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**Nonword Repetition and Reading in Deaf Children with Cochlear Implants<sup>1</sup>**

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## Nonword Repetition and Reading in Deaf Children with Cochlear Implants

**Abstract.** In the present study, we report analyses of nonword repetition responses from 76 experienced pediatric cochlear implant (CI) users. Immediate repetition of a spoken nonword stimulus requires a child to correctly perceive a novel sound pattern, maintain a representation and rehearse it in phonological working memory, and then reproduce a phonological pattern as an output response. Nonword repetition performance by normal-hearing participants has been shown to be affected by the structure of the language. Systematic effects of the structure of the ambient language on nonword repetition performance reflect the participants' reliance on their phonological knowledge, which developed based on their experience with the language. The acquisition of reading and literacy skills in normal-hearing children has also been found to be dependent on the development of phonological knowledge and the use of phonological processing skills. In the present study conducted with deaf children who use CIs, we report findings showing that nonword repetition performance is strongly correlated with several measures of phonological awareness and reading comprehension, and is related to lexical diversity. These new findings provide additional converging evidence for the proposal that the development of phonology is an important prerequisite for the acquisition of reading and literacy skills in this clinical population. The children's ability to provide nonword repetition responses, as well as correlations obtained between their performance on this task and several measures of reading indicate that they relied on phonological knowledge to complete both the nonword repetition and reading tasks. The ability to encode, decompose, and reassemble sound patterns of speech appears to be a fundamental prerequisite for both speech perception and reading.

### Introduction

Studies of children in pre-reading and early reading stages often discuss "reading readiness" skills (Adams, 1990). Reading readiness skills reflect phonological awareness, the extent to which the child is consciously aware that individual words have an internal structure that is composed of sequences of speech sounds (such as phonemes), which can be represented orthographically with graphemes (Rayner & Pollatsek, 1995). Phonological awareness is typically measured by the child's performance on behavioral tasks in which he/she is required to demonstrate implicit or explicit awareness of the existence of phonological structure. For example, in some procedures the child is asked to recognize whether words rhyme, or whether they start or end with the same sound or are minimal pairs. A child's conscious awareness of the existence of phonological structure (e.g., phonemes), indexed by these phonological awareness or reading readiness tasks, is a necessary prerequisite for him/her to develop the ability to map orthographic representations of speech (graphemes) onto phonemes. The ability to easily and rapidly complete grapheme-to-phoneme conversion is related to reading ability in young normal hearing children (Adams, 1990; Marschark, 2003; Rayner & Pollatsek, 1995). When learning to read, children who have developed phonological representations of the sounds of their ambient language can take greater advantage of such processes as "inner speech" (Conrad, 1979) and verbal rehearsal processes in working memory (Baddeley & Gathercole, 1992).

Phonological awareness is one set of cognitive operations involved in phonological processing of speech, along with retrieval of phonologically coded information from the lexicon, and encoding of sound patterns in phonological working memory (Troia, 2004; Wagner & Torgeson, 1987). Phonological processing abilities and reading and literacy development have been found to be interdependent, with development in each causing further development in the other (see Brady, 1997; Troia, 2004). For

example, Bradley and Bryant (1983) found that training children using phoneme awareness tasks led to better phonemic awareness and improved reading skills several years later in comparison to children in control groups. On the other hand, development of reading and spelling skills can also lead to increased phonological awareness (see, e.g., Cassar & Treiman, 2004).

The relationship between hearing status and reading skills has been a topic of interest for centuries (e.g., Dalgarno, 1680). In the more recent past, research on speech and reading has been guided at least in part by the development of theories and the completion of empirical studies in areas such as reading, visual word recognition, speech perception, spoken word recognition, and phonological working memory. Studies of the reading skills of deaf children and adults in the past 50 years have consistently shown that deaf children's reading readiness and reading skills are significantly delayed relative to their normal-hearing peers, and often do not exceed a 4th-grade level (Paul, 2003). Phonological knowledge and phonological processing skills in visual word recognition tasks and reading have also been shown to be utilized to some extent by deaf readers (Hanson, 1991).

The reading and literacy skills of deaf children with cochlear implants have been studied recently by several researchers. Spencer, Tomblin, and Gantz (1997) reported that a group of 2- to 13-year-old children with cochlear implants completed a reading comprehension task with greater accuracy than deaf children without cochlear implants. Although over one-fourth of the children with cochlear implants achieved reading levels that were 30 or more months below their grade levels, almost one-fourth of the children with cochlear implants achieved reading levels at or above their grade levels. Spencer et al. concluded that the auditory information about speech provided by a cochlear implant may facilitate a deaf child's ability to decode or recode orthographic representations of speech into a "speech code" (see Conrad, 1979).

Further support for Spencer et al.'s (1997) conclusions was provided by Geers (2003), who reported the results of a study that included all of the children who participated in the Central Institute for the Deaf (CID) Education of the Deaf Child program (N=181, including the 76 children described in the present study). The children in this study were all 8 and 9 years old and had received their cochlear implant before the age of 5. Geers found that the children averaged mid to high 2nd grade reading levels on the PIAT Recognition and PIAT Comprehension measures. They used the children's scores on these two measures to calculate total reading scores for each child, for which standard scores are available. The standard scores were based on the expected grade level of the children based on their chronological age. The total reading standard scores revealed that 52% of the children scored within the average range of children their age, and 48% were below average. On the rhyming task, children performed relatively well. The results suggested that the children were using both phonological and visual cues to complete this task. Incorrect responses were provided most often for word pairs that rhymed but were orthographically dissimilar.

