Published in final edited form as:
Ann Otol Rhinol Laryngol Suppl. 2002 May ; 189: 91–96.

IMITATION OF NONWORDS BY DEAF CHILDREN AFTER COCHLEAR IMPLANTATION: PRELIMINARY FINDINGS

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Abstract

Fourteen prelingually deafened pediatric users of the Nucleus-22 cochlear implant were asked to imitate auditorily presented nonwords. The children's utterances were recorded, digitized. and broadly transcribed. The target patterns and the children's imitations were then played back to normal-hearing adult listeners in order to obtain perceptual judgments of repetition accuracy. The results revealed wide variability in the children's ability to repeat the novel sound sequences. Individual differences in the component processes of encoding, memory, and speech production were strongly reflected in the nonward repetition scores. Duration of deafness before implantation also appeared to be a factor associated with imitation perfonnance. Linguistic analyses of the initial consonants in the nonwords revealed that coronal stops were imitated best, followed by the coronal fricative /s/, and then the labial and velar stops. Labial fricatives were poorly imitated. The theoretical significance of the nonword repetition task as it has been used in past studies of working memory and vocabulary development in nonnal-hearing children is discussed.

Keywords

child; cochlear implant; language; nonword; nonword repetition; phonology; speech; word recognition

INTRODUCTION

A primary goal of our current research program is to account more fully for the large individual differences in spoken language development that are typically observed after cochlear implantation in prelingually deafened children.[1] As part of this effort, we have recently begun using a nonword repetition task to study individual variation in how effectively children with cochlear implants (CIs) can use sublexical phonological knowledge about the sound patterns in their ambient language to decode spoken nonsense words.

In a typical non word repetition task, the child is asked to listen to a novel nonsense word and to repeat it back aloud.[2,3] The child is warned in advance that the stimuli will be unfamiliar and is told to approximate the items to the best of his or her ability. Despite its surface simplicity, nonword repetition is a complex information processing task that requires a child to perform reasonably well in each of its component processes. These component processes include auditory and phonological encoding, short-term storage of the target item in working memory, and speech production.

Our use of a nonword repetition task with CI users was motivated in part by an ongoing debate among speech perception researchers regarding the degree to which knowledge of word meaning plays a role in the identification of the individual constituent phonemes that constitute words.[4] This debate has carried over to discussion of how a child with a CI is able to perform a typical open-set speech perception task in which he or she is asked to repeat back spoken words. It has been suggested that a hearing-impaired child will be severely disadvantaged if he or she does not know the meaning of the target word to be repeated.[5] On the basis of some prior informal testing of a few children who are considered "star" CI users, we believe that in situations in which the child has reason to expect an unfamiliar word, the disadvantage may be somewhat overestimated for children with considerable implant experience. The actual linguistic behavior of these children suggests that they possess the ability, like normal-hearing children, to reproduce unfamiliar but "word-like" targets by using their knowledge of the phonological patterns present in their ambient language.

The nonword repetition task has attracted a great deal of interest over the past decade among researchers in language acquisition and developmental psychology because the performance of normal-hearing children on this task has been found to be correlated with individual differences in real-word vocabulary acquisition.[2,3,6] Many studies of special populations known to experience problems with language or other cognitive processing skills have subsequently been carried out with this procedure.[7] As a result of reviewing this research, we became interested in the nature of the nonword repetition task and its relationship to spoken language development.

The present study was designed to answer the following questions. First, how much variability is observed on the nonword repetition task in this clinical population? Second, are individual differences among children in each of the component processes of speech perception, working memory, and speech production reflected in nonword repetition performance? Finally, what specific phonological changes or distortions are evident in the imitation responses, and how are these errors distributed among the children?

METHODS

Participants

The 14 children who participated in this research were recruited as part of a larger study carried out at Central Institute for the Deaf in St Louis, Missouri.[8] All of the participants were 8 or 9 years of age. Eleven of the children were reported to be congenitally deaf. The remaining 3 became deaf before 2 years of age. The average duration of deafness before implantation was approximately 3 years (range, I year 6 months to 5 years 3 months). All of the children had used their implants for at least 3.5 years before the present testing (mean use, 5 years 6 months). Both oral and total communication children were represented in the group. All of the children used the Nucleus-22 device and the spectral peak (SPEAK) coding strategy.

