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Nonword imitation by children with cochlear implants: Consonant analyses

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Abstract

Objectives—To complete detailed linguistic analyses of archived recordings of pediatric cochlear implant users' imitations of nonwords; to gain insight into the children's developing phonological systems and the wide range of variability in nonword responses.

Design—Nonword repetition: repetition of 20 auditory-only English-sounding nonwords.

Setting—Central Institute for the Deaf “Education of the Deaf Child” research program, St Louis, Mo.

Participants—Eighty-eight 8- to 10-year-old experienced pediatric cochlear implant users.

Main Outcome Measures—Several different consonant accuracy scores based on the linguistic structure (voicing, place, and manner of articulation) of the consonants being imitated; analysis of the errors produced for all consonants imitated incorrectly.

Results—Seventy-six children provided a response to at least 75% of the nonword stimuli. In these children's responses, 33% of the target consonants were imitated correctly, 25% of the target consonants were deleted, and substitutions were provided for 42% of the target consonants. The children tended to correctly reproduce target consonants with coronal place (which involve a mid-vocal tract constriction) more often than other consonants. Poorer performers tended to produce more deletions than the better performers, but their production errors tended to follow the same patterns as the better performers.

Conclusions—Poorer performance on labial consonants suggests that scores were affected by the lack of visual cues such as lip closure. Oral communication users tended to perform better than total communication users, indicating that oral communication methods are beneficial to the development of pediatric cochlear implant users' phonological processing skills.

When exposed to speech, normal-hearing children quickly learn to ignore irrelevant variation in the acoustic signal and segment the signal into a series of contrastive sounds (phonological units). In doing so, children develop a *phonological system*. Detailed analyses of the consonant productions of children have provided new insights into normal and atypical processes involved in phonological development.¹⁻² Detailed studies of consonant productions by children who use cochlear implants (CIs) should also provide knowledge about their phonological development. One means of studying phonological development involves the use of nonword repetition tasks in which the phonological patterns that the children are asked to repeat are unfamiliar so that the participants cannot rely on previously established lexical knowledge. The present study used a nonword repetition task in which participants were presented with 20 nonword auditory patterns over a loudspeaker and were asked to repeat them aloud to the experimenter.

Nonword repetition is a complex linguistic task. To correctly repeat a nonword stimulus, it is necessary for the child to accurately complete the following subprocesses: (1) perceive a novel sound pattern in auditory-only mode without the aid of speech-reading or context; (2) verbally rehearse and maintain a phonological representation of the novel sound pattern in immediate memory; and finally (3) translate the perceived novel sound pattern into an articulatory program to produce speech. The nonword repetition task used in the present study was originally designed to measure phonological working memory.³ In studies of normal-hearing children, nonword repetition has been found to be strongly correlated with other measures of phonological working memory,⁴ vocabulary development,⁵ sentence comprehension,⁶ and reading ability.⁷

In studies of consonant production, researchers often analyze consonant accuracy in terms of the component features of the consonant segments. One feature is *place of articulation* (the place in the vocal tract where constriction occurs during production of the consonant). The gross places are labial (constriction involves one or both lips), coronal (or alveolar, which involves a mid-oral cavity constriction), and dorsal (or velar, in which the constriction is near the back of the oral cavity). A second feature is *manner of articulation*, which reflects the extent to which air is prevented from freely flowing through the vocal tract. The gross manners used in the present analyses are stop, fricative, nasal, and liquid. A broader manner classification involves the grouping of stops and fricatives as *obstruents* and nasals and liquids as *sonorants*. The third feature is *voicing*, which is based on the timing of the onset of vocal cord vibration during production of the consonant. Consonants can be *voiced* or *voiceless*.