In the present study on nonword repetition, we were interested in the extent to which the children's performance on traditional reading readiness, single-word reading, and reading comprehension measures was related to their performance on an auditory-only task that measures their sublexical phonological abilities to perceive, rapidly encode, rehearse, and then reassemble a novel sound pattern for speech production. Nonword repetition has been shown to be strongly correlated with the development of reading skills in normal-hearing children with and without phonological disorders (see Brady, 1997). Although simple on the surface, nonword repetition is a complex information processing task that loads heavily on phonological processing skills and verbal rehearsal processes (Pisoni, this volume). In order to accurately reproduce a nonword auditory pattern, it is necessary for a child to accurately complete the following subprocesses:

- Perceive and encode a novel sound pattern in an auditory-only mode without the aid of speech-reading or other context or content
- Store and verbally rehearse the novel sound pattern in immediate memory
- Reassemble and translate the perceived novel sound pattern into a sensory-motor articulatory program to produce speech output

We report analyses of a subset of the children in Geers' (2003) study, who also completed a nonword repetition task. If nonword repetition skills are highly correlated with reading skills as the literature on normal-hearing children would suggest, we would predict that better phonological processing skills would be related to better reading skills in deaf children with CIs.

## Method

### Participants

Eighty-eight children who participated in the CID Education and the Deaf Child program in 1999 or 2000 (see Geers & Brenner, 2003) participated in the both the nonword repetition task and the reading tasks described below. Twelve children were excluded from the analysis because they provided responses to less than 75% of the target nonwords. The remaining 76 children were included in the present study. Thirty-six were male and 40 were female. Seventy-four children used a Nucleus 22 CI and the SPEAK coding strategy. One child used a Nucleus 24 CI and one child used a Clarion CI.

Table 1 provides a summary of the demographic characteristics of the children. Their mean chronological age at the time of testing was 8.9 years (range 7.8-9.9,  $SD = 0.6$ ), as shown in Table 1. Sixty-four of the children were congenitally deaf, six became deaf before the age of one year, and the remaining six became deaf by the age of 3 years. The children's mean duration of deafness was 37.2 months (range 7-65,  $SD = 13.1$ ). The children's mean age at time of implantation was 3.3 years (range 1.9-5.4,  $SD = 1.0$ ). The children had used their implant for a mean of 5.6 years at the time of testing (range 3.8-7.5,  $SD = 0.8$ ). The children's mean communication mode scores were based on a parent questionnaire. Children with Communication Mode scores of 15 or higher were considered Oral Communication (OC) users (i.e., their educational programs emphasized oral communication methods). Children with communication mode scores below 15 were considered Total Communication (TC) users (i.e., both manual and oral communication methods were used in their educational environment; see Geers & Brenner, 2003).

Demographic Variable	Mean (SD)	Range
Age at Onset of Deafness (months)	2.3 (6.4)	0-36
Duration of Deafness (months)	37.2 (13.1)	7-65
Age at Implantation (years)	3.3 (1.0)	1.9-5.4
Duration of Implant Use (years)	5.6 (0.8)	3.8-7.5
Chronological Age (years)	8.9 (0.6)	7.8-9.9
Number of Active Electrodes	18.4 (2.3)	8-22
Communication Mode Score	19.8 (7.7)	6-30

**Table 1.** Summary of the demographic make-up of the 76 children.

## Nonword Repetition Task

**Stimulus Materials and Procedure.** The 20 target nonwords used in the present study were a subset of the nonwords in the Children’s Test of Nonword Repetition (Gathercole, Willis, Baddeley, & Emslie, 1994; see also Carlson, Cleary, & Pisoni, 1998). The nonwords, shown in Table 2, were balanced in terms of syllable number and included 112 target consonants and 68 target vowels. Each child was asked to listen to the novel nonwords, presented one at a time, and attempt to repeat the nonword aloud. The children heard digital recordings of a female native speaker of American English played over a loudspeaker at approximately 70 dB SPL. The stimuli and responses were recorded onto digital audio tape for later analysis.

Number of Syllables			
2	3	4	5
ballop	bannifer	comisitate	altupatory
prindle	berrizen	contramponist	detratopillic
rubid	doppolate	emplifervent	pristeractional
sladding	glistering	fennerizer	versatrationist
tafflist	skiticult	penneriful	voltularity

**Table 2.** The 20 nonwords used in the present study (adapted from Gathercole et al., 1994; see also Carlson et al., 1998).

**Nonword Transcriptions.** All of the nonword repetition responses were independently transcribed by two phonetically trained listeners. Disagreements were resolved by consensus (93% agreement). A third listener resolved the remaining 7% disagreements. These phonemic transcriptions were then used to calculate two “suprasegmental scores” for a subset of the children (N = 24), who provided responses to all 20 target nonwords: (1) percent of imitations with the correct number of syllables, and (2) percent of imitations with correct primary stress placement. The phonemic transcriptions were also used to calculate “segmental scores” for all 76 children: (1) percent consonants correct, based on the number of consonants reproduced with correct place (labial, coronal, dorsal), manner (stop, fricative, liquid, nasal), and voicing (voiced or voiceless), both out of the total number of target consonants (N = 112), and out of the total number of target consonants in the nonwords for which the child provided a response; and (2) percent vowels correct, based on the number of vowels reproduced with correct height (high, mid, or low) and backness (front, central, or back), both out of the total number of target vowels in the target nonwords (N = 68), and out of the total number of target vowels in the nonwords for which the child provided a response. In addition to these scores, the children’s nonword responses were played back to naïve listeners to obtain perceptual goodness ratings.

**Scores Based on Perceptual Accuracy Ratings.** The target nonword patterns and the child’s attempted nonword repetitions were played back to groups of normal-hearing college-age adult listeners who were asked to make similarity judgments. On each trial, the listener heard the target nonword followed by a child’s attempt to repeat that target nonword. Listeners were asked to provide goodness ratings of the child’s response on a scale of 1 (poor) to 7 (perfectly accurate), which were used to calculate a mean rating score per child.