Stimulus Materials and Procedure

The children were tested with a subset of 20 nonwords selected from the 40-item Children's Test of Nonword Repetition (CNRep).[9] The CNRep was originally developed to measure individual differences in phonological working memory in young children with normal hearing. All items on the CNRep are phonotactically legal sequences in English. Although there are some disadvantages to using this particular test, it was used in the present study because of the existence of a large body of previously published data obtained with these stimulus materials.

The subset of 20 nonwords was chosen by eliminating the 20 items that showed the least amount of variance in scores obtained previously in our laboratory from 5-year-old children with normal hearing.[10] We also eliminated some nonwords that were essentially common real words attached in an unfamiliar manner to a standard affix. Five nonwords remained at each of 4 word lengths: 2, 3, 4, and 5 syllables. Because the existing recordings of the CNRep were spoken in British English, the 20 target stimuli for the present study were re-recorded in the voice of a female adult speaker of American English.[10]

To elicit the children's imitations, we played each target item via a high-quality loudspeaker at approximately 70 dB sound pressure level. In a few cases, the level was increased at the child's request. The child was asked to "repeat each silly, made-up word" back to the examiner. A head-mounted microphone was used to record all responses onto digital audiotape. These audio recordings were later segmented with a digital waveform editor into individual sound files for use in the perceptual study.

Although 43 children were initially tested with this task, only 14 children provided responses to all 20 tokens. This outcome should not be interpreted to mean that most of the children were unable to carry out the task. In actuality, 88% of all children tested produced a response to 15 or more of the 20 nonwords. Missing tokens usually resulted from the child's failing to respond on a given trial. In a few cases, tokens were eliminated from the final data analysis because of problems with the recording procedure. This subselection of participants did, however, cause the remaining sample of children to contain a somewhat greater proportion of better-performing children than existed in the overall group of 43. Even so, as will be shown below, the children in the smaller group varied quite widely on many of the measures reported.

In the past, nonword repetition performance has usually been quantified with a binary scoring procedure crediting the child either I point or no points for each target item.[2,3] Any error, even of only a single segment (phoneme), usually resulted in no credit, although some provisions were made for predictable patterns of immature articulation in very young children.[2,3] This scoring procedure was not suitable for use in the present study because the children with CIs frequently made multiple segmental errors. Moreover, because we were specifically interested in examining the nature of the children's errors, a more sensitive measure of nonword repetition accuracy was needed.

In the present article, we report results of two different assessment methods: one based on a behavioral perceptual measure, and the other derived from a partial linguistic analysis of the children's productions. For the perceptual measure, we used ratings of repetition accuracy gathered from 10 monolingual English-speaking adult listeners with normal hearing who reported minimal to no experience with the speech of deaf or hearing-impaired persons. The perceptual ratings were obtained in the following manner. On each of 280 randomized trials, the listener heard a target nonword stimulus, followed after 1 second of silence by a child's imitation response. The listener then rated the child's imitation response on a 7-point scale with end point labels of 0 ("totally fails to resemble the 'target' utterance") and 6 ("perfectly accurate rendering of the 'target' utterance, ignoring differences in pitch").

A partial linguistic assessment of the children's imitations was also carried out. In the present article, we report results based only on our analyses of the accuracy of the initial consonant and the number of syllables produced in each imitation response. In order to complete these analyses, every imitation was listened to and transcribed by the second author. All imitations were also transcribed by the first author. There was 92% agreement on the transcription of the initial consonants and 85% agreement on number of syllables produced. When in conflict, the second author's transcriptions were used.

Because 3 target items began with an initial vowel or liquid, the analysis of the initial consonants involved only the 17 target nonwords with initial obstruents. These 17 nonwords included the following initial target consonants: /p/ in 3 instances, /b/ in 3 instances, /t/ in 1 instance, /d/ in 2 instances, /k/ in 2 instances, /g/ in 1 instance, /f/ in 1 instance, /v/ in 2 instances, and /s/ in 2 instances. This set therefore included 2 different *manners* of articulation (stop and fricative), consonants from each of the 3 gross *places* of articulation (labial, coronal, and dorsal), and both voiced and voiceless consonants.