Previous studies indicate that pediatric CI users correctly produce labial consonants more often than consonants with other places of articulation,⁸⁻¹¹ stops more often than fricatives,¹¹ and fricatives more often than liquids.¹¹ In the present study, we calculated accuracy scores for the children's nonword repetitions based on the place, manner, and voicing of the target consonants. We also examined the errors made by the children when they did not produce the correct response consonant. Such detailed error analyses are necessary if the phonological systems of pediatric CI users are to be understood both in relation to those of normal-hearing children as well as independently. Here we describe performance on the nonword repetition task for a group of 76 children. Our research group has already reported the results of a separate study of these children¹² and several preliminary findings on a subset of the present group of children.¹³⁻¹⁶

METHODS

Eighty-eight children participated in the nonword repetition task as part of a larger study by the Central Institute for the Deaf (St Louis, Mo) entitled "Cochlear Implants and Education of the Deaf Child"¹⁷ in 1999 or 2000. Twelve children were excluded from the present analyses because they produced a response to less than 75% of the nonword stimuli. Thus, 76 pediatric CI users were included in the final analyses (36 boys, 40 girls). Seventy-four children used a Nucleus 22 CI and the SPEAK coding strategy (Cochlear Corporation, Englewood, Colo); 1 child used a Nucleus 24 (Cochlear Corporation); and 1 child used a Clarion (Advanced Bionics, Sylmar, Calif). The mean number of active electrodes across the children was 18.4 (range [SD], 8-22 [2.3]).

The children's mean age at onset of deafness was 2.3 months (range [SD], 0-36 [6.4] months). Their mean duration of deafness was 37.2 months (range [SD], 7-65 [13.1] months). The mean age at implantation was 3.3 years (range [SD], 1.9-5.4 [1.0] years). The children had used their implant for a mean of 5.6 years (range [SD], 3.8-7.5 [0.8] years). Their mean chronological age at the time of testing was 8.9 years (range [SD], 7.8-9.9 [0.6]).

Communication mode scores, which are an index of the degree to which oral communication is emphasized in the child's educational environment, were also available for these children.¹⁷ The mean communication mode score was 19.8 of a possible 30 (range [SD], 6-30 [7.7]).

Children with communication mode scores below 15 are considered *total communication* users (ie, both manual and oral communication methods are used in their educational environment). Children with communication mode scores of 15 or higher are considered *oral communication* users (ie, their educational programs emphasize oral communication methods).

The 20 nonwords used in the present study were adapted from the Children's Test of Nonword Repetition^{3,18} (Table 1). The stimuli followed the sound patterns of English and were balanced in terms of number of syllables. These target nonwords contained 112 consonants (Table 2), including most of the consonants of English and a range of place, manner, and voicing features. The nonword stimuli were recorded by a female talker of American English and stored as digital files on a computer.

The present study used a nonword repetition task. Each child was asked to listen to a novel nonsense word and "repeat the silly word" aloud. The nonword stimuli were played over a loudspeaker at approximately 70 dB sound pressure level. Stimuli and responses were recorded onto digital audiotape. All imitations were then independently transcribed by 2 phonetically trained listeners. Disagreements in the independent transcriptions were resolved by consensus (93% agreement). A third phonetically trained listener resolved the remaining (7%) disagreements.

Previous studies of nonword repetition, originally designed for use with 3- to 5-year-old normal-hearing children, have measured performance using a binary scoring procedure in which responses received credit if all segments were phonologically correct and no credit otherwise; normal-hearing children the same age as the pediatric CI users in the present study perform at ceiling on this task.^{3,18} Because the children in the present study produced many segmental errors, the traditional scoring procedure was unable to capture variability among the children and did not provide insight into their performance. Instead, several more detailed scoring methods were applied to each child's nonword response. These methods involved scoring the production of each target consonant in the nonwords for which the child provided responses. Percent correct scores were calculated based on the total number of target consonants in only the nonword stimuli for which the child actually provided a response. Thus, the total number of target consonants used to calculate the percent correct scores differed according to the number of consonants in the targets for which the child actually provided a response. Percent correct scores were calculated using the following 4 methods:

- **Consonant Score:** An imitation segment was scored as correct and given 1 point if the segment was correctly reproduced. For example, for a target /p/, if a child produced a /p/, he/she was given 1 point. The production of any other phoneme received 0 points.
- **Voice Feature Score:** An imitation consonant was scored as correct and given 1 point if the consonant was correct in terms of voicing.
- **Manner Feature Score:** An imitation consonant was scored as correct and given 1 point if the consonant was correct in terms of manner of articulation.

