

Phonological Awareness, Reading Skills, and Vocabulary Knowledge in Children Who Use Cochlear Implants

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In hearing children, reading skills have been found to be closely related to phonological awareness. We used several standardized tests to investigate the reading and phonological awareness skills of 27 deaf school-age children who were experienced cochlear implant users. Approximately two-thirds of the children performed at or above the level of their hearing peers on the phonological awareness and reading tasks. Reading scores were found to be strongly correlated with measures of phonological awareness. These correlations remained the same when we statistically controlled for potentially confounding demographic variables such as age at testing and speech perception skills. However, these correlations decreased even after we statistically controlled for vocabulary size. This finding suggests that lexicon size is a mediating factor in the relationship between the children's phonological awareness and reading skills, a finding that has also been reported for typically developing hearing children.

The myths that hearing impairment is equivalent to lack of intelligence and lack of articulatory capacity have existed at least since the time of Aristotle and persist even today (Dalgarno, 1680; Gannon, 1981; Leigh, 2009). However, in the late 19th and early 20th centuries, Laura Bridgman and Helen Keller made great strides in dispelling these beliefs by demonstrating that despite profound deafness (and blindness), a person could learn to communicate via sign language, to speak, write, and succeed as an author and champion of social causes (Freeberg, 2001). At the same time, the establishment of schools for the Deaf began to spread the use of American Sign Language (Fischer and de Lorenzo, 1983; Gordon, 1892), whose status as a formal, dynamic

language was well-established by linguists in the 20th century (Armstrong, Karchmer, Van Cleve, & Stokoe, 2002; Maher, 1996). More recently, the invention and use of cochlear implants have increased the use of spoken language communication by deaf children substantially (Moog & Geers, 2003) and to a lesser extent by both prelingually and postlingually deafened adults (Firszt et al., 2004).

Despite an increase in the access to and use of manual and spoken communication by the deaf, their use of written communication has remained limited (Waters & Doehring, 1990) and challenging (Biser, Rubel, & Tuscano, 2007). Studies of the reading skills of deaf children and adults over the past 50 years have repeatedly shown that the reading skills of children who are deaf tend to be significantly delayed relative to their hearing peers. Deaf adults' reading levels often do not exceed a fourth-grade level (Conrad, 1979; Karchmer, Milone, & Wolk, 1979; Moog & Geers, 1985; Paul, 2003). However, deaf adults' reading levels span a wide range, with some individuals reading at college level (Hanson, 1991 cites Reynolds, 1975). Keeping in mind that some deaf readers are able to demonstrate greater reading skill than their average hearing peers, why do so many deaf children and adults have reading difficulties?

Research from the last 40 years on the reading skills of hearing children and adults has provided some initial insights into the answers to this question. Researchers have investigated various aspects of the complex processes involved in the task of reading. The process of reading English involves fluent word recognition and comprehension of the meaning of the written words, phrases, sentences, and so on. Word recognition can be accomplished via recognition of words as wholes and/or

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via decoding by “sounding out” or making the connections between written letters and the spoken sounds they represent. Comprehension involves many subskills such as knowledge of the meanings of individual words (vocabulary knowledge) in context, ability to infer necessary information that is not directly stated, and ability to make associations between the written language and background knowledge. Because reading is a complex process that involves multiple skills, discovering the source of reading difficulty in poor readers is a complex task in itself.

In the early 1970s, Isabelle Liberman, Don Shankweiler, Ignatius Mattingly, and their colleagues proposed that an important source of poor readers’ difficulty was the dissociation between the continuous nature of the acoustic speech signal of *spoken language* and the discrete abstract nature of the alphabetic orthography that is used to represent speech in *written language* (Liberman, 1971; Liberman, Shankweiler, Fischer, & Carter, 1974; Mattingly, 1972). Beginning readers of alphabetic languages such as English need to grasp the alphabetic principle: the fact that speech, the spoken form of the language which is carried by a continuous acoustic signal, can be represented by sequences of discrete symbols (graphemes) in the written form of the language (Liberman et al., 1974). Furthermore, skilled reading depends upon one’s ability to conceive of spoken words not only as meaningful lexical items but also as sound units with internal phonological structure. The conscious awareness that individual words have an internal phonological structure and can be broken down into linear *sequences of sound units* is referred to as a person’s phonological awareness. These sound units can be syllables, onsets/rimes, or phonemes; accordingly, a person’s phonological awareness reflects knowledge of phonological structure at the syllable level, the level of onsets and rimes, or the phoneme level (Brady, 1991; Gillon, 2004; Treiman & Zukowski, 1991).

Phonological Awareness at the Syllable Level

Phonological awareness at the syllable level—knowledge that a word can be decomposed into syllables—can be assessed with a variety of behavioral tasks that require the participant to count the number of syllables in a word, clap their hands for each syllable, place objects on a table to represent the number of syllables in a word, delete a syllable from a spoken word, and so on.

Phonological Awareness at the Onset-Rime Level

Phonological awareness at the onset-rime level is knowledge that words consist of collated onsets and rimes. An onset is all of the phonemes that precede the vowel in a syllable, and a rime is the vowel and all of the phonemes that follow the vowel in a syllable. Tasks intended to measure onset-rime level awareness include rhyme recognition, rhyme oddity (detection of one word that does not rhyme with two or more other words), spoken rhyme generation, and onset-rime blending.

Phonological Awareness at the Phoneme Level (Phonemic Awareness)

Phonological awareness at the phoneme level, often called “phoneme awareness” or “phonemic awareness”, is knowledge that words can be decomposed into discrete phonemes. Phonemic awareness has been measured with a wide variety of procedures, including phoneme isolation tasks in which participants are asked to say a word but pause between each phoneme, phoneme blending tasks in which participants are asked to combine a sequence of individual sounds into a word (or nonword), and phoneme reversal tasks in which participants are asked to metathesize two phonemes in a word (Gillon, 2004).

Relative Difficulty of Phonological Awareness Tasks

The relative difficulty of phonological awareness tasks has been investigated by several researchers. Schatschneider, Francis, Foorman, Fletcher, and Mehta (1999) found that a group of kindergarten to second-grade children performed better on onset-rime blending, phoneme matching and phoneme categorization tasks than they did on phoneme segmentation, phoneme blending (of nonwords), and phoneme deletion tasks. Stahl and Murray (1994) found that a group of 5- to 7-year-old children obtained higher scores on a phoneme isolation task than on phoneme blending and phoneme deletion tasks, while performing most poorly on a phoneme segmentation task. Overall, results regarding the relations between the levels of phonological awareness have not yielded consistent, definitive results across studies. In general, however, tasks that involve explicit manipulation of phonological units seem to be more difficult for children to carry out than tasks that involve isolating or classifying (matching) units.

Similarly, findings regarding phonological awareness at the onset-rime level have been debated in the literature (Morais, 1991; Read, 1991). For example, Yopp (1988) found that onset-rime level awareness was not correlated with phoneme-level awareness. However, in a series of studies in which stimuli were carefully controlled for several characteristics including onset-rime versus phonemic level contrasts, Treiman and colleagues (see Treiman & Zukowski, 1991) obtained more robust results. They found that young children who are not yet capable of demonstrating phonemic awareness were nevertheless able to display onset-rime level awareness. Furthermore, they found that syllable level awareness seems to precede onset-rime level awareness. An in-depth investigation into whether the stimuli and tasks intended to assess onset-rime level awareness rather than awareness at another phonological level (or some other auditory processing or cognitive skills) should provide new insights into this debate (see Morais, 1991).

One consistent finding that has been reported in the literature is that children tend to demonstrate phonological awareness at the syllable level earlier than they show phonological awareness at the phoneme level (see Gillon, 2004; Liberman et al., 1974; Lonigan, Burgess, Anthony, & Barker, 1998). More importantly, phonological awareness at both of these levels has been shown to predict reading ability later in the child's development, but correlations between phonemic awareness and reading skills tend to be stronger and more consistent than correlations between syllable-level phonological awareness and reading skills (Gillon, 2004). This general finding is not surprising given that the representation of spoken language with an alphabet hinges critically on the graphic representation of *phonemes*, not syllables. Liberman and her colleagues hypothesized that phonemic awareness is strongly related to reading ability (e.g., Liberman et al., 1974; Liberman, Shankweiler, & Liberman, 1989). Research findings over the past 40 years have repeatedly confirmed this original hypothesis, consistently finding high levels of phonemic awareness to be a strong concurrent and future predictor of reading skills in the hearing population (see the National Institute of Child Health and Human Development, 2000; Shankweiler, 1991).