## Reading Outcome Measures

**Stimulus Materials and Procedures.** Three measures of reading were also obtained from these children. The Word Attack subtest of the Woodcock Reading Mastery Tests - Revised (WRMT; Woodcock, 1987) was administered to all of the children. The Word Attack subtest is a nonword reading task that includes 45 nonwords or extremely rare real words. Each child was asked to read aloud the nonwords one at a time. The child cannot complete this task by relying on visual recognition or reading skills because the stimuli are unfamiliar nonwords. Instead, the Word Attack subtest measures the child's "ability to apply phonic and structural analysis skills to pronouncing words that are not recognizable by sight" (Woodcock, 1987: 6).

The children also completed the two subtests of the Peabody Individual Achievement Test-Revised (PIAT; Dunn & Markwardt, 1989). The Reading Recognition subtest of the PIAT includes 100 items. The first 16 items consist of four-alternative forced choice questions requiring a pointing response. This measure was designed to test "reading readiness" skills, which are assumed to be essential prerequisites for a child learning to read (Markwardt, 1998). Several types of items are included in the reading readiness part of the PIAT Reading Recognition subtest. For example, the child is shown a letter or word such as "B," "GO," or "to" and is asked to point to one like it from among four choices; or, the child is asked to name the object shown in four pictures and then choose the picture of an object whose name does not start with the same sound as the other three objects, such as "ball" from among pictures of a ball, pencil, pan and pie. Several other items require the child to choose an item that begins with the same sound as a stimulus picture, from among four pictures or four written words. Items 17-100 all involve single real-word reading. The questions are ordered in terms of increasing difficulty, ranging from kindergarten level to 12th-grade level. In the Reading Recognition subtest, the child earns one point for every correct answer to items 1 through 16, and for every correct pronunciation of items 17-100, with each pronunciation counted as either correct or incorrect after one attempted pronunciation.

The Reading Comprehension subtest of the PIAT was also given to all of the children. This reading measure includes 82 four-alternative forced-choice items that require a pointing response. The test items are meaningful narrative sentences designed to test literal reading comprehension (as opposed to interpretation of information or recognition of inferences; Markwardt, 1998). For each item, the child is shown a sentence and is told to read it to him/herself only once. Then the child is shown a page with four pictures and is asked to point to the picture that best represents the meaning of the sentence. As in the Reading Recognition subtest, the items in the Reading Comprehension subtest are ordered in terms of increasing difficulty over a wide range, e.g., *There is the sun.*, *The eagle floats on its wings as it travels in search of a feast.*, and *The residence has been essentially reduced to rubble, the remainder being only the foundation.* The child is given one point for each correct response.

Finally, the children also participated in a Rhyming Task (Geers, 2003) in which, on each trial, they were presented with two words and asked to state whether or not the two words rhymed. The two words in each pair either rhymed or did not rhyme, and were either orthographically similar or dissimilar. The word pairs were counterbalanced in terms of these two characteristics. All of the reading tasks described above are referred to as "reading outcome measures" in the present report.

**Scores.** Grade Equivalent Scores were determined for the Word Attack (Woodcock, 1998), the Reading Recognition, and Reading Comprehension tasks (Markwardt, 1998). A Total Reading standard score was also calculated for each child. The child's raw scores on the two PIAT reading subtests were summed and converted to a standard score using the child's expected grade levels based on his/her age, because grade levels were not available for all children (Markwardt, 1998). Forty-one children were

considered 3rd-graders and 35 children were considered 4th-graders. The Rhyming task was scored for “rhyme errors,” the percentage of word pairs for which the child responded incorrectly (Geers, 2003).

### Lexical Diversity

Recent findings have revealed that nonword repetition performance is related to vocabulary size in normal-hearing adults, typically-developing children, and children with phonological disorders (Edwards, Beckman, & Munson, 2004; Munson, Edwards, & Beckman, in press). A direct measure of vocabulary size was not available for the deaf children with cochlear implants in the present study. However, the children had participated in a conversational oral interview as part of the larger CID study (Geers, Nicholas, & Sedey, 2003). The number of different words used by each child during the interview was calculated, and considered to be a measure of “lexical diversity,” which is likely to reflect overall vocabulary knowledge. In the present study, we used this measure to investigate the relationship between lexical diversity, nonword repetition performance, and reading skills.

## Results

### Nonword Repetition Task

All of the children described in the present study provided a response to at least 15 of the 20 original nonword stimuli. More detailed summaries of the nonword repetition task results are reported in earlier studies by Carter, Dillon, and Pisoni (2002), Dillon, Cleary, Pisoni, and Carter (2004), Dillon, Pisoni, Cleary, and Carter (2004), and Dillon, Burkholder, Cleary, and Pisoni (in press). The children’s nonword responses varied in terms of suprasegmental, consonant, vowel, and overall perceptual accuracy. A summary is provided in Table 3.

<b>Nonword Repetition Score</b>	<b>Mean (SD)</b>	<b>Range</b>
% Correct # of syllables (N=24)	65% (18%)	35 - 95%
% Correct primary stress placement (N=24)	62% (13%)	30 - 85%
% Correct Cs out of Cs in all 20 target NWs (N=76)	30% (17%)	1 - 76%
% Correct Cs out of target Cs in responses (N=76)	33% (17%)	1 - 76%
% Correct Vs out of Vs in all 20 target NWs (N=76)	44% (17%)	9 - 75%
% Correct Vs out of target Vs in responses (N=76)	48% (17%)	13 - 78%
Mean Perceptual Accuracy Ratings (N=76)	3.1 (1.1)	1.1 - 5.7

**Table 3.** Summary of means, standard deviations (SD), and ranges for the nonword repetition scores.

The 24 children for whom suprasegmental accuracy scores (i.e., number of syllables and placement of primary stress) were calculated had all produced responses to the complete set of 20 target nonwords. Overall, they produced a mean of 65% (range = 35-95%, *SD* = 18%) of their responses with the correct number of syllables, and 62% (range = 30-85%, *SD* = 13%) of their responses with the correct placement of primary stress. Percent consonants (Cs) and vowels (Vs) correct scores were calculated first out of the total number of target Cs in all 20 target nonwords (*N* = 112) and target Vs in all 20 nonwords (*N* = 68), respectively. Because some of the 76 children did not produce a repetition response to all 20 target nonwords, we also calculated individual percent Cs and Vs correct scores out of the total number of target consonants in only the target nonwords for which the child provided a response. The mean percent consonants correct scores, calculated in both ways described above, were 30% (range = 1 - 76%, *SD* = 17%), and 33% (range = 1-76%, *SD* = 17%), respectively. The mean percent vowels correct scores were slightly higher, 44% (range = 9-75%, *SD* = 17%) and 48% (range = 13-78%, *SD* = 17%), respectively.