- Place Feature Score: An imitation consonant was scored as correct and given 1 point if the place feature of the consonant was produced correctly in terms of the 3 gross places of articulation (labial, coronal, and dorsal).

In addition, we calculated Pearson correlations between the children's percent correct consonant scores out of all 112 consonants in the 20 target nonwords and the demographic variables described above as well as several separate speech and language outcome measures.

RESULTS

Seventy-six of the 88 participating children provided a response to at least 15 of the 20 target nonword stimuli. The 12 children who provided fewer than 15 responses were excluded from the analyses presented here. In another study,¹² normal-hearing adults were asked to rate the accuracy of the children's nonword repetitions in comparison with the target nonwords. Results indicated that children who produced fewer responses also tended to receive lower mean accuracy ratings. Thus, for the present analyses we divided the children into groups according to the total number of responses that they provided. The children who provided 20 responses comprise the "20-response" (20r) group, the children who provided 19 responses comprise the "19-response" (19r) group, and so on through the "15-response" (15r) group.

The individual children's consonant scores ranged from 1% to 76% correct. Overall, the children produced substitutions (ie, consonants that were not the target consonant) in response to a higher proportion of target consonants than those for which they provided correct reproduction or deletions, and they provided correct reproductions for a higher proportion of target consonants than those that they deleted (Table 3). The subgroups of children (based on the number of responses they provided overall) also tended to follow the overall pattern demonstrated by the whole group of 76 children. However, the children in the 15r group differed from all other groups because they produced more deletions of the target consonants than substitutions or correct responses.

The whole group of children tended to correctly reproduce the coronal place of articulation more often than the labial or dorsal places of articulation (Figure 1). When the children did not reproduce the target coronals with the correct place, they tended to delete them rather than produce them incorrectly. However, when the children did not correctly produce target labials and dorsals, they tended to produce coronals instead.

The children correctly reproduced the manner feature of the target consonants about equally often for target stops (52%), fricatives (54%), nasals (50%), and liquids (46%). When they did not correctly reproduce the manner feature, the children nevertheless tended to produce obstruents in response to target obstruents (ie, stops and fricatives) and sonorants in response to target sonorants (ie, nasals and liquids). The children also tended to delete target sonorants (39%) more often than target obstruents (31%).

The children correctly reproduced the voicing feature for voiceless target consonants (59%) nearly as often as for voiced target consonants (63%), and they also deleted voiceless target consonants (24%) nearly as often as voiced target consonants (26%). Only the 15r group provided the correct voicing less often than they deleted target consonants. Overall, the mean consonant segment scores were highest for the voicing, then place, then manner feature. The children's mean consonant segment scores were higher for imitations of the shorter target nonwords than the longer target nonwords (2-syllable, 38%; 3-syllable, 40%; 4-syllable, 35%; 5-syllable, 32%).

The children's performance was not significantly correlated with age at implantation, duration of CI use, chronological age at the time of testing, or number of active electrodes ($P = .39, .55, .47, \text{ and } .83$, respectively). Age at onset of deafness and duration of deafness were correlated with nonword repetition performance. In addition, the children's communication mode scores were correlated with their nonword repetition performance. Children whose educational programs emphasized oral communication tended to correctly reproduce more target consonants than children in total communication programs. In addition, the children's nonword repetition performance was correlated with independent measures¹⁷ of the speech processing skills that contribute to the ability to repeat a target nonword: speech perception,¹⁹ speech intelligibility,²⁰⁻²¹ language comprehension,²² sentence durations²³ (as a measure of speaking rate, which reflects the rate at which an individual rehearses a phonological representation in phonological working memory as he/she prepares to reproduce it²⁰⁻²¹), and phonological working memory capacity as indexed by forward digit span (Table 4).²⁴⁻²⁵ Finally, the children's nonword repetition performance as measured by their consonant segment scores was strongly correlated with accuracy ratings¹² of the same nonword repetitions. The accuracy ratings were provided by a group of normal-hearing adults who were asked to listen to the target nonword immediately followed by a child's response and to rate how well the child repeated the nonword on a scale of 1 (poor) to 7 (perfectly accurate).