Phonological Processing Skills and Vocabulary Knowledge

Phonological awareness skills are a subset of phonological processing skills, which also include phonological working memory skills and lexical retrieval (see Brady, 1991). Several recent studies of hearing children have found that phonological processing skills are related to vocabulary size (e.g., Edwards, Beckman, & Munson, 2004; Munson, Edwards, & Beckman, 2005). Other researchers (e.g., Elbro, Borstron, & Petersen, 1998; Fowler, 1991; Studdert-Kennedy, 2002) have proposed that the relationship between vocabulary knowledge and phonological processing skills arises because children's phonological representations become more robust as they are able to make more generalizations about the phonological structure of language due to the increases in their lexicon size that accompany increased exposure to spoken language. Thus, it is important to take vocabulary knowledge into consideration when investigating the relationship between phonological skills and reading.

Development of Phonological Awareness and Phonological Representations

The development of phonological awareness is predicated upon the opportunity and ability to explicitly access the phonological structure of spoken language and construct phonological representations in the mental lexicon. Deaf children who receive little or no benefit from sensory aids have been shown to develop phonological knowledge, which may be due to their development of phonological representations based on articulatory information obtained from their lipreading and speaking experiences (Hanson, 1991). Their knowledge of phonological units is knowledge related to articulatory gestures used in speech production, rather than knowledge based on perceptual units parsed from an acoustic stream (Hanson, 1991). Indeed, in a pioneering monograph on deaf school children, Conrad (1979) found that within the deaf population, good lipreaders perform much better than poor lipreaders on tasks that require phonological coding. Thus, even children with little or no hearing can benefit from their (articulatory) knowledge of the phonological units of their language when reading (see also Musselman, 2000; Perfetti & Sandak, 2000).

The auditory signal provided by cochlear implants to children who are deaf allows some cochlear implant users to perceive speech. The speech perception skills that cochlear implant users develop to varying extents through speech and language therapy provides a mechanism by which they can develop phonological representations. These phonological representations could theoretically provide a basis for cochlear implant users to develop phonological awareness to a greater extent than was previously possible for children who are deaf. Recently, James and colleagues (2005) explored the developmental sequence of phonological awareness skills in a group of deaf children who use cochlear implants and in a group of severely deaf and profoundly deaf children who do not use cochlear implants. James and colleagues found that the children with cochlear implants and the profoundly deaf children without cochlear implants achieved phonological awareness scores that were highest at the syllable level, then at the rhyme (onset/rime) level, and poorest at the phoneme level. The severely deaf children differed from the other groups in that they had higher rhyme awareness scores than syllable awareness scores, but like the other groups they also performed most poorly on the phoneme awareness measure.

Results reported by Carter, Dillon, and Pisoni (2002) on deaf children with cochlear implants are also consistent with these findings. A group of children who were experienced cochlear implant users completed a nonword repetition task. Analyses of their nonword repetition responses showed that they produced the correct suprasegmental features (number of syllables and stress placement) more often than the correct segmental features (consonant place, manner, and voicing; vowel height and backness). Additional findings are described in Cleary, Dillon, and Pisoni (2002), Dillon, Burkholder, Cleary, and Pisoni (2004), Dillon, Cleary, Pisoni, and Carter (2004), Dillon and Pisoni (2006), and Dillon, Pisoni, Cleary, and Carter (2004). These results are consistent with the hypothesis that phonological awareness develops at levels of larger phonological units (syllable, onset-rime) prior to awareness at the phoneme level in deaf children, as has also been found in hearing children. Although the precise relationship between nonword repetition skills and phonological awareness is not yet understood, perhaps

the children's ability to accurately reproduce the syllable structure of the target nonwords even when they did not accurately reproduce the phonemic content of the target nonwords was a reflection of the earlier development of phonological awareness at the syllable level relative to phonological awareness at the phonemic level.

Development of Reading Skills

Among children with hearing loss, greater amounts of residual hearing are related to the development of better reading skills (Conrad, 1979). This finding makes sense in light of the close relationship between phonological awareness and reading skills: greater access to spoken language provides greater opportunity to rapidly access the phonological structure of language and develop phonological representations to be used in acquiring phonological awareness and later decoding skills. The increased access to spoken language provided to deaf children via cochlear implants may underlie recent findings of better-than-expected reading scores among many profoundly deaf children who use cochlear implants compared to typical findings for deaf children without cochlear implants (Geers, 2003, 2004; Moog & Geers, 1999; Spencer, Tomblin, & Gantz, 1997).

Geers (2003) investigated the reading skills of a large group ($N = 181$) of 8- and 9-year-old experienced cochlear implant users. She found that about half of the children performed at or above grade level on standardized reading tests and about half performed below grade level. The children who performed well on the reading tasks also tended to perform better on a rhyme detection (phonological awareness at the onset-rime level) task. Another study of the same children showed that the children's reading scores were also strongly correlated with their performance on a phonological processing task, nonword repetition (Dillon & Pisoni, 2006). This finding suggests that the children were not simply using visual word recognition processes to complete the reading tasks, but instead were using phonological encoding and decoding skills to read.

In our earlier study (Dillon & Pisoni, 2006), we were interested in exploring the contribution of vocabulary knowledge to the children's reading skills and nonword repetition performance. A standardized

vocabulary measure was not available, so we used a measure of “lexical diversity” based on the number of different words the children used in an oral interview. We found that when variation in the children’s lexical diversity scores was statistically controlled for, the correlations between the children’s reading scores and nonword repetition scores decreased substantially. This finding suggested that the children who had larger vocabularies (i.e., greater lexical diversity) also developed more robust phonological processing and reading skills, in accord with the findings in hearing children described above (Munson et al., 2005). Connor and Zwolan (2004) also found that vocabulary knowledge has a direct positive effect on the development of reading skills in children with cochlear implants.

The Present Study

In the present study, we extended these initial findings in a different group of children who were experienced cochlear implant users, using a standardized phonological awareness task that includes normative tests of phonemic awareness and syllable-level awareness. We also included a standardized measure of vocabulary knowledge in place of the lexical diversity measure used in Dillon and Pisoni (2006). The specific research questions addressed in this investigation are the following. First, how do deaf children with cochlear implants compare to their hearing peers on standardized phonological awareness, reading, and vocabulary tests? Second, do deaf children with cochlear implants perform better on syllable-level phonological awareness than phoneme-level phonological awareness? Third, to what extent are phonological awareness measures in deaf children predictive of their reading skills? Fourth, to what extent is the relationship between the children’s reading skills and phonological awareness mediated by

the children’s demographic characteristics, speech perception scores, and vocabulary knowledge?

Methods

Participants

Twenty-seven profoundly deaf children (17 boys and 10 girls) who use cochlear implants participated in this study. Eleven of the children had received their cochlear implants in Indianapolis, IN, at Riley Hospital for Children. Six participants were current or former students at an oral school in Illinois. Ten participants were current or former students in deaf and hard of hearing programs at elementary schools in Michigan. At the time of testing, 4 children were attending an oral school for the deaf, 8 children were attending mainstream schools with a deaf and hard of hearing program, and 14 children were attending mainstream schools. All of the children used oral communication (spoken English). Three children were deaf due to Mondini malformations, 1 child became deaf due to meningitis, and 2 children were reported to have genetic or hereditary deafness. The etiology of deafness for the other 21 children was unknown. Most of the children were congenitally deaf; two children became deaf before age 1, one child became deaf before age 2, and one child became deaf at 3.5 years old. The age at onset of deafness for three of the children was not reported by the children’s parents.