Each imitation response was scored in 4 different ways on the basis of its initial consonant. The first method was a *segment-based* accuracy score. An imitation was counted as correct and given 1 point if the initial consonant was correctly reproduced. No partial credit was assigned for any incorrect productions. Each of the 3 remaining scoring methods reflected the accuracy of a specific phonological feature of the initial consonant: the *place* feature (labial, coronal, dorsal), the *manner* feature (stop, fricative), or the *voicing* feature (voiced, voiceless). In these score assignments, 1 point was given to a child's response if it was a correct imitation simply in terms of the feature in question. For example, in scoring *place* of articulation, if the target segment was a labial such as /p/, then a point was given for any imitation that began with a labial sound (ie, any response beginning with a /p/, /b/, /f/, /v/, or nonphonemic labial sound was scored as correct).

In one final analysis, each imitation response was also scored for the number of syllables produced. For this analysis, responses to all 20 of the target non words were examined and scored.

RESULTS

Perceptual Results

To answer our first question regarding how much variability among children we would observe on the nonword repetition task, we examined the group distribution of the perceptual ratings averaged across all items and listeners. As illustrated in the Figure, the group was not at floor on this task, and most of the children were able to produce approximate imitations of at least some of the target nonwords. The mean score of all 14 children was 2.26 on the rating scale of 0 to 6 (SD, 0.93 units). Although this sample of 14 children did contain a larger proportion of better-performing CI users than was present in the larger sample of 43 children, these results suggest that some pediatric CI users are able, like young children with normal hearing, to partially imitate unfamiliar sound sequences for which they have no lexical representation.

The inter-rater reliability across our 10 naive listeners was very high ($\alpha > .90$). Every listener's average perceptual rating (across the 20 items) for individual children was correlated with an r value of .89 or higher with every other rater's average rating for those same children (mean correlation, .94). These values indicate that our naive listeners were strongly in agreement regarding the performance of individual children on this task.

In order to answer our second question, whether individual differences in the children's speech perception, working memory, and speech production skills would be reflected in their success at the nonword repetition task, we calculated a series of simple correlations between the nonword repetition scores and supplementary speech, language, and memory data gathered for another project by clinicians at Central Institute for the Deaf within a few days of the nonword repetition recordings.[8] These supplementary measures are briefly summarized in Table 1.[5,11-14] Nonword repetition perfonnance was quantified in these calculations as either the mean perceptual rating assigned to each child's productions averaged over items and listeners (Table 1, at left) or the transcription-based initial-consonant accuracy score for each child averaged over items (Table 1, at right).

The simple bivariate correlations shown in Table 1 indicate that both measures of nonword repetition perfonnance, mean perceptual rating and initial consonant accuracy, were strongly positively correlated with measures of word recognition, receptive language comprehension, auditory digit span, and speech intelligibility in meaningful sentences. In addition, we found that children who tended to speak more slowly when encouraged to produce their "best" spoken language tended to do less well on the nonword repetition task.

Because we were concerned about the possible influence of intervening variables on the size of the above relationships, we also calculated the simple correlations between a number of demographic variables and the nonword repetition scores. These are shown in Table 2. In general, the only relationship of note was a sizable negative correlation with duration of deafness, indicating that children who had been deaf for a longer period of time before implantation tended to do more poorly on the nonword repetition task. Moderate but nonsignificant positive correlations were also obtained between nonword repetition perfonnance and age at onset of deafness (although there was very little variability in this demographic variable within the sample). We therefore recalculated the correlations between nonword repetition perfonnance and word recognition, receptive language comprehension, auditory digit span, speech intelligibility, and sentence duration with the co-varying demographic factors of age at onset of deafness and duration of deafness statistically partialled out. As shown in Table 1, partialling out these demographic variables, however, had very little effect on the size of the observed correlations.