COMMENT

Seventy-six of 88 children provided a response on at least 75% of all trials. Although these children demonstrated a wide range of variability in overall performance, they were not at floor on this task despite the need for complex phonological processing. The responses provided by the children in each of the 6 different response groups (20r-15r) tended to follow similar overall patterns. That is, the groups of children who provided fewer overall responses tended to perform slightly more poorly in terms of number of consonants produced correctly, but the error patterns of all groups tended to be similar (eg, all groups tended to produce coronals in response to dorsal target consonants rather than vice versa). Poorer overall performers tended to provide fewer responses to the 20 nonword stimuli, and they tended to delete more target consonants than the better performers. The results of this study indicate that the wide variability exhibited by the children in terms of nonword repetition performance can be described as a difference between children in terms of the proportion of consonants for which they provided any response (either the correct consonant or a substitute consonant), as opposed to a difference in terms of the types of errors they made (ie, the types of substitutions that they provided when they did not produce the correct response consonant).

In terms of place of articulation, the children produced coronals in response to coronal targets more often than they produced labials in response to labial targets or dorsals in response to dorsal targets. Moreover, when the children produced the incorrect place of articulation for labial or dorsal targets, they tended to produce coronals instead. Thus, the children demonstrated a "coronal preference." This response bias conflicts with previous reports that labial consonants were produced correctly more often than consonants with other places of articulation.⁸⁻¹⁰ These earlier studies differed from the present investigation because they used open-set word recognition tasks in which the stimuli were familiar English words that were presented to the children livevoice by an examiner. It is likely that the children in these previous studies made use of visual cues, especially the lip closure of labial consonants. The present results indicate that future studies of the use of audio-only vs audio-visual stimulus presentation formats could lead to differing results. Thus, presentation format should be considered in future studies of pediatric CI users' speech production performance and explicitly stated in reports of such studies.

In terms of manner of articulation, the children did not perform better in response to target consonants of particular manners of articulation (eg, no advantage was observed for stops over fricatives). The results for the manner feature also conflict with some previous findings.¹¹ Again, the stimuli in the previous study were real words, while the stimuli in the present study were nonwords. Further research with phonologically balanced stimuli (ie, with the manner feature controlled across stimuli) is needed to resolve the conflicting results.

The children demonstrated poorer performance in response to longer (4- and 5-syllable) target nonwords than to shorter (2- and 3-syllable) target nonwords. This finding could reflect the greater processing load placed on phonological working memory by the longer nonwords.²³ This explanation is consistent with our earlier findings that nonword repetition performance was strongly correlated with digit span (an index of phonological working memory capacity²⁵) and negatively correlated with sentence durations. Longer mean sentence duration reflects a slower speaking rate, which is considered to be an index of verbal rehearsal rate in phonological working memory.²³

The correlations found between the children's nonword repetition performance and age at onset of deafness and duration of deafness suggest that a shorter period of deafness prior to implantation is beneficial for postimplantation phonological development. It is possible that the limited range of variability in age at implantation, duration of CI use, and chronological age among the children in the present study attenuated the correlations between these demographic variables and nonword repetition performance.

Children who performed well on the nonword repetition task tended to be oral communication users. This result is consistent with other recent findings showing that total communication users tend to perform more poorly than oral communication users on a wide range of speech outcome measures.¹⁷ Children who imitated consonants correctly also tended to perform well on independent measures of speech perception and production, 2 of the component processes involved in nonword repetition. In addition, our finding that nonword repetition performance was also correlated with independent measures of language comprehension is consistent with previous findings in normal-hearing children⁶ and suggests that future research should explore the contribution of phonological working memory to the development of vocabulary and reading ability in children with CIs.

In summary, the results of this study demonstrate that detailed linguistic analyses of pediatric CI users' nonword repetition performance can provide new insights into the development of their phonological processing systems and the relationships between phonological development, demographics, communication mode, and development of other related skills such as language comprehension. Further investigation of the phonological systems of children who use CIs could provide detailed knowledge about the specific ways in which their phonological development differs from, and ways in which it parallels, the phonological systems of normal-hearing children.