The children's nonword responses received mean accuracy ratings that ranged from 1.1 to 5.7 out of 7 ( $M = 3.1$ ,  $SD = 1.1$ ). As shown in Table 4, the different methods of scoring the nonword repetition task yielded scores that were strongly intercorrelated with each other.

<b>Nonword Repetition Score</b>	<b>1. Syls</b>	<b>2. Str</b>	<b>3. Cs 1</b>	<b>4. Cs 2</b>	<b>5. Vs 1</b>	<b>6. Vs 2</b>	<b>7. Ratings</b>
1. % Correct # of Syllables (N=24)	1	+.40	+.69***	+.69***	+.70***	+.70***	+.67***
2. % Correct Primary Stress Placement (N=24)		1	+.63**	+.63**	+.51*	+.51*	+.69***
3. % Correct Cs out of Cs in all 20 target NWs (N=76)			1	+.99***	+.87***	+.87***	+.92***
4. % Correct Cs out of target Cs in responses (N=76)				1	+.88***	+.88***	+.92***
5. % Correct Vs out of Vs in all 20 target NWs (N=76)					1	+.98***	+.88***
6. % Correct Vs out of target Vs in responses (N=76)						1	+.87***
7. Mean Accuracy Ratings (N=76)							1

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

**Table 4.** Intercorrelations among the nonword repetition scores.

Correlations between the measures of nonword repetition accuracy and age at implantation, duration of CI use, chronological age at the time of testing, and number of active electrodes did not reach significance. Correlations between nonword repetition accuracy and the demographic factors that did reach significance are shown in Table 5.

<b>Nonword Repetition Score</b>	<b>Age at Onset</b>	<b>Comm. Mode</b>	<b>PIQ</b>
% Correct # of syllables (N=24)	+.38	-.18	+.01
% Correct primary stress placement (N=24)	+.52**	+.36	-.01
% Correct Cs out of Cs in all 20 target NWs (N=76)	+.31**	+.54***	+.22
% Correct Cs out of target Cs in responses (N=76)	+.28*	+.54***	+.22
% Correct Vs out of Vs in all 20 target NWs (N=76)	+.24*	+.47***	+.25*
% Correct Vs out of target Vs in responses (N=76)	+.20	+.45***	+.27*
Mean accuracy ratings (N=76)	+.32**	+.51***	+.26*

**Table 5.** Significant correlations between the children's demographic characteristics and their nonword repetition scores.

## Reading Outcome Measures

A summary of the children's scores on the reading outcome measures is shown in Table 6. We report grade equivalent scores for the WRMT Word Attack subtest and the PIAT Recognition and Comprehension subtests. PIAT Total Reading standard scores were calculated using estimated grade levels based on the children's ages because grade levels were not available for all children (see also Geers, 2003). Forty-one children were considered 3rd-graders and 35 children were considered 4th-graders. Fifty-three children (70%) obtained Total Reading standard scores within the normal range for children their age. The remaining 23 children (30%) had Total Reading standard scores that were below the normal range for children their age (based on norms from Markwardt, 1998; Geers, 2003 results are based on norms from Dunn & Markwardt, 1987).

Reading Outcome Measure	Mean (SD)	Range
WRMT Word Attack (Grade Equivalent Scores)	3.3 (2.8)	0.0 - 12.6
PIAT Recognition (Grade Equivalent Scores)	2.9 (1.0)	0.4 - 6.1
PIAT Comprehension (Grade Equivalent Scores)	2.9 (1.5)	0.0 - 8.7
PIAT Total Reading (Standard Scores)	87.6 (6.5)	72 - 106
Rhyme Errors (Percent)	12.4 (7.2)	0 - 37

**Table 6.** Summary of means, standard deviations (SD), and ranges for the reading outcome measures (N=76).

The number and corresponding percentage of children that performed at several grade levels on the WRMT Word Attack subtest and the PIAT Recognition and Comprehension subtests are shown in Table 7. Seventeen children (22%) scored above the 4th-grade level on the Word Attack, two children (3%) on Reading Recognition, and eight children (11%) on Reading Comprehension. Ten children (13%) scored below the first-grade level on at least one of the Word Attack, Reading Recognition, and Reading Comprehension tasks. As shown in Table 8, scores on the reading outcome measures were all highly intercorrelated; the percentage of rhyme errors was moderately correlated with the other reading outcome measures.

Reading Outcome Measure	Below 1st grade level	1st grade level	2nd grade level	3rd grade level	4th grade level	Above 4th grade level
WRMT Word Attack (GE Scores)	7 (9%)	23 (30%)	16 (21%)	7 (9%)	6 (8%)	17 (22%)
PIAT Recognition (GE Scores)	2 (3%)	10 (13%)	29 (38%)	25 (33%)	8 (11%)	2 (3%)
PIAT Comprehension (GE Scores)	6 (8%)	6 (8%)	37 (49%)	16 (21%)	3 (4%)	8 (11%)

**Table 7.** The number and corresponding percentage of children with grade equivalent scores below 1st grade level to above 4th grade level on the three reading outcome measures for which grade equivalency scores were available (N=76).

