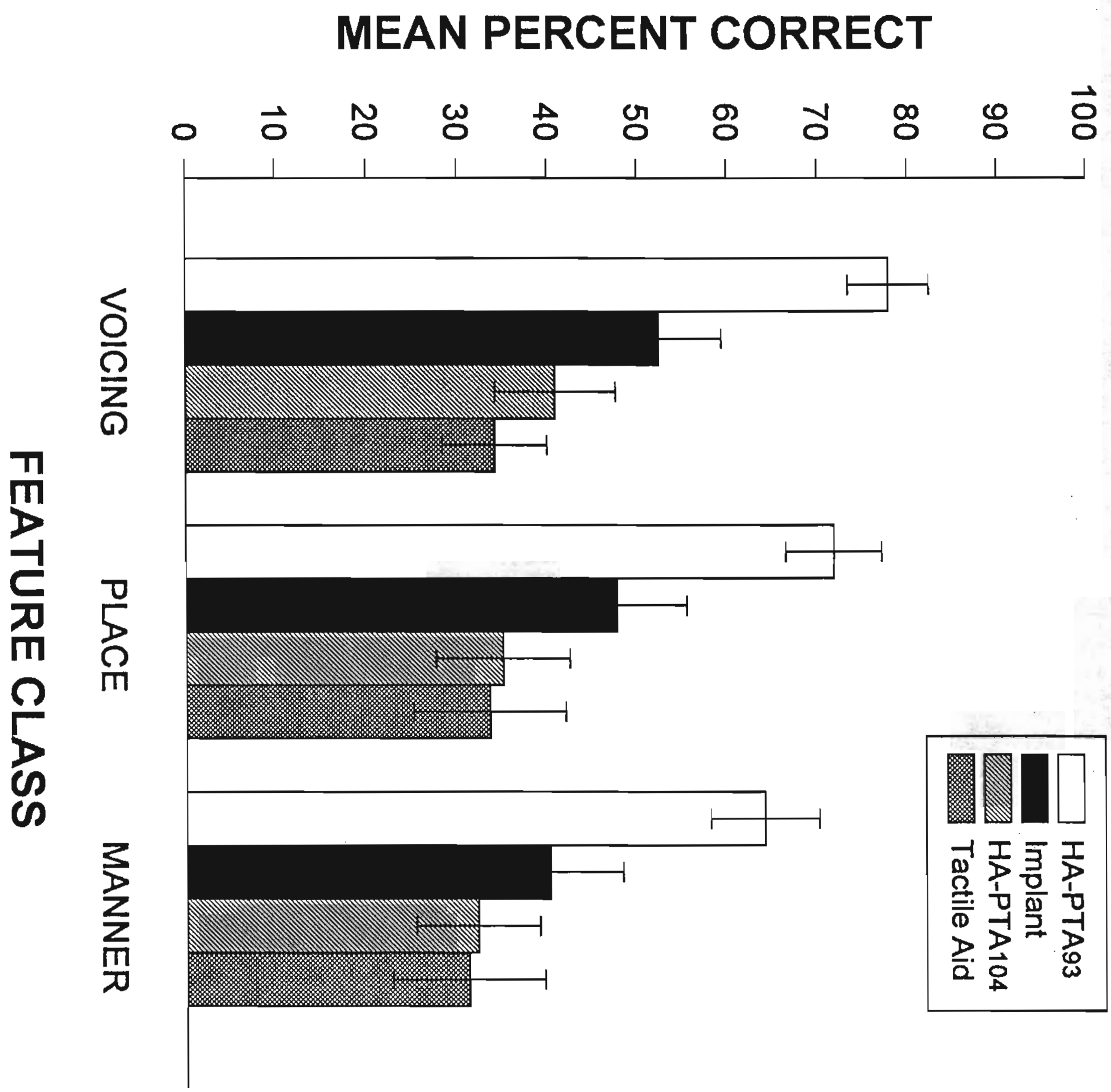

Figure 2: Mean percent correct production by feature class and device. Error bars indicate standard errors of means.