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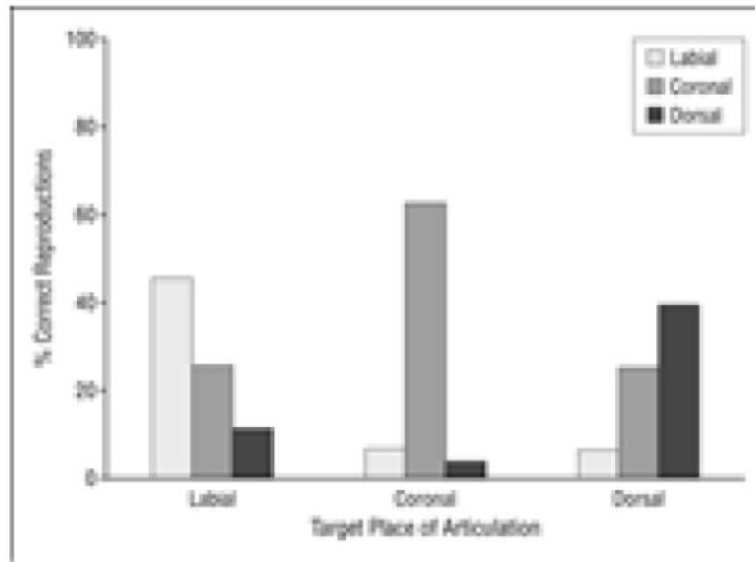
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1.

Table 1

The 20 Nonwords Used in the Present Study*

2 Syllables	3 Syllables	4 Syllables	5 Syllables
ballop	bannifer	comisitate	altupatory
prindle	berrizen	contramponist	detratapilic
rubid	doppolate	emplifervent	pristeractional
sladding	glistering	fenrierizer	versatrationist
tafflist	skiticult	penneriful	voltularity

* Words were adapted from the Children's Test of Nonword Repetition.^{3,18}

Table 2

The 112 Target Consonants in the 20 Nonwords*

		Labial	Coronal	Dorsal	Total
Stop	Voiceless	9/p/	17/t/	6/k/	44
	Voiced	4/b/	5/d/, 2/r/	1/kg/	
Fricative	Voiceless	5/f/	9/s/, 2/ʃ/	}	22
	Voiced	3/v/	2/z/		
Affricate	Voiceless		1/tʃ/		
Nasal	Voiced	3/m/	10/n/	2/ŋ/	15
Liquid	Voiced		14/l/, 17/r/		31
Total		24	79	9	112

* The symbols /r/, ʃ/, /tʃ/ and /ŋ/ are from International Phonetic Alphabet and correspond, respectively, to the consonant sound in the middle of the word "butter", the "sh" sound, the "ch" sound, and the consonant sound at the end of "sing."

Table 3

The Children's Nonword Repetition Scores

Response Group*	% Correct Reproductions	% Deletions	% Substitutions
20r (n = 24)	39	21	40
19r (n = 19)	34	22	44
18r (n = 12)	38	20	42
17r (n = 10)	28	31	41
16r (n = 3)	36	21	43
15r (n = 8)	9	48	43
Mean (n = 76)	33	25	42

*r indicates number of responses provided.

Table 4

Correlations Between Consonant Segment Scores and Several Demographic and Performance Variables

	<i>r</i> Value	<i>P</i> Value
Age at onset of deafness	0.31	<.01
Duration of deafness	-0.24	<.05
Communication mode scores	0.54	<.01
Perception (closed-set word identification; WIPI) ¹⁹	0.77	<.01
Intelligibility (McGarr Sentence Intelligibility Test) ^{20,21}	0.72	<.01
Language comprehension (TACL-R) ²²	0.52	<.01
Mean sentence durations (7-syllable McGarr sentences) ^{20,21}	-0.72	<.01
Working memory: forward digit span (WISC-III) ²⁴	0.53	<.01
Perceptual accuracy ratings ¹²	0.92	<.01

Abbreviations: TACL-R, Test for Auditory Comprehension of Language–Revised; WIPI, Word Intelligibility by Picture Identification; WISC-III, Wechsler Intelligence Scale for Children–Third Edition.