Reading Outcome Measure	WRMT Word Attack	PIAT Reading Recog.	PIAT Reading Comp.	PIAT Total Reading	Rhyme Errors
WRMT Word Attack	1	+.83***	+.68***	+.82***	-.37**
PIAT Reading Recognition		1	+.78***	+.88***	-.40***
PIAT Reading Comprehension			1	+.89***	-.41***
PIAT Total Reading				1	-.42***
Rhyme Errors					1

\*\* $p < .01$ , \*\*\* $p < .001$

**Table 8.** Intercorrelations among the reading outcome measures (N=76).

We did not find any significant correlations between the reading measures and age at onset of deafness, duration of deafness, age at implantation, duration of CI use, or chronological age at the time of testing (all  $p$ 's  $> .11$ ) or number of electrodes (after one outlier was removed, all  $p$ 's  $> .08$ ). A t-test revealed no differences in performance by gender ( $p$ 's = .69, .71, .96, .81, .09 for the WRMT Word Attack, PIAT Recognition, PIAT Comprehension, PIAT Total Reading, and Rhyme Errors tasks, respectively). Correlations between the reading measures and both communication mode and performance IQ (Wechsler, 1991) reached significance (see Table 9).

Reading Outcome Measure	Comm. Mode	PIQ
WRMT Word Attack	+.41***	+.34**
PIAT Raw Recognition Scores	+.26*	+.35**
PIAT Raw Comprehension Scores	+.15	+.39***
PIAT Reading Standard Scores	+.25*	+.45***
Rhyme Errors	-.14	-.21

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

**Table 9.** Significant correlations between the children's demographic characteristics and their scores on the reading outcome measures (N=76).

## Correlational Analysis

Because the different methods of scoring the nonword repetition task were all highly correlated with each other, we report only the correlations between the nonword repetition accuracy ratings and the reading outcome measures. We found that age at onset of deafness, communication mode, and performance IQ (measured using the WISC III, Wechsler, 1991; see also Geers, 2003 and Dillon et al., in press) were all significantly correlated with nonword repetition performance. We also computed partial correlations between nonword repetition accuracy ratings and the reading measures to control for these demographic variables. After these potentially confounding demographic factors were partialled out, we found that the children's performance on nonword repetition, a phonological processing task, and their performance on the measures of reading readiness and reading still remained significantly correlated. Finally, we computed partial correlations in which lexical diversity was also controlled, in addition to the potentially confounding demographic characteristics (age at onset of deafness, communication mode, and performance IQ). When lexical diversity was controlled, several of the correlations between children's nonword repetition performance and their reading scores no longer reached significance. The reading

recognition scores and total reading scores remained significantly correlated with nonword repetition performance, but were substantially decreased.

Reading Outcome Measure	Bivariate correlation	Partial correlation 1	Partial correlation 2
WRMT Word Attack	+.61***	+.49***	+.22
PIAT Reading Recog. Scores	+.57***	+.50***	+.26*
PIAT Reading Comp. Scores	+.43***	+.41***	+.15
PIAT Total Reading Scores	+.59***	+.55***	+.32**
Rhyme Errors	-.37**	-.29*	-.12

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

**Table 10.** Correlations between nonword repetition accuracy ratings and reading outcome measures (N=76): Simple bivariate correlations, partial correlations 1 (controlling for age at onset of deafness, communication mode, and performance IQ), and partial correlations 2 (controlling for age at onset of deafness, communication mode, performance IQ, and lexical diversity).

## Discussion and Conclusions

Nonword repetition is a difficult information processing task that requires immediate and rapid phonological processing. Most of the deaf children with cochlear implants in the present study were able to complete the nonword repetition task with some measurable level of accuracy, although their performance was substantially worse than normal-hearing children. Several methods of scoring their performance were all highly intercorrelated. The deaf children with cochlear implants in this study demonstrated higher level reading skills than have traditionally been reported in deaf children (but see also Geers, 2003; Spencer et al., 1997). Many of the children's reading scores fell within the range of their normal-hearing age-mates. We also found that nonword repetition performance was strongly correlated with measures of reading readiness (such as letter-sound correspondences and rhyme recognition), single-word reading, nonword reading and read-sentence comprehension.

The strong correlation between the children's nonword repetition performance and their performance on a nonword reading task, the Word Attack, suggests that the children used the same phonological processing skills to read nonwords out loud as they did to repeat spoken nonword stimuli. Because the nonword reading task requires a spoken response, differences in speech production and speech intelligibility could be potentially confounding factors. However, we also found that the children's nonword repetition performance was strongly correlated with their performance on the PIAT Reading Comprehension subtest, a sentence comprehension task that does not involve processing speech or spoken language input signals. Children who were better able to "decompose" and "reassemble" spoken nonwords were also better at reading and comprehending meaningful written sentences.

This correlation is revealing and is theoretically significant. Because the stimuli used in the nonword repetition task are nonword phonological patterns, the children could not rely directly on the retrieval and access of previously developed lexical representations of the stimuli. However, we also found that the correlations between nonword repetition and reading scores decreased when the children's lexical diversity was statistically controlled. This finding suggests that when a child who uses a greater number of real words in conversation performs nonword repetition and reading tasks, he/she relies on phonological representations that are more robust and stable due to the existence of a larger number of

lexical items in the child's mental lexicon.<sup>2</sup> If any similarity between the nonword and real words in English affected the children's performance, the effect was dependent on the children's ability to abstract and generalize phonological regularities and structure of the nonwords to real words in their lexicon. These linguistic skills rely on the use of phonology and the construction of phonological representations (both new representations of the nonwords and pre-existing representations of real words), not access to semantic representations. The nonword repetition task thus relies on phonological processing skills: the ability to perceive, encode, decompose, rehearse, and then reassemble for speech production a novel phonological pattern.