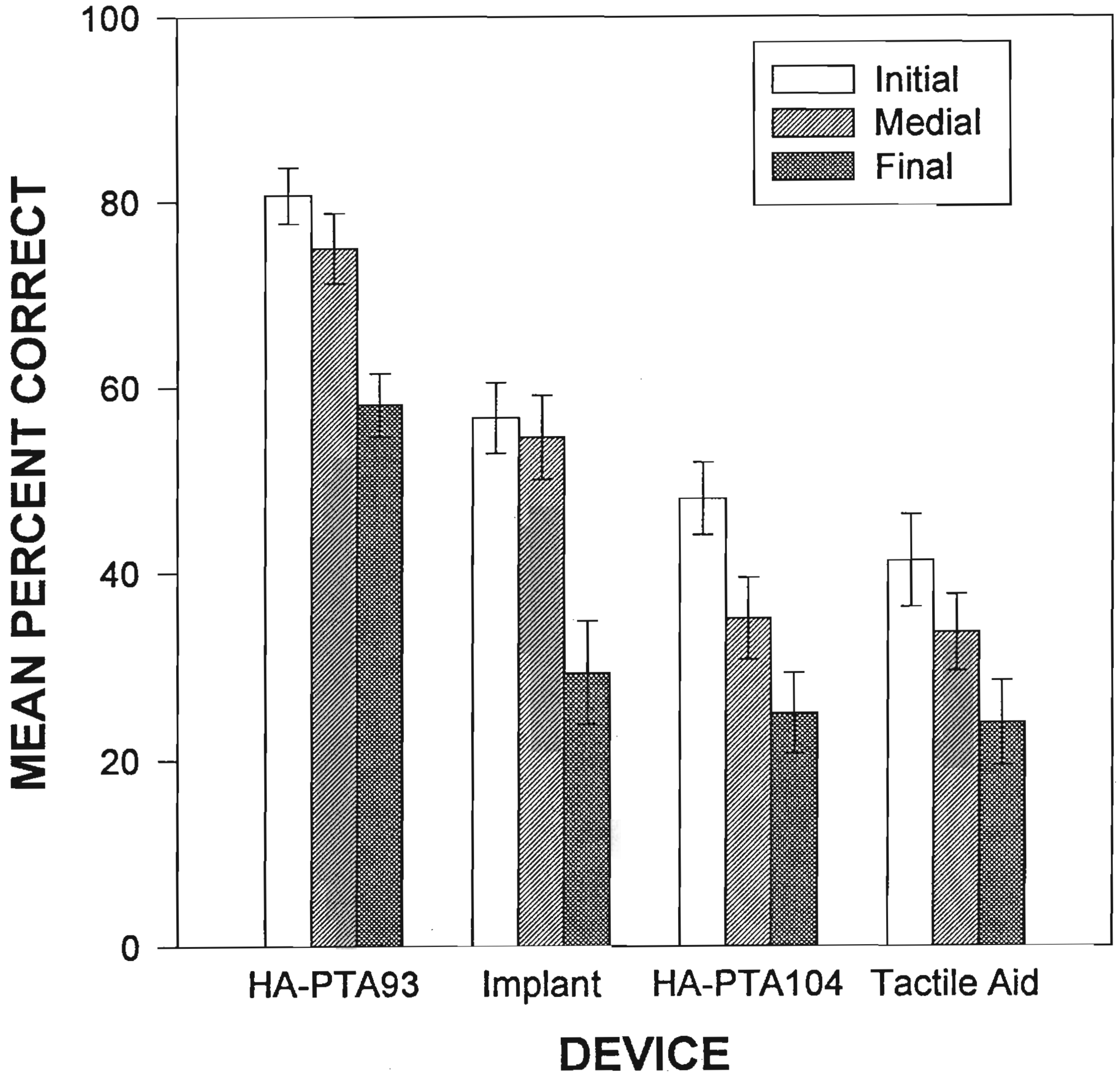

Figure 3: Mean percent correct production by word position and device. Error bars indicate standard errors of means.

Additionally, both PTA_{93} hearing aid users and cochlear implant users displayed a significant difference ($p < .05$) between medial and final position but not between initial and medial position. Neither PTA_{104} hearing aid nor tactile aid users showed a significant difference between medial and final position. Finally, PTA_{104} hearing aid users showed a significant difference between initial and medial position, but tactile aid users did not. These results are summarized in Table 4.

Table 4: Significant Differences ($p < .05$) in Scores for Device Groups as a Function of Word Position Opposition

Word Position Opposition	PTA_{93} Hearing Aid	Cochlear Implant	PTA_{104} Hearing Aid	Tactile Aid
Initial vs. Medial	No	No	Yes	No
Initial vs. Final	Yes	Yes	Yes	Yes
Medial vs. Final	Yes	Yes	No	No

As Table 4 shows, PTA_{93} hearing aid users and cochlear implant users displayed a common pattern in their differentiation of word positions. In addition, both displayed common differences from the patterns shown by PTA_{104} hearing aid and tactile aid users.