Table 1 shows a summary of the demographic characteristics of the sample.¹ Twenty of the children were deaf for less than 3 years before implantation. None of the children received their implant before age 1, 10 children received their implant before age 2, an additional 8 children received their implant before age 3, another child received his implant before age 4, and 3 more children received their implant before age 5. Two

Table 1 Demographic characteristics of the children in the present study

Demographic variable	Mean	<i>SD</i>	Range
Age at onset of deafness in years (<i>N</i> = 24)	0.23	0.76	0.0–3.5
Duration of deafness in years (<i>N</i> = 24)	2.3	1.4	0.5–6.0
Age at implantation in years (<i>N</i> = 24)	2.5	1.3	1.0–6.0
Duration of implant use in years (<i>N</i> = 24)	6.7	2.2	3.7–11.8
Chronological age in years (<i>N</i> = 25)	9.1	2.5	6.2–14.0

Note. The number of children (*N*) for whom information on each demographic characteristic was available is shown in parentheses in Column 1, followed by the mean, standard deviation (*SD*), and range for each characteristic.

children received their implant at ages 5.4 and 6.0, and age at implantation was not reported for three children (but should not have been above age 5 according to the instructed inclusion criteria). Twenty children had used their implant for over 5 years. At the time of testing, 8 children were 6 years old (2 in kindergarten, 4 in first grade, 2 unreported by parents), 2 children were 7 years old (1 in first grade, 2 in second grade), 6 children were 8 years old (1 in first grade, 2 in second grade, 2 in 3rd grade, 1 unreported by parent), 1 child was 9 years old (grade was unreported by parent), 2 children were 10 years old (both in fifth grade), 4 children were 11 years old (2 in 5th grade, 1 in sixth grade, 1 unreported by parent), 2 children were 12 years old (1 in sixth grade, 1 in seventh grade), 1 child was 13 years old (in seventh grade), and 1 child was 14 years old (in eighth grade). That is, participants were either in the same grade as their typical hearing peers or one grade below.

Procedure

Each child was tested in a quiet room over a period of approximately 1.0–1.5 hr. The children were given breaks as necessary during the testing period. Tests were administered in the same order for all children except one. Each child received \$28 and an Indiana Speech Research Laboratory tee shirt for his/her participation. The responses provided by the children during all tasks were recorded onto digital audiotape and transferred to a computer for storage and later analysis.

Tasks and Stimuli

The present study included a standardized measure of phonological awareness, three standardized measures of reading (single word reading, nonword reading, and sentence comprehension), a measure of speech perception, and a standardized measure of vocabulary knowledge. Details about these measures are provided below.

Phonological awareness skills. In order to examine the children's phonological awareness skills, we administered the Lindamood Auditory Conceptualization Test—Third Edition (LAC3; Lindamood PC & Lindamood P, 2004) to each child. The LAC3 is a standardized phonological awareness test that is normed for children ages 5;0–

18;11. The LAC3 consists of five subtests; a raw score is obtained for each child on the subtests, and the raw scores are summed to calculate a LAC3 Total score.

In the first subtest, “Isolated Phoneme Patterns” (IPP), the child is asked to listen to sequences of two or three isolated phonemes (which may be any combination of same and different phonemes). The child is asked to indicate whether the phonemes are the “same” or “different” by placing colored blocks in a row: two same colored blocks in response to two same phonemes (such as /s//s/) or two blocks of the same color followed by one block of a different color in response to the phoneme pattern /b//b//z/. The purpose of the IPP subtest is to assess the child's ability to discriminate phonemes and perceive the number and order of phonemes in a sequence and to introduce the child to the idea of using colored blocks to represent sounds and sound patterns.

The second subtest, “Tracking Phonemes (TP) (Monosyllables),” assesses the child's ability to track the number and order of phonemes within a syllable. The syllables in these test items are all pronounceable nonwords. In addition, the child is asked to demonstrate his/her understanding of the addition, deletion, substitution, shift, or repetition of a phoneme in a monosyllabic sequence. The examiner sets a row of blocks in front of the child (e.g., a green block followed by a white block) that represents a phoneme sequence, and pointing to the blocks, says to the child, for example, “If that says /Ip/, show me /pI/.” If the child switches the order of the two blocks in front of him/her, the response is scored as correct.

In the third subtest, “Counting Syllables” (CS), the child is asked to listen to a nonword stimulus and indicate the number of syllables in the nonword by placing a sequence of colored felt squares (not blocks) in a row in front of him/her. The fourth subtest, “Tracking Syllables” (TS), assesses the child's ability to track the number and order of syllables within a nonword and recognize the addition, deletion, or substitution of a syllable in the nonword. In the final subtest, “Tracking Syllables and Phonemes” (TSP), the child is asked to monitor changes that occur in a nonword as the examiner adds, deletes, or substitutes either a syllable or a phoneme. In this task, the syllable(s) in the nonword are represented with the

colored felt squares, and the phoneme(s) in only *one* of the syllables are represented by placing the colored blocks on top of the felt square that represents that syllable. For each item, the child is asked to explicitly manipulate the block(s) or square(s) to represent the change made to the nonword.

We selected the LAC3 to measure phonological awareness for several reasons. First, the subtests of the LAC3 measure phonological awareness on two different levels (phoneme and syllable). Second, the LAC3 test items do not require the child to produce a potentially confounding spoken response. Third, the use of nonsense syllables and nonwords minimizes the child's ability to rely on lexical knowledge in producing their responses. Fourth, the LAC3 was unlikely to elicit floor or ceiling level performances because it spans a wide range of difficulty. Fifth, the test is standardized and has been shown to be valid and reliable. The LAC3 manual provides norm-referenced standard scores for hearing children of a wide age range including all ages of children who participated in this study.

Reading Recognition: letter/phoneme matching and single-word reading. The children also completed two subtests of the Peabody Individual Achievement Test—Revised (PIAT-R; Markwardt, 1998). The Reading Recognition subtest of the PIAT-R includes 100 items. The first 16 items consist of 4 alternative forced choice questions requiring a pointing response. Several types of items are included: letter matching, initial-phoneme matching, and matching of initial phonemes to letters. 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 (letter matching), the child is asked to name the object shown in four pictures and then choose the *picture* of an object whose name starts (or does not start) with the same sound as the other three objects (initial-phoneme matching), or the child is asked to look at a picture of, for example, a mouse and then point to the *word* that starts with the same sound as “mouse”, such as “may” (matching of initial phonemes to letters). Items 17–100 all involve single real-word reading. The words are ordered in terms of increasing difficulty, ranging from kindergarten level to 12th-

grade level, for example, “and,” “height,” “statistics,” and “vitate.”

In the Reading Recognition subtest, children earn one point for every correct answer to items 1–16, and one point for every correct pronunciation of items 17–100, with each pronunciation counted as either correct or incorrect after one attempted pronunciation. The test is administered until the child provides an incorrect response for five out of seven consecutive items. Because most of the items on the Reading Recognition subtest involve reading a single real word, we refer to it as a measure of single-word reading in the present report.

Nonword reading. The Word Attack subtest of the Woodcock Reading Mastery Tests—Revised (WRMT, Form G; Woodcock, 1998) was also administered to the children. The Word Attack subtest is a nonword reading task that includes 45 nonwords or rare real words. Each child was asked to read the nonwords aloud to the examiner one at a time. In order to complete this task, children cannot rely on visual recognition of the stimuli 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, 1998, p. 6). The children received one point for each nonword that was pronounced correctly. The test is administered until the child incorrectly produces six consecutive items (within a subgroup of nonwords).

Sentence comprehension. The Reading Comprehension subtest of the PIAT-R (Markwardt, 1998) was also administered to the children. This test includes 82 four-alternative forced-choice items that require a pointing response. The test items are meaningful sentences designed to test literal reading comprehension, as opposed to, for example, interpretation of information or recognition of inferences (Markwardt, 1998). For each test item, the child is shown a sentence and is told to read it to himself/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, for example, “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. The test is administered until the child provides an incorrect response for five out of seven consecutive items.