In contrast, the PIAT Reading Comprehension measure requires the child to match a written sentence with a picture that represents what is described by the sentence. In this sentence comprehension task, the child must be able to recognize and read written words, and access lexical representations (at least semantic if not phonological) and syntactic representations. This task also does not require the child to produce any spoken responses. Theoretically, it does not require the use of phonological representations at all. A child could recognize the words in the sentence directly using pre-existing visual representations of the letters and/or words, and process the sentence for meaning without constructing or accessing phonological representations of spoken words from his/her lexicon. On the other hand, there is now a great deal of evidence in the literature that suggests that young children convert the visual (graphemic) representations of print into phonological representations (phonemes or lexical phonological representations), as a part of the process of reading comprehension (Lieberman, Shankweiler, & Lieberman, 1989).

In the present study, we found that the children's nonword repetition performance and their reading comprehension scores were also correlated ( $r = +.43$ ,  $p < .001$ ). This indicates that nonword repetition, which involves speech perception, encoding and verbal rehearsal in phonological working memory, and speech production, is related to reading comprehension, which on the surface does not involve speech perception or speech production. The correlation between these two measures suggests that these deaf children were utilizing phonological processing skills in order to complete the reading comprehension task, and were relying on the same phonological processing skills for reading comprehension as they did for nonword repetition. Previous research on reading in young children has shown that nonword repetition relies heavily on preexisting phonological processing skills (see Brady, 1997). The present findings indicate that the strategies used by deaf children with cochlear implants to complete a reading comprehension task also rely on phonological knowledge and phonological processing skills. Like normal-hearing children, in order to carry out the reading comprehension task, the children in this study had to convert graphemes to phonemes (without excluding the possibility that they used more direct visual word recognition as well), and create a phonological representation of the sentence (or parts of it) and maintain that in phonological working memory to successfully complete this information processing task.

This use of phonological processing skills is a prerequisite to processing the sentence for meaning. The use of phonological processing in reading comprehension is predicated upon the previous existence of phonological representations. That is, in order to benefit from the use of phonological processing to complete a reading comprehension task, the child must be able to use abstract representations of the contrasting sounds of his/her ambient language; he/she must be able to map the

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<sup>2</sup> In a preliminary investigation into the effect of the wordlikeness and phonotactic probability of the target nonwords on the children's nonword repetition performance, we found that overall performance on the 20 target nonwords (averaged across all 76 children) was not significantly correlated with the nonwords' wordlikeness (see Carlson et al., 1998) or phonotactic probability, when calculated either according to individual phoneme frequency by word position or according to biphone frequency (based on Vitevitch & Luce, submitted).

visual graphemes onto abstract phonological units. The more robust their phonological representations were, the more reliably these children could decompose and reassemble a spoken nonword. In addition, the present study reveals that the children who are better able to decompose and reassemble an auditorily-presented nonword (i.e., whose nonword repetition scores are higher), also tended to be the children who were better able to comprehend meaningful written sentences. We hypothesize that this correlation is based on the fact that these better performing children used phonological processing in completing the reading comprehension task. Thus, performance on both tasks relies at least to some extent on the construction of phonological representations and the use and development of phonological processing skills. The more accurate and robust a child's phonological representations are, the more useful they will be in phonological processing, and the better the child will perform on a wide range of information processing tasks that involve phonological processing such as nonword repetition, reading comprehension, and rhyme detection.

The findings obtained in the present study are consistent with other findings reported recently in the literature for children with phonological disorders. Using a nonword repetition task in which the nonwords were systematically varied in terms of biphone frequency, Munson et al. (in press) found that children with phonological disorders (PD) and typically-developing (TD) children repeated nonwords with low frequency sequences less accurately than nonwords with high frequency. Although the children with PD repeated the nonwords less accurately overall than the TD children, the children with PD were no more affected by frequency differences than typically developing children. Munson et al. also found that across both groups, children with larger vocabularies repeated the nonwords with greater accuracy than children with smaller vocabularies. Furthermore, they found that nonword repetition performance was not dependent on the speech perception or articulatory ability of the children in their study. Based on their findings, Munson et al. concluded that poorer overall performance by the children with PD in comparison to TD children in the nonword repetition task was not related to difficulties with speech perception, articulation, or even the ability to form abstract representations, but rather to having abstract representations that were not as robust or well specified as those of the TD children. According to this view, nonword repetition tasks index the robustness of the participant's abstract phonological representations, which is related to vocabulary size and the building of lexical representations. Similarly, Edwards et al. (2004), in a study of adults and TD children, found that nonword repetition performance (on the same task used in Munson et al.) was related to vocabulary size, and that performance by children who have larger vocabularies was less affected by biphone frequency differences than performance by children with smaller vocabularies.

The findings of Edwards et al. (2004) and Munson et al. (in press) provide support for a proposal of Studdert-Kennedy (2002: 11), who stated that "If segmentation of words into their phonological components is an emergent consequence of lexical growth, as several authors have proposed... we may hypothesize that a smaller than usual lexicon will result in defective ('fuzzy'/'weak') phonological representations, and so defective phoneme awareness." Inasmuch as nonword repetition involves segmentation of a novel sound pattern into units that are encoded as abstract phonological segments, Munson et al.'s interpretation of their finding is consistent with Studdert-Kennedy's hypothesis that a smaller lexicon will lead to deficits in phonological representations. Studdert-Kennedy's position is that deficits in phonemic awareness are related to the fuzziness or weakness of phonological representations, which stems from poor speech-specific perception rather than a general auditory processing deficit (as proposed by Tallal and colleagues, e.g., Tallal, Miller, & Fitch, 1993). Munson et al. reject the idea that weak phonological representations stem from poor speech perception. Thus, Studdert-Kennedy and Munson et al. have disparate views on the *source* of 'weak' or non-robust phonological representations, but their views appear to be similar in that they see deficits in phonological awareness and phonological disorders (respectively) as directly related to poorly specified or incomplete phonological representations.