Although not shown in Table 1, we also examined whether the correlations between nonword repetition perfonnance and each of the three component processes (ie, speech perception, working memory, and speech production) would shrink in size if representative measures of the other two processing components were statistically partialled out. In these analyses, we found that the correlations between nonword repetition perfonnance and working memory were the least affected by the partialling out of representative outcome measures from the other two processing components. That is, the correlations between nonword repetition perfonnance and digit span remained strong even when individual differences in word identification and speech intelligibility were statistically partialled out. This result suggests that the component process of working memory contributes more unique variance to the observed individual differences in nonword repetition scores than do the speech perception and speech production components of the task. This latter finding should be viewed as preliminary in nature, given our very small sample size at the present time, but the general pattern is consistent with results obtained in previous studies with nonnally developing children.[2]

Linguistic Analyses—The children's imitations were next examined for generalizable patterns of phonological changes or distortions. The first linguistic analysis focused on the nature of these errors and how the errors were distributed among the children. The overall accuracy of the initial consonant averaged across children was 39%. The children's scores were quite variable, ranging from 0% to 76% correct. The *voicing* feature of the initial consonant was correctly imitated in an average of 67% of the nonword productions, with individual subject scores ranging between 29% and 88%. The *manner* feature of the initial consonant was accurately imitated in an average of 64% of the nonword repetitions, with scores ranging from 35% to 76%. Only 4 subjects scored at or below 60% on this measure. On average, the children correctly imitated place in 59% of the nonwords; the scores ranged from 35% to 88%, with a relatively flat distribution between these extremes. To summarize, voicing was imitated correctly most often, followed by manner, and then by place of articulation. The distributions of manner and voicing scores across the 14 children were more skewed in favor of correct imitation than was the distribution of place scores.

Reanalyzing these results in tenns of the initial consonant of the target nonwords, we found that overall, stops were imitated correctly more often than fricatives. However, the 3 most accurately imitated wordinitial segments were /t, d, s/, a set composed of 2 coronal stops and a coronal fricative. The next 4 most accurately imitated word-initial segments were the noncoronal stops /p, b, k, g/, which were followed by the noncoronal fricatives /f, v/. This distribution indicates that targets that were coronal in terms of place were easier for the children to produce than targets that were labials or velars, regardless of manner. That is, *coronal fricatives* were produced, on average, more accurately than *labial and dorsal stops*. This particular finding is not consistent with previous reports in the literature suggesting that stops are more often correctly produced than fricatives or that labials are generally more often correctly produced than other consonants.[15] The differences observed in this study may be a result of the inability of our participants to rely on visual cues to labial articulation because all of the nonwords were presented in an auditory-only format. Earlier reports that show better production of labial consonants may not reflect pediatric CI users' accurate *auditory* perception of labial sounds per se, but may instead reflect the availability of visual cues when audiovisual presentation methods are used in testing.[16]

Examination of the syllable production scores showed that overall, the children produced the correct number of syllables in 66% of the imitations. The individual subject scores ranged from 30% to 95% of responses produced with the correct number of syllables. When the imitations did not have the correct number of syllables, the children tended to produce fewer syllables than were in the target nonword. Although the results for 1 particular test item inflated the error rate for 2-syllable nonwords, the children's imitation of the number of syllables in each target tended to be correct more often for nonwords with fewer syllables. Specifically, 76% of the 3-syllable targets, 74% of the 2-syllable targets, 66% of the 4-syllable targets, and 49% of the 5-syllable targets were imitated with the correct number of syllables. The perceptual ratings of the nonword responses mirrored this syllable length effect. We found a reliable negative correlation between the length of the intended target pattern and the perceptual rating for that nonword averaged across children ($r = -.62$; $P < .01$). Finally, the perceptual ratings were also correlated with the syllable production scores ($r = .67$; $P < .01$) — a finding suggesting that listeners gave higher ratings to non word imitations that preserved the correct number of syllables.

DISCUSSION

The present results indicate that these experienced pediatric CI users are able to use their existing linguistic knowledge to decode novel sound sequences. Within the sample studied, individual differences in the component processes of encoding, working memory, and speech production were strongly reflected in nonword repetition scores, regardless of whether these scores were derived from a behaviorally based perceptual ratings measure using naive listeners or from a more formal transcription-based linguistic analysis of their responses.

We are currently trying to identify the factors that naive listeners weight most heavily when asked to rate the accuracy of children's nonword imitations. As evident in the above results, preserving the same number of syllables as present in the target stimulus is one key factor — a condition usually fulfilled by the speech productions of the children in this study. Detrimental to perceived accuracy are feature-based segmental errors such as those described for the children's initial consonants. In producing initial consonants, the pediatric CI users were less consistent in maintaining the 3-way place contrast than the 2-way manner and voicing contrasts. Our linguistic analysis suggests that in the future it may be better to use a more phonologically balanced set of nonword stimuli in order to investigate the favored production of coronal consonants over other places of articulation and the impact of the absence of visual cues on the perception of labial consonants.