The two-way RMANOVA also indicated a significant main effect of device type on percent correct feature production [$F_{3,32} = 6.55$, $p < .01$]. Figure 4 shows percent correct feature class production as a function of word position and device group.

Insert Figure 4 about here

As Figure 4 shows, there was a consistent pattern of scores across the three word positions, such that PTA_{93} hearing aid users scored highest, followed by cochlear implant users, and then PTA_{104} hearing aid and tactile aid users. In initial and medial positions, differences in scores between the PTA_{93} hearing aid users and the PTA_{104} hearing aid and tactile aid users were significant ($p < .05$); importantly, scores for cochlear implants users and PTA_{93} hearing aid users did not differ significantly. In final position, where scores were lowest regardless of device, there were no significant differences due to type of device. Finally, there were no significant interaction effects of device type and word position [$F_{6,64} = 1.79$, $p = .1149$ (n.s.)].

Discussion

The results of this study show that users of cochlear implants improved significantly on their correct production of voicing, place of articulation, and manner of articulation features from the early interval to the late interval. This finding indicates that cochlear implants promote the development of appropriate nonimitative speech production in children with profound hearing impairments.

When the production of cochlear implant users after approximately two years was compared with that of PTA_{93} hearing aid users, PTA_{104} hearing aid users, and tactile aid users of the same chronological age, results were consistent with previous studies (e.g., Sehgal et al., 1998). That is, PTA_{93} hearing aid users demonstrated significantly better production of consonant features than did other device groups.