Taken together, studies such as those summarized in Studdert-Kennedy (2002; see also Mody, Studdert-Kennedy, & Brady, 1997), Edwards et al. (2004), Munson et al. (in press), and the present results lend converging support to the notion that robust phonological representations are behind better performance on tasks such as nonword repetition and phonemic awareness tasks. Further research is warranted regarding the *sources* of the development of weak abstract phonological representations, and the extent to which the sources vary across populations (e.g., NH children with phonological disorders versus deaf children with cochlear implants in OC or TC environments). Insights into the sources of the development of phonological representations should come from further behavioral research, and may also come from genetic studies. Several recent studies have demonstrated a connection between nonword repetition performance and three specific chromosomes (SLI Consortium, 2002; Watkins, Dronkers, & Vargha-Khadem, 2002, and Stein et al., 2004; see Kent, 2004). Such research could also provide insight into methods of identifying and treating children who fall into multiple clinical populations, e.g., deaf children who have phonological deficits independent of those caused by auditory deprivation.

The correlation between nonword repetition performance and reading comprehension suggests that the deaf children with cochlear implants in the present study were utilizing phonological processing skills in order to complete the reading comprehension task. A child's ability to use abstract phonological representations of the linguistically significant sound contrasts in his/her ambient language contributes to reading readiness and reading skills. This finding is not informative regarding the causality or directionality of this relationship. However, it provides important motivation for investigation into whether pediatric cochlear implant users' participation in tasks specifically aimed at strengthening phonological representations and processing skills would also lead to and contribute to increased reading and, ultimately, literacy skills. Support for such investigation is also warranted by the fact that numerous studies have found that normal-hearing children's reading skills can benefit significantly from training in phonemic awareness and grapheme-phoneme mapping skills (phonics) (see National Institute of Child Health and Human Development, 2000; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001).

Further understanding of the development of phonology and phonological processing skills may inform treatment of phonological disorders and habilitation of children with cochlear implants, and conversely, studies of the effects of treatment and habilitation may also provide insight into the sources and characteristics of robust categories in a phonological system. In a recent summary of treatment studies of children with phonological disorders, Gierut (2004) reported that phonological learning is greatest when linguistically complex or difficult sounds or sound pairs are used as the targets in treatment. Perhaps the development of more robust abstract phonological representations in deaf children with CIs could be aided by a focus on linguistically complex sounds in treatment for phonological disorders.

In summary, our results are consistent with the notion that phonological processing and knowledge are important for both nonword repetition and reading performance in deaf children with cochlear implants. The findings from this study suggest that the children's use of abstract representations (robust or not) of phonological structure is reflected in their performance on these tasks. The correlations obtained between spoken nonword repetition and phonological awareness and reading comprehension tasks suggest that early intervention, including explicitly training children in ways that may help them to develop robust, stable phonological representations, may be crucial in the habilitation of deaf children if they are ultimately to achieve maximal literacy levels. Methods developed in clinical phonology to help children with phonological disorders improve their speech intelligibility may prove to be useful in helping the clinical population of deaf children with cochlear implants to development phonological knowledge and skills.

## References

- Adams, M.J. (1990). *Beginning to Read*. Cambridge, MA: MIT Press.
- Baddeley, A., & Gathercole, S. (1992). Learning to read: The role of the phonological loop. In J. Alegria, D. Holender, J. de Morais, & M. Radeau (Eds.), *Analytic Approaches to Human Cognition* (pp. 153-167). New York: Elsevier Science Publishers.
- Brady, S.A. (1997). Ability to encode phonological representations: An underlying difficulty of poor readers. In B. Blachman (Ed.), *Foundations of Reading Acquisition and Dyslexia* (pp. 21-47). Mahwah, NJ: Lawrence Erlbaum Associates.
- Bradley, L., & Bryant, P.E. (1983). Categorizing sounds and learning to read - a causal connection. *Nature*, *301*, 419-421.
- Carlson, J.L., Cleary, M., & Pisoni, D.B. (1998). Performance of normal-hearing children on a new working memory span task. In *Research on Spoken Language Processing Progress Report No. 22* (pp. 251-273). Bloomington IN: Speech Research Laboratory, Indiana University.
- Carter, A.K., Dillon, C.M., & Pisoni, D.B. (2002). Imitation of nonwords by hearing impaired children with cochlear implants: Suprasegmental analyses. *Clinical Linguistics & Phonetics*, *16*, 619-638.
- Cassar, M., & Treiman, R. (2004). Developmental variations in spelling: Comparing typical and poor spellers. In C.A. Stone, E.R. Silliman, B.J. Ehren, & K. Apel (Eds.), *Handbook of Language and Literacy: Development and Disorders* (pp. 627-643). New York: The Guilford Press.
- Conrad, R. (1979). Deafness and reading. In R. Conrad (Ed.), *The Deaf Schoolchild* (pp. 140-175). London: Harper and Row.
- Dalgarno, G. (1680; 1971). Didascalocophus or The deaf and dumb man's tutor. In R.C. Alston (Ed.), *English Linguistics 1500-1800*. Menston, England: The Scholar Press Limited.
- Dillon, C.M., Burkholder, R.A., Cleary, M., & Pisoni, D.B. (in press). Perceptual ratings of nonword repetition responses by children who are deaf after cochlear implantation. *Journal of Speech, Language, and Hearing Research*.
- Dillon, C.M., Cleary, M., Pisoni, D.B., & Carter, A.K. (2004). Imitation of nonwords by hearing-impaired children with cochlear implants: Segmental analyses. *Clinical Linguistics & Phonetics*, *18*, 39-55.
- Dillon, C.M., Pisoni, D.B., Cleary, M., & Carter, A.K. (2004). Nonword imitation by children with cochlear implants: Consonant analyses. *Archives of Otolaryngology - Head and Neck Surgery*, *130*, 587-591.
- Dunn, L.M., & Markwardt, F.C. (1989). *Peabody Individual Achievement Test-Revised*. Circle Pines, MN: American Guidance Service, Inc.
- Edwards, J., Beckman, M.E., & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in nonword repetition. *Journal of Speech, Language, and Hearing Research*, *47*, 421-436.
- Gathercole, S.E., Willis, C.S., Baddeley, A.D., & Emslie, H. (1994). The Children's Test of Non-word Repetition: A test of phonological working memory. *Memory*, *2*, 103-127.
- Geers, A.E. (2003). Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing*, *24*, 59S-68S.
- Geers, A., & Brenner, C. (2003). Background and educational characteristics of prelingually deaf children implanted by five years of age. *Ear and Hearing*, *24*, 2S-14S.
- Geers, A., Nicholas, J.G., & Sedey, A.L. (2003). Language skills of children with early cochlear implantation. *Ear and Hearing*, *24*, 46S-58S.
- Gierut, J.A. (2004). Enhancement of learning for children with phonological disorders. Paper presented at From Sound to Sense, June 11-13, 2004, MIT, Cambridge, MA.
- Hanson, V.L. (1991). Phonological processing without sound. In S.A. Brady & D.P. Shankweiler (Eds.), *Phonological Processes in Literacy* (pp. 153-161). Hillsdale NJ: Lawrence Erlbaum Associates.
- Kent, R.D. (2004). Development, pathology and remediation of speech. Paper presented at From Sound to Sense, June 11-13, 2004, MIT, Cambridge, MA.