Speech perception. The children’s speech perception skills were measured using the Phonetically Balanced Kindergarten (PBK; List 3A) test. The PBK is an open-set test of spoken word recognition (Haskins, 1949; see Meyer & Pisoni, 1999). Several lists of 50 monosyllabic words that are balanced to include multiple examples of most English phonemes are included in the PBK. In the present study, we administered List 3A using live-voice auditory-only presentation to all of the children. We report two raw scores (number of words correct and number of phonemes correct) and two percent-correct scores (out of the 50 words; out of the 140 key phonemes in the PBK words).

Vocabulary. In order to obtain a measure of the children’s vocabulary knowledge, each child completed the Peabody Picture Vocabulary Test (PPVT; Dunn LM & Dunn LM, 1997). The PPVT has been shown to be reliable and valid. The manual provides norm-referenced standard scores for individuals ages 2–90+. For each item, the child is asked to listen to a word presented live voice using auditory-visual presentation and to point to a picture that best represents the meaning of the word (out of four pictures on a response page). The PPVT consists of 12 sets of 17 items each. The sets increase in difficulty throughout the test. The PPVT is administered until the child responds incorrectly to 8 out of 12 items within a set.

Data Analyses

We calculated raw scores and percent correct scores for the LAC3, PIAT Reading Recognition, WRMT Word Attack (WRMT-WA), PIAT Reading Comprehension, and PPVT. PIAT Total Reading scores were also calculated by summing the children’s scores on the PIAT Reading Recognition and PIAT Reading Comprehension tests.

For comparison with hearing children (Research Question 1), we used the children’s raw scores to determine their standard scores on the LAC3, PIAT Reading Recognition, WRMT-WA, PIAT Reading Comprehension, and PPVT. Standard scores are transformed raw scores. A standard score of 100 corresponds to the mean raw score obtained from a large sample of the population. A standard score of 85 is 1 standard deviation (*SD*) below the mean, and a standard score of 115 is 1 *SD* above the mean. In addition, we determined the children’s percentile ranks using the tables provided with the LAC3, PIAT, WRMT, and PPVT in order to investigate what percentage of the children’s hearing peers obtained lower scores than the children who participated in the present study.

To compare the children’s performance on syllable-level and phoneme-level phonological awareness (Research Question 2), we calculated LAC3 subtest scores and compared the percent-correct subtest scores across and within the individual children. To investigate the extent to which measures of the children’s phonological awareness indicated their ability to complete the reading tasks (Research Question 3), we computed correlations between the LAC3 and the reading tests. Finally, we computed partial correlations between reading skills and performance on the LAC3, statistically controlling for potentially confounding demographic characteristics, speech perception scores, and vocabulary knowledge (Research Question 4). In order to know which demographic variables to control, we first computed bivariate correlations between the test scores and the children’s demographic characteristics.

Results

Overall Performance on Tests

A wide range of scores was obtained from the children on all of the tests. Most of the children performed with some success on the phonological awareness, reading, and vocabulary tests, although several of the youngest children could not complete two of the tests. More specifically, three children scored zero on the Reading Comprehension test. Two of those children were 6 years old and were only beginning to read single words; one child was 8 years old. The same three children also scored zero on the Word Attack nonword reading test, in addition to another 6-year-old child.

Performance Relative to Hearing Children on Standardized Tests

Standard scores. The children's standard scores on the LAC3, PIAT Reading Recognition, PIAT Reading Comprehension, PIAT Total Reading, WRMT-WA, and PPVT are shown in Table 2. Standard scores corresponding to the distribution of scores obtained from hearing populations that were either the same chronological age (standard scores based on age) or the same grade in school (standard scores based on grade) were calculated for each of the children. As described in the Data Analyses section above, a standard score of 100 corresponds to the mean raw score obtained from the normalization. One *SD* corresponds to 15 points on the standard scores scale; thus, if a child obtains a standard score (based on age) between 85 and 115, he/she could be said to fall within the normal range of performance for hearing, typically developing children who are his/her age. Standard scores based on grade level are not available for the LAC3 and the PPVT.

As shown in Table 2, the mean score obtained by the children in the present study for the LAC3 falls just within the normal range (85 is 1 *SD* below the mean). The children's vocabulary knowledge as measured by the PPVT was just under 1 *SD* below the mean, indicating that as a group, the children in the present study had slightly lower than average vocabularies compared with hearing children their age. The standard scores based on age for the reading tests are all close to 100, indicating that these children on average performed nearly as well as the hearing sample populations of children their ages and grades. However, children's scores varied widely on all of these tasks.

Table 3 shows the number of children whose standard scores fall within 1 *SD* bins with respect to the mean. At least three children scored more than 1 *SD* both above and below the mean for every test (for both the age-based and grade-based standard scores). However, the majority of children scored within 1 *SD* of the mean or higher for all tests except the PPVT.

Percentile ranks. The standard scores presented above reveal how the children's performance on the various tests was distributed around the mean obtained from hearing, typically developing children in their age groups. The percentile ranks shown in Figure 1 indicate the proportion of the hearing population that would perform more poorly than the deaf children in the present study. A child's percentile rank indicates the percent of children in the normative sample who scored at or below the same level as the child (when the normative sample includes children in the same age group as the child in question). Percentile ranks are useful measures because they provide a benchmark as to where a child would fall within an average group of his/her hearing peers.

The children's individual percentile ranks for the LAC3 (Figure 1) are shown as a function of age. The bar for each child indicates the percentage of the child's hearing peers whose standard scores would be lower than the standard score obtained from the deaf child. For instance, as shown in Figure 1, the 6-year-old child C11 obtained a higher score than approximately 75% of hearing 6-year-olds on the LAC3. Child C11 was one of only four children in the present study whose performance on the LAC3 was better than 50% of their hearing age peers (the others are children C10, C24, and C07, as shown in Figure 1).

Table 2 The children's standard scores on the standardized tests

Test	Standard scores based on child's age				Standard scores based on child's grade			
	<i>N</i>	Mean	<i>SD</i>	Range	<i>N</i>	Mean	<i>SD</i>	Range
LAC3 Total (phonological awareness)	25	88	13	55–111	Not available			
PIAT Reading Recognition	24	95	15	75–128	23	100	17	75–132
PIAT Reading Comprehension	24	94	20	55–132	22	99	22	55–136
PIAT Total Reading	25	94	18	55–130	23	99	20	57–134
WRMT-WA (nonword reading)	23	101	15	70–125	23	103	22	39–133
PPVT(vocabulary)	24	81	19	40–117	Not available			

Note. LAC3, Lindamood Auditory Conceptualization Test—Third Edition; PIAT, Peabody Individual Achievement Test; WRMT-WA, Woodcock Reading Mastery Test Word Attack; and PPVT, Peabody Picture Vocabulary Test.

Table 3 The percent of children whose standard scores were within various *SD* bins of the mean

		Standard scores					
		Less than −2 <i>SD</i>	−2 to −1 <i>SD</i>	−1 to 0 <i>SD</i>	0 to +1 <i>SD</i>	+1 to +2 <i>SD</i>	Greater than +2 <i>SD</i>
Outcome measures		<70	70–84	85–99	100–114	115–129	>129
Standard scores based on age	LAC3	8%	24%	52%	16%	0%	0%
	PIAT Recognition	0%	21%	50%	17%	13%	0%
	PIAT Comp	13%	13%	33%	25%	13%	4%
	PIAT Total	4%	17%	50%	13%	13%	4%
	WRMT-WA	0%	13%	35%	35%	17%	0%
	PPVT	29%	29%	25%	13%	4%	0%
Standard scores based on grade	PIAT Recognition	0%	22%	43%	9%	22%	4%
	PIAT Comp	9%	5%	45%	9%	23%	9%
	PIAT Total	5%	14%	41%	9%	27%	5%
	WRMT-WA	9%	4%	22%	43%	4%	17%

Note. LAC3, Lindamood Auditory Conceptualization Test—Third Edition; PIAT, Peabody Individual Achievement Test; WRMT-WA, Woodcock Reading Mastery Test Word Attack; and PPVT, Peabody Picture Vocabulary Test. Standard scores within normal range (i.e., within 1 *SD* of the mean) are shown in bold. Half of the normative sample of hearing children fall below the mean, half above the mean. Thirty-four percent of the normative sample of hearing children fall within 1 *SD* below the mean, 14% fall between 1 and 2 *SD*s below the mean, and 2% fall more than 2 *SD*s below the mean. Similarly, thirty-four percent of the normative sample of hearing children fall within 1 *SD* above the mean, 14% fall between 1 and 2 *SD*s above the mean, and 2% fall more than 2 *SD*s above the mean.