In summary, the results of this imitation study using the nonword repetition task demonstrate that some children with CIs are, like normal-hearing children, able to use their knowledge about the phonological patterns present in their ambient language to reproduce novel sound patterns. These children show evidence of being able to "decompose" nonsense words into familiar parts (ie, phonemes, phonetic segments), and rapidly "reassemble" or

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“translate” these elements into recognizable motor outputs despite the absence of learned lexical representations. This work is still preliminary and will require larger sample sizes before more specific claims can be made. However, in light of these initial results, we suggest that it may be worthwhile to further investigate whether individual differences in the phonological processing skills assessed by nonword repetition can serve to predict, in part, real-word spoken vocabulary acquisition and language development in hearing-impaired children with CIs.

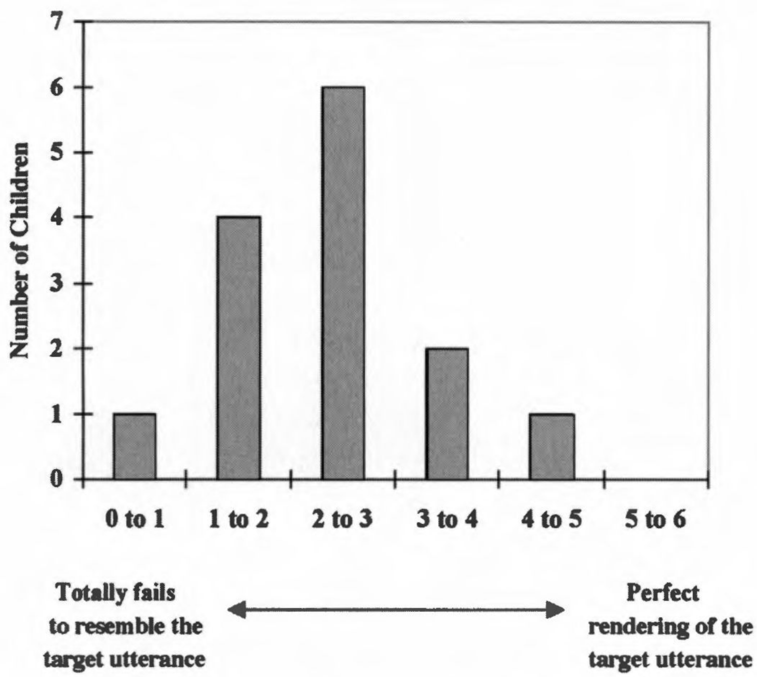
Acknowledgments

We acknowledge the kind cooperation of Dr Ann Geers of Central Institute for the Deaf in this project, and the technical assistance of R. Uchanski and C. Brenner. We also thank Dr Emily Tobey and her colleagues from the Callier Advanced Hearing Research Center at the University of Texas, Dallas, for making available the McGarr Intelligibility test scores and McGarr sentence durations for the children discussed in this paper.