- Liberman, I.Y., Shankweiler, D., & Liberman, A.M. (1989). The alphabetic principle and learning to read. In D. Shankweiler & I.Y. Liberman (Eds.), *Phonology and Reading Disability: Solving the Reading Puzzle* (pp. 1-33). Ann Arbor MI: University of Michigan Press.
- Markwardt, F.C. (1998). *Peabody Individual Achievement Test-Revised*. Circle Pines, MN: American Guidance Service, Inc.
- Marschark, M. (2003). Interactions of language and cognition in deaf learners: From research to practice. *International Journal of Audiology, 42*, S41-S48.
- Mody, M., Studdert-Kennedy, M., & Brady, S.A. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64*, 199-231.
- Munson, B., Edwards, J., & Beckman, M.E. (in press). Relationships between nonword repetition accuracy and other measures of linguistic development in children with phonological disorders. *Journal of Speech, Language, and Hearing Research*.
- National Institute of Child Health and Human Development (2000). *Report of the National Reading Panel. Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction* (NIH Publication No. 00-4769). Washington, DC: U.S. Government Printing Office.
- Paul, P.V. (2003). Processes and components of reading. In M. Marschark & P.E. Spencer (Eds.), *Deaf Studies, Language, and Education* (pp. 97-109). New York: Oxford University Press.
- Pisoni, D.B. (this volume). Speech perception skills of deaf children with cochlear implants. In *Research on Spoken Language Processing Progress Report No. 26*. Bloomington IN: Speech Research Laboratory, Indiana University.
- Rayner, K., Foorman, B.R., Perfetti, C.A., Pesetsky, D., & Seidenberg, M.S. (2001). How psychological science informs the teaching of reading. *Psychological Science in the Public Interest, 2*, 31-54.
- Rayner, K., & Pollatsek, A. (1995). *The Psychology of Reading*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- SLI Consortium (2002). A genomewide scan identifies two novel loci involved in specific language impairment. *American Journal of Human Genetics, 70*, 384-398.
- Spencer, L., Tomblin, B., & Gantz, B. (1997). Reading skills in children with multi-channel cochlear implant experience. *Volta Review, 99*, 193-202.
- Stein, C.M., Schick, J.H., Taylor, H.G., Shriberg, L.D., Millard, C., Kundtz-Kluge, A., Russo, K., Minich, N., Hansen, A., Freebairn, I.A., Elston, R.C., Lewis, B.A., & Iyengar, S.K. (2004). Pleiotropic effects of a chromosome 3 locus on speech-sound disorder and reading. *American Journal of Genetics, 74*, 283-297.
- Studdert-Kennedy, M. (2002). Deficits in phoneme awareness do not arise from failures in rapid auditory processing. *Reading and Writing: An Interdisciplinary Journal, 15*, 5-14.
- Tallal, P., Miller, S., & Fitch, R.H. (1993). Neurobiological basis of speech: A case for the preeminence of temporal processing. In P. Tallal, A.M. Galaburda, R.R. Llinas, & C von Euler (Eds.), *Temporal Information Processing in the Nervous System. Annals of the New York Academy of Science*, Vol. 82 (pp. 27-47). New York: New York Academy of Sciences. Paper reprinted in *Irish Journal of Psychology* (1995), 16: 194-219.
- Troia, G.A. (2004). Phonological processing and its influence on literacy learning. In C.A. Stone, E.R. Silliman, B.J. Ehren, & K. Apel (Eds.), *Handbook of Language and Literacy: Development and Disorders* (pp. 271-301). New York: The Guilford Press.
- Vitevitch, M.S., & Luce, P.A. (submitted). A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments, & Computers*.
- Wagner, R.K., & Torgeson, J.K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192-212.
- Watkins, K.E., Dronkers, N.F., & Vargha-Khadem, F. (2002). Behavioral analysis of an inherited speech and language disorder: Comparison with acquired aphasia. *Brain, 125*, 452-464.
- Wechsler, D. (1991). *Wechsler Intelligence Scale for Children-III*. San Antonio, TX: The Psychological

- Corporation.
- Woodcock, R.W. (1987) *Woodcock Reading Mastery Tests-Revised*. Allen, TX: DLM Teaching Resources.
- Woodcock, R.W. (1998). *Woodcock Reading Mastery Tests-Revised*. Allen, TX: DLM Teaching Resources.