Note that the older children's scores tended to be in the bottom half of their peer group scores more frequently than the younger children's scores. This result must be interpreted cautiously, however, and will be addressed in the Discussion section. We also observed similar patterns in the percentile ranks for the other standardized tests (not shown in figures), with lower overall percentile ranks on the PPVT. The percentile ranks for the PPVT revealed that only three children's performance fell within the top half of the scores obtained by their hearing age peers.

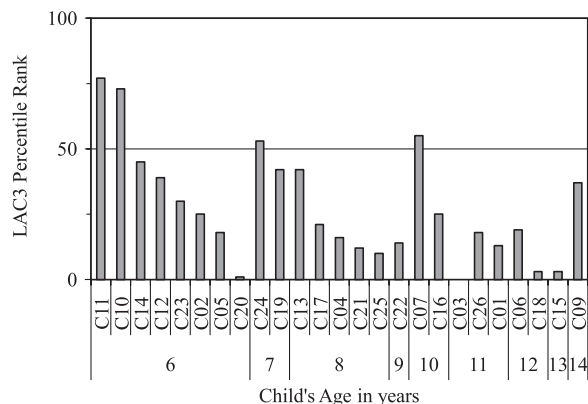


Figure 1 Lindamood Auditory Conceptualization Test (LAC3)—Third Edition percentile ranks derived from the children's standard scores based on age, shown as a function of the child's age.

Speech Perception Scores

When the speech perception test (PBK) was scored as percent words correct, the children's mean score was 68% words correct ($SD = 14\%$). No child received a score lower than 30% words correct; the highest score was 84% words correct. When the PBK was scored as percent phonemes correct, the children's mean score was 86% phonemes correct ($SD = 9\%$). Only two children obtained scores lower than 81%; these two children still obtained relatively high percent phonemes correct scores, 61% and 63%. The highest score was 94% phonemes correct. Thus, the children in this sample exhibit fairly good speech perception abilities in quiet listening conditions. Hearing children ages 3 and 4 perform at ceiling on the PBK (Kluck, Pisoni, & Kirk, 1996).

Phonological Awareness

Overall, the children exhibited a great deal of variability on all of the LAC3 subtests. The children obtained the highest average scores on the Isolated Phoneme Patterns (IPP) subtest ($M = 87\%$, $SD = 23\%$, range = 13–100%), followed by their performance on the Counting Syllables (CS) subtest ($M = 52\%$, $SD = 21\%$, range = 0–100%). The children performed similarly on the Tracking Syllables (TS) and Tracking Phonemes (TP) subtests

($M = 24\%$, $SD = 23\%$, range = 0–70%; $M = 22\%$, $SD = 17\%$, range = 6–61%, respectively). Finally, the Tracking Syllables and Phonemes (TSP) subtest was only administered to children who obtained a score of 50% or higher on the Tracking Phonemes subtest.² Thus, only seven children participated in the TSP subtest ($M = 15\%$, $SD = 24\%$, range = 0–67%). Three of the children who participated in the TSP subtest were unable to provide any correct responses and received scores of 0. The other four children obtained percent correct scores of 8%, 33%, 42%, and 67% on the TSP.

Correlations Between Phonological Awareness and Reading

In order to investigate the relations between phonological awareness and reading skills, we computed simple bivariate correlations between the children's scores on the phonological awareness measure (LAC3 Total scores) and their scores on the reading measures (PIAT Reading Recognition, WRMT-WA, PIAT Reading Comprehension, and PIAT Total Reading scores). The phonological awareness scores were strongly correlated with all of the reading scores (Pearson r 's = +.82, +.74, +.86, +.85, respectively, $p < .001$; shown in Table 5 below).

Factors Related to Phonological Awareness and Reading

Given that the children's phonological awareness and reading skills were strongly related, we also investigated the extent to which this relationship was mediated by other factors. First we examined demographic characteristics that were potentially confounding variables.

Correlations between the children's demographic characteristics and their scores on the phonological awareness, reading, vocabulary and speech perception tests are shown in Table 4. Because this initial analysis included a large number of correlations, we also investigated which correlations reached significance when we used a Bonferroni correction, dividing the desired alpha (.05) by the number of correlations (42) in order to determine the corrected alpha level ($\alpha = .00119$).

In general, the correlations that remained significant at this corrected alpha level were the correlations between the children's age at testing and grade in school on the one hand and their reading and vocabulary scores on the other hand (shown in bold in Table 4). The children's age at onset of deafness and duration of deafness prior to implantation were not significantly correlated with any of the test scores. Age at implantation was only weakly correlated with nonword reading (WRMT-WA) and sentence comprehension (PIAT Comp). Age at time of testing and grade level in school were also moderately correlated with phonological awareness (LAC3), reading (PIAT Rec, WRMT-WA, PIAT Comp, PIAT Total), and vocabulary (PPVT) scores. None of the demographic variables were significantly correlated with the children's speech perception (PBK) scores.

The demographic variables that emerged as possible underlying mediating factors because they were significantly correlated with phonological awareness and/or reading were the children's age at testing, grade in school, and duration of cochlear implant use. These variables were all strongly intercorrelated with each other (Pearson r 's = +.98, +.85, +.86; p 's < .001); thus it was not necessary to control for

Table 4 Correlations between the children's demographic characteristics and their scores on the outcome measures

	LAC3	PIAT Recognition	WRMT-WA	PIAT Comp	PIAT Total	PPVT	PBK
Age at onset	ns	ns	ns	ns	ns	ns	ns
Duration of deafness prior to implantation	ns	ns	ns	ns	ns	ns	ns
Age at implantation	ns	ns	+ .41*	+ .43*	ns	ns	ns
Duration of cochlear implant use	+ .48*	+ .63**	+ .49*	+ .56*	+ .60**	+ .61**	ns
Age at testing	+ .45*	+ .70***	+ .66***	+ .69***	+ .64***	+ .63***	ns
Grade level	+ .47*	+ .75***	+ .65***	+ .72***	+ .69***	+ .68***	ns

Note. LAC3, Lindamood Auditory Conceptualization Test—Third Edition; PIAT, Peabody Individual Achievement Test; PBK, Phonetically Balanced Kindergarten Test; PPVT, Peabody Picture Vocabulary Test; and ns, nonsignificant. * $p < .05$, ** $p < .01$, *** $p < .001$. We also applied Bonferroni corrections (because of the large number of correlations run in this analysis) by dividing the desired alpha (.05) by 42 (the number of correlations calculated). Thus, the corrected alpha was .00119. Correlations that were significant using the Bonferroni corrected alpha value are shown in bold.

them independently. We chose to control for age at testing, and computed partial correlations between the LAC3 and the reading measures with age at testing partialled out. As shown in Table 5, the correlations between the LAC3 and the reading measures did not decrease when age at testing was controlled (Pearson r 's = $+.80$, $+.74$, $+.77$, $+.82$).

Second, because the children in this study were deaf and because speech perception skills have been shown to play an important role in phonological awareness (see McBride-Chang, 1995), we were interested in the extent to which the children's open-set speech perception skills (as measured with the PBK) played a role in the relationship between their phonological awareness and reading skills. To do this, we computed partial correlations between the LAC3 and reading scores, partialling out the children's PBK scores. The obtained results were very similar whether we partialled out the PBK percent words correct scores or percent phonemes correct scores; the results of the partial correlations in which we controlled percent words correct PBK scores are shown in Table 5. Again, we found that these partial correlations were not smaller than the simple bivariate correlations (Pearson r 's = $+.87$, $+.85$, $+.89$, $+.85$).