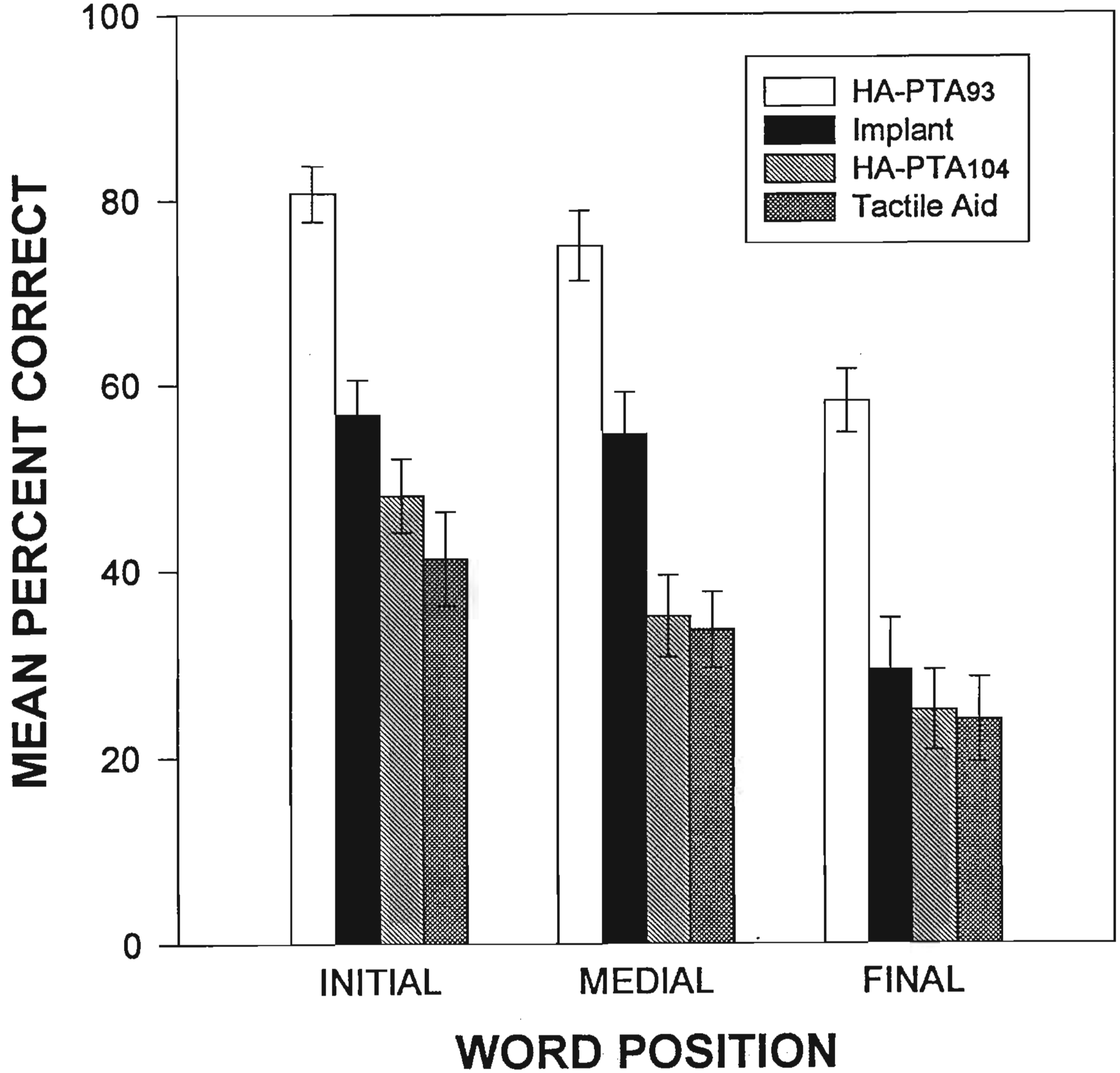

Figure 4: Mean percent correct production by device and word position. Error bars indicate standard errors of means.

However, there was a trend for the cochlear implant users to produce consonant features more correctly than either PTA_{104} hearing aid users or tactile aid users. Previous research has shown that consistent speech perception benefits of cochlear implants frequently are apparent only after approximately two years of device use. If production skills lag behind perception skills, this may account for the general lack of significant differences between cochlear implant users and PTA_{104} hearing aid and tactile aid users, as well as for the fact that PTA_{93} hearing aid users scored significantly higher than cochlear implant users at the late interval. Moreover, because of the additional task demands, it is probable that the type of nonimitative speech production elicited in this study is considerably more difficult than imitative speech production and may develop at a later age (or with more device experience, especially if children are implanted earlier). Thus, it is possible that only after continued experience with a cochlear implant beyond the stage reported here will differences among cochlear implant, hearing aid, and tactile aid users be significant.

This same observation is relevant for interpretation of the results stemming from comparison of production in different word positions. There were consistent and generally significant differences in scores for different word positions across device types, and the hierarchy of production ability (initial > medial > final) is consistent with findings for children with normal hearing (e.g., Ingram, 1989; Templin, 1957). Word position effects on consonant production thus apply equally to both hearing-impaired and normal-hearing children. In comparing differences between word positions, it was also found that cochlear implant users and PTA_{93} HA users demonstrated a pattern not shown by the tactile aid users and PTA_{104} HA users. Specifically, cochlear implant users and PTA_{93} HA users were alike in showing significant differences in performance between initial and final positions and between medial and final positions, but not between initial and final positions. The pattern of differentiating word position exhibited by PTA_{93} hearing aid users and cochlear implant users is furthermore consistent with that demonstrated by children with normal hearing (e.g., Templin, 1957; Wellman et al., 1936). The difference in performance may be due to differences in the acquisition of English syllabification. PTA_{93} hearing aid users and users of cochlear implant users appear to be aware that in English, word-medial singleton consonants are generally syllabified with the following syllable (as onset). This might account for the lack of significant differences in performance between initial and medial positions, as well as for the significant differences between initial and final position and between medial and final position. For PTA104 hearing aid users and users of tactile aids, however, medial consonants may be either ambisyllabic or syllabified with the preceding syllable. This might account for the lack of significant difference in performance between medial and final position. Continued experience with cochlear implants may illuminate further differences in performance among users of various sensory aids, in particular differences between users of cochlear implants and users of hearing aids with considerable residual hearing (e.g., the present PTA_{93} hearing aid users).

There is thus an increasing need to examine linguistically relevant speech production among users of cochlear implants and other sensory aids. It is to be expected that as these children mature, their awareness of sound-to-meaning correspondences will become more acute. Furthermore, spoken language acquisition is not a matter of pure imitation or of producing consonants only at the beginnings of words. As children with profound hearing impairment and various sensory aids continue to mature, develop, and expand their linguistic abilities, and as new processing strategies (e.g., CIS, SPEAK) become available, it is incumbent on researchers to expand their own assessment repertoires as well.

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