REFERENCES

1. Pisoni DB, Cleary M, Geers A, Tobey E. Individual differences in effectiveness of cochlear implants in children who are prelingually deaf: new process measures of perronnance. Volta Rev. 2000; 101:111–64. [PubMed: 21666760]
2. Gathercole, SE.; Baddeley, AD. Working memory and language. Lawrence ErlbaumAssociates; Hillsdale, NJ: 1993.
3. Gathercole SE, Service E, Hitch GJ, Adams AM, Martin AJ. Phonological short-term memory and vocabulary development: further evidence on the nature of the relationship. Appl Cogn Psychol. 1999; 13:65–77.
4. Samuel AG. Knowing a word affects the fundamental perception of the sounds within it. Psychol Sci. 2001; 12:348–51. [PubMed: 11476105]
5. Kirk KI, Pisoni DB, Osberger MJ. Lexical effects on spoken word recognition by pediatric cochlear implant users. Ear Hear. 1995; 16:470–81. [PubMed: 8654902]
6. Avons SE, Wragg CA, Cupples L, Lovegrove WJ. Measures of phonological short-term memory and their relationship to vocabulary development. Appl Psycholinguistics. 1998; 19:583–601.
7. Edwards J, Lahey M. Nonword repetitions of children with specific language impainnent: exploration of some explanations for their inaccuracies. Appl Psycholinguistics. 1998; 19:279–309.
8. Geers, AE.; Nicholas, J.; Tye-Murray, N., et al. Central Institute for the Deaf research periodic progress report No. 35. Central Institute for the Deaf; St Louis, Mo: 1999. Center for Childhood Deafness and Adult Aural Rehabilitation. Current research projects: Cochlear implants and education of the deaf child. second-year results; p. 5-20.
9. Gathereole, SE.; Baddeley, AD. The Children’s Test of Nonword Repetition. Psychological Corporation; London, England: 1996.
10. Carlson, J.; Cleary, M.; Pisoni, DB. Research on spoken language processing: progress report 22. Speech Research Laboratory Indiana University; Bloomington, Ind: 1998. Performance of normalhearing children on a new working memory span task; p. 251-75.
11. Ross M, Lerman J. A picture identification test for hearing-impaired children. J Speech Hear Res. 1970; 13:44–53. [PubMed: 4192711]
12. Carrow-Woolfolk, E. Test for Auditory Comprehension of Language–Revised (TACL-R). Pro-Ed; Austin, Tex: 1985.
13. Wechsler, D. Wechsler Intelligence Scale for Children–III. The Psychological Corporation; San Antonio, Tex: 1991.
14. McGarr NS. The intelligibility of deaf speech to experienced and inexperienced listeners. J Speech Hear Res. 1983; 26:451–8. [PubMed: 6645470]
15. Tobey E, Geers A, Brenner C. Speech production results: speech feature acquisition. Volta Rev. 1994; 96:109–29.

16. Dillon, CM.; Cleary, M. Research on spoken language processing: progress report 24. Speech Research laboratory Indiana University; Bloomington, Ind: 2001. Using non word repetition to study speech production skills in hearing-impaired children with cochlear implants; p. 113-47.



1. .

Frequency histogram illustrates distribution of perceptual non word repetition accuracy ratings averaged across items and listeners.

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TABLE 1

CORRELATIONS BETWEEN NONWORD REPETITION AND SPEECH-LANGUAGE MEASURES (N = 14)

	Perceptual Rating (Whole Item)		Initial Consonant Accuracy	
	Simple Bivariate	Partial	Simple Bivariate	Partial
	r	r*	r	r*
Encoding or perception				
Word identification, closed set, pointing response				
Word Intelligibility by Picture Identification (WIPI) [11] (group mean± SD, 69.1% ± 12.4%)	.69**	.75**	.44	.42
Word identification, open set, spoken repetition				
Lexical Neighborhood Test, Easy Words (LNTe)[5] (group mean± SD, 68.6% ± 14.0%)	.69**	.61*	.63*	.59*
Comprehension				
Test of Auditory Comprehension of Language- Revised† (TACL-R)[12] (group mean± SD, 7.28 ± 1.29 y)	.60*	.49	.65*	.58*
Memory				
Phonological working memory, spoken repetition				
Wechsler Intelligence Scale for Children, Auditory Digit Span Subtest, Forward Recall of Digit-Name Lists[13] (group mean± SD, 5.7 ± 1.9 points)	.76**	.73**	.73**	.69*
Production				
Speech intelligibility				
McGarr Sentences Intelligibility[14] (group mean± SD, 79.6% ± 16.8%)	.70**	.83**	.68**	.76**
Articulated sentence duration				
McGarr Average Duration of 7 -Syllable Sentences [14] (group mean± SD, 2.88 ± 0.86 s)	−.70**	−.56	−.64*	−.53

Correlation between perceptual rating and initial consonant accuracy, r = .86. "Part ial r" means age at onset and duration of deafness are partialled out.

*p < .05.

**p < .01.

†Administered via total communication, age-equivalent score.

TABLE 2

CORRELATIONS BETWEEN NONWORD REPETITION PERFORMANCE AND DEMOGRAPHIC VARIABLES (N = 14)

	Perceptual Rating (r)	Initial Consonant Accuracy (r)
Age at test	−.14	.05
Age at onset of deafness	.50	.39
Duration of deafness	−.58*	−.41
Duration of cochlear implant use	.31	.91
Degree of exposure to oral-only communication environments	.11	.09
No. of active electrodes	−.02	−.07

*p < .05.