These findings indicate that the children's age at testing and speech perception skills were not mediating factors in the relationship between their phonological awareness and reading skills. However, when we controlled for the children's vocabulary size by partialling out their PPVT scores, the correlations between the LAC3 and the reading measures decreased, as shown in Table 5 (Pearson r 's = $+.63$, $+.56$, $+.58$, $+.63$, respectively). This decrease in the magnitude of the correlations indicates that the correlation between the children's reading and phonological awareness is partially mediated by their vocabulary knowledge. That is, vocabulary knowledge is a mediating factor in the relationship between reading and phonological awareness.

Because we found that vocabulary size plays a role in the relationship between reading and phonological awareness, we also investigated the reciprocal relationships. We computed bivariate correlations between reading and vocabulary and then partialled out phonological awareness to investigate its role in the

Table 5 Correlations of reading with phonological awareness and with vocabulary

Outcome measure	Correlations with phonological awareness (LAC3)			Correlations with vocabulary knowledge (PPVT)				
	Bivariate	Partial 1 (age or grade)	Partial 2 (speech perception)	Partial 3 (vocabulary)	Bivariate	Partial 1 (age or grade)	Partial 2 (speech perception)	Partial 3 (phonological awareness)
PIAT Recognition	$+.82^{***}$	$+.80^{***}$	$+.87^{***}$	$+.63^{***}$	$+.93^{***}$	$+.88^{***}$	$+.93^{***}$	$+.85^{***}$
WRMT-WA	$+.74^{***}$	$+.74^{***}$	$+.82^{***}$	$+.56^{**}$	$+.83^{***}$	$+.73^{***}$	$+.86^{***}$	$+.61^{**}$
PIAT Comp	$+.86^{***}$	$+.77^{***}$	$+.88^{***}$	$+.58^{**}$	$+.91^{***}$	$+.84^{***}$	$+.87^{***}$	$+.76^{**}$
PIAT Total	$+.85^{***}$	$+.82^{***}$	$+.89^{***}$	$+.63^{***}$	$+.94^{***}$	$+.90^{***}$	$+.92^{***}$	$+.86^{***}$

Note. LAC3, Lindamood Auditory Conceptualization Test—Third Edition; PIAT, Peabody Individual Achievement Test; WRMT-WA, Woodcock Reading Mastery Test Word Attack; and PPVT, Peabody Picture Vocabulary Test. $*p < .05$, $**p < .01$, $***p < .001$. The left half of the table shows bivariate correlations between reading and phonological awareness followed by partial correlations in which we factored out age (results were nearly identical when grade level was factored out), speech perception, or vocabulary. The right half of the table shows bivariate correlations between reading and vocabulary followed by partial correlations in which we factored out age (results were nearly identical when grade was factored out), speech perception, or phonological awareness.

relationship between reading and vocabulary. As shown in the right half of Table 5, the results were very similar to the first set of correlations. The children's reading test scores and vocabulary knowledge were strongly correlated (Pearson r 's = +.93, +.83, +.91, +.94). These correlations were only slightly affected by the children's chronological age and were not affected by the children's speech perception scores on the PBK. However, when phonological awareness was partialled out, the correlations between reading and vocabulary decreased but remained significant.

Taken together, the correlations shown in Table 5 indicate that reading is strongly related to phonological awareness and is also strongly related to vocabulary knowledge. However, the decrease in the correlations when either of these measures is factored out indicates that there is substantial (but not complete) overlap in the contributions made to reading skills by these two factors. That is, phonological awareness and vocabulary are both independently related to reading, as well as to one another.

Discussion

Twenty-seven experienced cochlear implant users ages 6–14 participated in the present study. The children ranged in age from 6 to 14 years old. Most were congenitally deaf and received an implant before age 3. All of the children were deaf before age 3.5, received an implant by age 6, and had used their implant for at least 3.7 years. The children completed three reading tests (single-word reading, nonword reading, and sentence comprehension), a phonological awareness test, a speech perception test, and a vocabulary test. A few of the younger children who were unable to read could not complete the reading tasks and several subtests of the phonological awareness tasks. However, most of the children could perform with some accuracy on all of the tests, and many of the children performed with higher levels of accuracy than would typically be expected for profoundly deaf children. We address this finding in more detail in the following section.

Comparisons to Hearing Children

On the standardized tests of reading, phonological awareness, and vocabulary knowledge, we found that

approximately 40% to 75% of the children in the present study obtained scores that were within the normal range (1 *SD* above or below the mean) of hearing children. About a quarter of the children performed below normal for hearing children their age. Up to approximately 25% of the children performed above the norm compared with their hearing peers.

The reading tests used in the present investigation included tests that assessed single-word reading and early Reading Recognition (PIAT Reading Recognition), nonword reading (WRMT-Word Attack), and sentence comprehension (PIAT Reading Comprehension). Profoundly deaf children typically perform below the age/grade level of their hearing peers on these tests, with their reading skills asymptoting at about a third- or fourth-grade level. In the present study, we found that the children's standard scores on the phonological awareness and vocabulary measures indicated that they were on the low end of the normal range of scores obtained by their hearing peers. At least three children obtained above-normal scores for their age or grade on each standardized test (which measured phonological awareness, reading skills, and vocabulary). However, the children exhibited overall poorer vocabulary scores given their relatively high reading scores. Further exploration of the relations between vocabulary knowledge and reading in deaf children who use cochlear implants would be worthwhile in future studies.

Whereas the standard scores reported above showed that many of the children performed within the normal range for children their age or grade level, the percentile rank scores revealed that a greater proportion of the older children who used cochlear implants (compared to the younger children) performed in the bottom half of their hearing peer groups on the phonological awareness and reading tests. The older children with cochlear implants had less success performing at levels equivalent to those of their hearing peers.³ From the present data, we are unable to assess whether the younger children in the present study will continue to develop improved phonological awareness and reading skills, performing on par with their hearing peers as they get older; or whether the younger children's phonological awareness and reading skills will not improve at the same rate as their hearing peers, causing them to fall increasingly behind

the hearing population as they get older. The difference between the older children and younger children could be due to differences in demographic characteristics that we were unable to assess precisely with the present group of participants. Another possibility is that the difference between the older and younger children is related to variation in the educational environments of the children. Perhaps older children whose phonological awareness skills were substantially behind those of their hearing peers were not receiving phonological awareness instruction because it is not typically a focus of reading instruction for older children, while it is more commonly included in reading instruction for younger children. In addition, a larger proportion of the younger children were enrolled in oral schools for the deaf, where emphasis is on spoken language development that may help improve phonological awareness skills, rather than mainstream classroom programs (Harris & Terlektsi, 2010). A longitudinal study in which the phonological awareness, vocabulary, and reading skills of children with cochlear implants are tracked from pre-reading (pre-school) age to adulthood in various educational environments is necessary for a better understanding of the time course of the development of phonological awareness and its relationship to the development of reading skills and the acquisition of vocabulary knowledge.

In addition, although many of the younger children performed quite well relative to their hearing peers on the LAC3 and reading measures, the younger children who did not perform as well tended to perform very poorly. It is possible that the extremes of performance that we observed among the younger children on these tasks were due to differences in the children's educational experiences as well. Perhaps oral schools provided opportunities for students to develop phonological awareness skills to a greater extent than other schools because of their emphasis on the development of spoken language skills. Future studies will need to explore the relative performance of children who are in different school environments and/or exposed to different educational approaches (see Easterbrooks, 2010; Schirmer & Williams, 2011). Future studies should be particularly informed by recent findings showing that deaf/hard of hearing students' phonological skills benefit from educational

approaches in which phonologically related skills are explicitly taught (Trezek & Malmgren, 2005; Wang, Trezek, Luckner, & Paul, 2008) and that phonological awareness (at the rhyme level) develops in conjunction with reading skills rather than as a prerequisite (Kyle & Harris, 2010). The relationship between reading skills and the extent to which phonologically related skills—especially phoneme-level awareness—are explicitly taught and learned should be examined in children who use cochlear implants in future longitudinal studies.

The children's sentence comprehension scores tended to be closer to those of their hearing peers than their vocabulary scores were. This finding suggests that deaf children may make greater use of higher order top-down sentence context in order to interpret sentences for meaning on the comprehension test than hearing children did, allowing them to perform at a relatively higher level on the sentence comprehension task than on the PPVT compared with hearing children. Another interpretation of this finding is related to the administration of the PPVT, which required the use of speech perception skills while the reading tests did not. This difference could have led to the children's relatively better performance on the reading tasks. However, the children's speech perception scores on the PBK test were generally high, and they did not express difficulty perceiving the stimuli during the administration of the PPVT.

A third point to consider when interpreting these results is that recent studies have provided converging evidence that measures of reading comprehension at the sentence level are inferior to measures of reading comprehension that involve passage comprehension and that many items in sentence-level comprehension tests may measure phonological knowledge rather than comprehension (Cutting & Scarborough, 2006; Keenan & Betjemann, 2006). In the present study, we used a measure of sentence comprehension to obtain reading comprehension levels. Future studies should investigate performance on measures of reading comprehension that involve passage comprehension.

Performance on Phonological Awareness Subtests

The phonological awareness test used in this study included five subtests of varying phonological levels.

We expected that the children's performance would vary across the subtests. Specifically, based on earlier reports in the literature regarding the performance of hearing children, we expected that the relative difficulty of the subtests, from least difficult (highest percent-correct scores) to most difficult (lowest percent-correct scores) would be:

Counting Syllables \geq Isolated Phoneme Patterns \geq
Tracking Syllables > Tracking Phonemes >
Tracking Syllables and Phonemes.

The children's actual percent-correct scores from highest to lowest on the LAC3 subtests were:

Isolated Phoneme Patterns > Counting Syllables >
Tracking Syllables, Tracking Phonemes >
Tracking Syllables and Phonemes

In expecting that the children would perform better on the CS subtest than the IPP subtest, we did not consider that the trials for the IPP subtest involved *isolated* phonemes. The child did not have to extract individual phonemes from a continuous speech stream in order to provide the correct response for the IPP. However, for the CS subtest, the child was required to parse a continuous speech stream into syllables in order to correctly tell the experimenter how many syllables were in the stimulus. Thus, although the IPP involves phonemes and the CS subtest involves syllables (and in general, children's syllable-level awareness seems to precede phoneme-level awareness), we believe that the need to *parse* in the CS subtest caused the children to perform more poorly on the CS subtest than on the IPP subtest. Similar to hearing children, these children performed better when the task did not require them to explicitly manipulate the phonological units in question as the tracking tasks did (cf., Schatschneider et al., 1999; Stahl and Murray, 1994).

Overall, the LAC3 results indicate that the children in the present study were able to utilize the albeit degraded speech signal transmitted by their cochlear implants (along with visual and tactile information) in order to at least begin to develop phonological awareness skills. The children's phonological awareness as indexed by the various subtests of the LAC3 phonological

awareness test followed a similar pattern of development as might be predicted for hearing children. They performed more poorly on phonological awareness tasks that required them to explicitly manipulate the phonological units in question. They were able to count syllables in nonwords with greater accuracy than they were able to track syllables or phonemes, and they had the most difficulty tracking both syllables and phonemes in a single task. The only surprising finding was that the children with cochlear implants were not able to track syllables better than they were able to track phonemes. This finding may be task specific, especially because it conflicts with recent findings reported in James and colleagues (2005). Further exploration of the relationships between reading skills and specific levels of phonological awareness (e.g., phoneme level, syllable level, onset-rime level) may provide additional insights into the foundational linguistic skills that underlie reading in deaf children who use cochlear implants.

Relations Between Reading Skills and Phonological Awareness

We found that the children's reading scores were strongly correlated with their phonological awareness skills. This is an important finding because it is consistent with an extensive body of earlier research findings obtained from hearing children: like hearing children, among children who use cochlear implants, those children who have better phonological awareness skills also tend to be better readers. The correlations between phonological awareness and the reading tests in the present study were strong even with a modest sample size of only 27 participants.

The Role of Demographic Characteristics

The children's age at testing and grade level in school were the only demographic variables that were found to be significantly correlated with most of the outcome measures. These correlations are consistent with the literature on behavioral measures of children who use cochlear implants. The two moderate positive correlations between age at implantation and WRMT and PIAT scores indicate that children who were implanted at older ages tended to obtain higher scores on these measures than younger children. This result was surprising given that children implanted at younger

ages tend to outperform children implanted at older ages on behavioral measures. We wondered if these correlations could be attributed to the fact that the *older* children in our sample were those who had received their implants at later ages—and therefore had more experience with their implants than many of the younger-implanted children. Thus, we reran these correlations partialling out chronological age. We found that the correlations were no longer significant when chronological age was partialled out, indicating that the positive correlations between age at implantation and WRMT and PIAT scores may be due to the fact that later-implanted children were older and more experienced cochlear implant users. Future studies should continue to investigate the relation between these demographic variables and performance on speech- and reading-related behavioral measures.

Age at onset of deafness was unlikely to be significantly correlated with the outcome measures because most of the children in this study were congenitally deaf, making this variable relatively homogeneous. Although the other demographic variables were more heterogeneous, perhaps enough children fell within a crucial range (or time frame) for each variable, reducing the significance of variability across participants. Specifically, almost all of the children were deaf for less than 2 years before implantation, were implanted before age 3, and had used their implant for more than 5 years. Thus, these children had early access to spoken language and were experienced cochlear implant users at the time they participated in the present study. However, it is also noteworthy that children within the same age groups sometimes exhibited a great deal of variability in their performance. Thus, early implantation by itself does not guarantee later age- or grade-level performance on phonological awareness, reading, and vocabulary tasks.

Because age at testing was significantly correlated with the outcome measures, we factored out the children's age at testing from the correlations between reading and phonological awareness and from the correlations between reading and vocabulary. The correlations between phonological awareness and reading did not change, however, indicating that the children's age was not a mediating factor in the correlation between the reading measures and phonological awareness. The correlations between vocabulary and reading decreased

slightly when age was factored out, indicating that the children's age had very little effect on this relationship.

The Role of Speech Perception

We also found that the correlations between reading and phonological awareness and the correlations between reading and vocabulary did not decrease when speech perception was statistically controlled. This finding indicates that the speech perception skills of this group of children were sufficiently developed as to have little effect on the development of phonological processing skills and lexical knowledge which they use while reading. That is, cochlear implants provide an audible speech signal for deaf children who do not perceive speech without the aid of their CIs; thus, this finding that speech perception was not significantly correlated with performance on speech and reading-related measures should not be interpreted to mean that cochlear implants do not improve speech perception. Rather, it is likely that this finding is due to the lack of heterogeneity in the children's speech perception scores. That is, perhaps this finding was at least partially due to the children's relatively high level of performance on the PBK. The average *phonemes* correct score obtained on the PBK test was 86% phonemes correct and the lowest score was 61% phonemes correct. The children's mean percent *words* correct score was necessarily lower ($M = 68%$, lowest score = 14%), but these scores were higher than previously reported scores for another group of deaf children. In earlier work, Cleary, Pisoni, and Kirk (2000) studied a group of 32 deaf children who use cochlear implants and oral communication. The children in their study were comparable to the children in the present study in terms of chronological age and age at onset of deafness. However, overall they had longer durations of deafness, received their implants at later ages, and had less experience with their implants at the time of testing. Cleary and colleagues found that the children in their study obtained an average score of only 46% words correct on the PBK, with a *SD* of 23% and a range of 8–88% percent words correct.

Thus, in comparison to the results reported in Cleary and colleagues (2000), the children in the

present study obtained substantially higher overall scores on the PBK. At this high level of speech perception performance, despite relatively wide variability in their PBK scores, the children's speech perception skills did not appear to play a significant role in mediating the relationship between their phonological awareness and reading skills. It is important to keep in mind, however, that the speech perception task we used in the present study was carried out in the quiet and did not include speech perception in noise, which may have elicited greater individual differences among the children. Even greater variability among the children may have resulted in speech perception scores emerging as a factor in the relationship between phonological awareness and reading.

The Role of Vocabulary Knowledge

We found that the children's reading scores were strongly correlated with their vocabulary size, showing that reading skills and lexical knowledge are closely linked in deaf children with cochlear implants, as they are in hearing children. The correlations between phonological awareness and reading decreased when vocabulary was statistically controlled. This finding suggests that the children with larger vocabularies may also have more robust phonological representations for the words they know. Several researchers (e.g., Edwards et al., 2004; Munson et al., 2005; Studdert-Kennedy, 2002) have hypothesized that children's phonological representations are strengthened with the acquisition of additional vocabulary items in their lexicons. This view is consistent with Beckman and Pierrehumbert's (2003) conceptualization of the mental lexicon in which representations are built up as the language user makes generalizations across the words he/she learns. The existence of highly detailed, more "robust" phonological representations in a child's lexicon allows for better performance on phonological awareness tasks and better reading skills on tasks that rely on phonological representations. Brady (1991) has proposed that more robust and detailed phonological representations may also enable the children to dedicate more resources to *processing* abstract phonological representations of words and nonwords (e.g., explicitly manipulating phonological units or interpreting words or phrases for

meaning) than to encoding and storing them. In the present study, the children with larger vocabularies may have developed more robust phonological representations that enabled them to obtain higher scores on the phonological awareness and reading tasks because they had to allocate fewer cognitive resources to the encoding of phonological units, and thus could dedicate more resources to other processing tasks (e.g., manipulating phonological units or processing sentences for meaning). This hypothesis should be further investigated in future studies of the relations between phonological working memory skills, phonological awareness skills, and reading development (see Pisoni, Conway, Kronenberger, Henning, & Anaya, 2010).

We also found that correlations between reading and vocabulary decreased when phonological awareness was statistically factored out. This finding is consistent with the hypothesis that the children who obtained higher phonological awareness scores may have been able to do so because they have developed more robust lexical representations by building their vocabulary as a result of reading more. Indeed, the relationship between phonological awareness development and reading skills development has been found to be bidirectional in hearing children: improvement or training in one domain corresponds with improvement in the other as well (Brady, 1997; Perfetti, Beck, Bell, & Hughes, 1987; Shaywitz et al., 2004; Troia, 2004; Wagner & Torgeson, 1987). Similarly, it has been found that development of reading and spelling skills can lead to increased phonological awareness (see, e.g., Cassar & Treiman, 2004) and vice versa (see, e.g., Ellis & Cataldo, 1992).

The finding that phonological awareness performance differed across subtests in a way that might be expected for hearing children, taken together with the finding that phonological awareness, reading, and vocabulary knowledge are strongly related skills in these children who are deaf (as has been found in hearing children), indicates that explicit training methods that have been shown to benefit hearing children with poor reading skills may also be beneficial to deaf children who use cochlear implants as well. Further investigation is merited into whether pediatric cochlear implant users' participation in tasks specifically aimed at building more robust phonological representations and

processing skills would also contribute to increased reading and, ultimately, improved literacy skills in this clinical population. Support for such an investigation is also warranted by the fact that numerous studies have reported that hearing children's reading skills can benefit from explicit training in phonological awareness and grapheme-phoneme mapping (phonics or phonological encoding; e.g., Ball & Blachman, 1988; Bradley and Bryant, 1983; Brady, Fowler, Stone, & Winbury, 1994; Gillon, 2004; Lundberg, Olofsson, & Wall, 1980; National Institute of Child Health and Human Development, 2000; Rayner et al., 2001; Treiman & Baron, 1983; for a review, also see Ehri et al., 2001).

In addition, if children's phonological representations are strengthened as their vocabulary expands, perhaps their phonological processing skills and reading skills would benefit from explicit vocabulary instruction (see Coyne, 2006; Mezynski, 1983; Paul, 1996). Vocabulary instruction, if carefully planned with the needs of deaf children in mind, could facilitate not only the children's phonological development but also their semantic knowledge and understanding of relationships among concepts (see Marschark, 2003; Marschark, Convertino, McEvoy, & Masteller, 2004; Marschark & Wauters, 2011). Longitudinal studies of the effects of phonological awareness training and/or vocabulary training in children with cochlear implants could provide further insights into the development of these skills and the relations between reading and vocabulary knowledge.

Conclusions

The results of the present investigation revealed strong relations between reading skills (single-word reading, nonword reading, and read-sentence comprehension) and phonological awareness skills in children who use cochlear implants. This relationship was not mediated by any of the traditional demographic variables or the children's speech perception scores but was found to be partially mediated by their vocabulary knowledge. Taken together, these findings are consistent with the hypothesis that larger vocabularies and more robust phonological representations partially underlie better phonological awareness and reading skills in this clinical population. The children with larger vocabularies are hypothesized to have developed more robust phonological representations, which contrib-

uted to their ability to obtain higher scores on the phonological awareness and reading tests. In addition, the finding that the link between reading and phonological awareness was explained partially but not fully by vocabulary knowledge indicates that performance on the phonological awareness test was not simply a direct reflection of vocabulary knowledge but was also dependent on the development and use of other cognitive skills. Accordingly, future studies of the development of reading skills in children who are deaf and use cochlear implants should include investigation into the contribution of more general cognitive skills such as nonverbal intelligence (IQ), along with other factors that have been found to contribute to reading skills in hearing children such as gender, parent involvement, and family socioeconomic status.⁴

Overall, the findings from the present study provide more detailed knowledge about the cognitive and linguistic processes used by deaf children with cochlear implants as they develop and acquire reading skills than has been reported in the past. Additional studies are needed in order to determine whether the children's performance in the present study is typical of cochlear implant users in general and in order to provide further insights into other aspects of reading acquisition and reading-related skills in deaf children with cochlear implants. Some additional areas that have been investigated in hearing children that may be worthwhile avenues of investigation in deaf children with cochlear implants include performance on speeded confrontational naming tasks, studies of sensory- and perceptual-motor development, spelling skills, and the development eye movements during reading. Furthermore, longitudinal studies should investigate the extent to which explicit instruction in phoneme-level awareness is related to reading skills in children who use cochlear implants. This article was an initial contribution to a novel research program that we hope will help lead to increased literacy skills in children who are deaf.

Notes

1. Demographic information was obtained from parents via a questionnaire. Because some children were tested in schools, the experimenter did not always meet parents. Some parents failed to complete the questionnaire and in a few cases the experimenters were unable to obtain omitted information from

the parents. Thus, the specific *N* for which information was available is provided throughout this report.

2. Child C26 was eligible to be given the TSP because he earned a score of 50% on the TP subtest, but due to time constraints Child C26 did not complete the TSP. In addition, despite the fact that Child C09 only received a score of 40% on the TP subtest, the experimenter administered the TSP subtest and so C09's TSP score is included above (67%). Child C09's LAC3 Total score was the highest in the group (70%). This raises a question as to whether other children's Total scores may have been higher if they had been given the opportunity to complete the TSP as well, even if they did not receive a score of 50% or higher on the TP subtest. The next highest TP score (below C09's 40%) was 24%. It is possible but unlikely that the administration of the TSP subtest to any other children who obtained TP scores lower than 50% would have resulted in a change in the overall performance within or between participants.

3. Note that, as reported above and shown in Table 4 as correlations between age at testing and several behavioral measures, the older children's raw scores were higher overall than the younger children's scores. The older children's scores were on the lower end of the normal range of scores obtained by their hearing peers, but the older children's scores still tended to be higher than the scores obtained by younger cochlear implant users.

4. In an attempt to investigate the role of socioeconomic status on the children's performance in the present study, we obtained information from the children's parents about their vocabulary knowledge, their highest level of education, their annual income, and the extent to which they spent time reading or looking at books with their children from birth until the time of testing. We found that none of these factors were significantly correlated with the children's performance on the speech- and reading-related measures in the present study. These negative results require further investigation before they can be interpreted.

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Conflicts of Interest

No conflicts of interest were reported.

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