RESEARCH ON
SPOKEN LANGUAGE PROCESSING

Technical Report No. 14

January 27, 2006

Speech Research Laboratory
Department of Psychological and Brain Sciences
Indiana University
Bloomington, Indiana 47405

Supported by:

Department of Health and Human Services
U.S. Public Health Service
National Institutes of Health
Research Grant DC00111
and
Training Grant DC00012

PHONOLOGICAL PROCESSING SKILLS AND THE DEVELOPMENT OF READING IN DEAF CHILDREN WHO USE COCHLEAR IMPLANTS

Caitlin M. Dillon

Submitted to the Faculty of the University Graduate School

in partial fulfillment of the requirements

for the degree

Doctor of Philosophy

in the Department of Linguistics,

Indiana University

December, 2005

Dedicated to my Mom and Dad,

who have now earned honorary doctorates in Linguistics.

Your love, guidance, faith and sense of humor have kept me going strong. Thank you!

Acknowledgements

Although only one author is listed here, this thesis is the work of many. I am sincerely grateful for the help and generosity of everyone who was my academic, emotional, physical, or spiritual mentor. Thank you for teaching and challenging me, keeping me healthy and making me laugh, motivating and encouraging me.

I learned an immeasurable amount about linguistics, psycholinguistics and academic life in general from my advisors and committee members Ken de Jong, David Pisoni, Stuart Davis, and Karen Kirk. I would like to thank Ken for pushing me with great kindness to do my best work; David for taking me into the Speech Research Lab when I had barely heard of cognitive psychology and patiently teaching me step by step; Stuart for feeding my interests in deaf culture and the history of linguistics and for providing much helpful mentoring; and Karen for making essential input into the design and analysis of this study, and for so willingly driving down from Indianapolis. I also truly appreciate the funding for my graduate studies provided by Indiana University, by the National Institutes of Health (NIDCD Research Grant R01 DC00111 and T32 Training Grant DC00012 to Indiana University), and by the generosity of my family.

I was given much guidance and assistance by my fellow SRLers over the years. I am especially grateful to my "mentors" and friends Miranda Cleary and Susie Levi. Thanks also to Cynthia, Rose, Steve, Jen, Sara, Becka, Luis, Darla, Tonya, Derek, David, Rachael, Marcia, all of the other SRLers and DeVaulters over the years; to Marilyn Estep, Lana Fish, Linette Staley, Robyn Britt, and Teri Kerr for their administrative help and the implementation of this study; and to Beth, Carolyn and the de Jong children. I was also given inspiring advice and real-life examples of excellent scholarship by Ann Geers, Emily Tobey, Jean Sachar Moog, Bob Port, Diane Kewley-Port, Bob Botne, Dan Dinnsen, Richard Bier, Kathleen Bardovi-Harlig, and Natsuko Tsujimura.

I have enormous gratitude to the following people, whose generous cooperation allowed me to test participants for this study: Richard Miyamoto; Brian Dunn, Michele Wilkins, Kerry Moriarty, Tanis and the teachers and staff at Child's Voice school in Wood Dale, IL; Jim Parker, Julie Swanson, and the staff in the Hearing Impaired Program at Shawnee Park school in Grand Rapids, MI; Jan Bermingham, Jonna, and the teachers and staff in the Hearing Impaired Program at Sylvester Elementary School in Berrien Springs, MI; Mary Clark-Kaiser and the Gatehouse staff at Aquinas College in Grand Rapids, MI, for kindly providing testing space; Tami, Cynthia, Liz, Marcie and Brian; and the parents and children that I had the pleasure of testing.

I would not have had the thrill of completing this degree without the comfort, encouragement, perspective, and laughter given to me by my mom, dad, Brian, Mary and Laura. My friends have helped me remember the most important things in life, especially fellow Michiganders/Aquinas friends Siobha⇔n, Yvette, Katie, Angie, Michael, Matt, Tami, Liz, Marcie, Brian, Beth, Steve, Tom, Kyle, Alicia, Andie, Kevin, Melissa, Meg, Paul, Brian and Heather; my St. Paul's friends Lori, Danielle, Lee, Dana, Donna, Angela, Rebecca, Bill, Kara, Bob, Anna, Merl, Fr. Don, Fr. Dan, Fr. Joe, Sr. Chet, Fr. Rich, Fr. Bob, Fr. Stan; my HPER friends Terese, Elisabeth, Steve, Tricia, Kris, Colleen, Megan, Tony, Tom and Judy; and my linguistics friends Vicki, Jon, Judy, Karen, Kelly, Laura, Sarah, Sean, Rose, Brian, Noah, Kyoko, Iskra, Steve, Masha, Lydia, Eric and Lisa.

Finally, my deepest thanks to the exceptionally inspiring teachers that I have had over the years, especially to the greatest teacher of all. Go runners, readers, and leapers!

Abstract

The reading skills of normal-hearing (NH) children have been found to be closely related to the development and use of phonological processing. In particular, children who have poor phonological awareness, i.e., who have difficulty understanding the concept that spoken words can be analyzed and decomposed into a sequence of smaller abstract units such as syllables or phonemes, often have difficulty learning to read as well.

Many deaf children and adults do not reach reading levels above the 4th-grade level. In the present investigation, we examined the cognitive and linguistic skills that underlie reading in deaf children who use cochlear implants. We recruited 27 children ages six to 14 who had several years' experience with a cochlear implant and used oral communication. On standardized phonological awareness, reading and vocabulary tests, approximately half of the children performed below the average level of their NH peers, and approximately half of the children performed at or above the average level of their NH peers. The children performed most poorly relative to their NH peers on the vocabulary test. Overall, more older children performed in the bottom half of their NH peer groups.

Although the children's performance on the standardized tests relative to their NH peers was encouraging in general, the deaf children examined in this investigation did not display sensitivity to differences in phonotactic frequency on a nonword repetition task. This finding suggests that these children have not had sufficient phonological experience to make broad phonological generalizations across the lexicon about the phonotactics of English. It is possible that if these children were asked to complete a processing task that did not require speech production, they would display evidence of phonotactic knowledge.

The children's phonological awareness skills were found to be strongly correlated with their reading skills. This relationship was mediated by the children's vocabulary size and not their demographic characteristics, speech perception skills, or phonological working memory skills. This new finding in deaf children with cochlear implants indicates that, as reported for NH children, the development of robust phonological and lexical representations also underlies the development of reading skills in this clinical population.

PHONOLOGICAL PROCESSING SKILLS AND THE DEVELOPMENT OF READING IN DEAF CHILDREN WHO USE COCHLEAR IMPLANTS

TABLE OF CONTENTS

CHAPTER I: INTRODUCTION

The education of deaf children has improved dramatically over the last century (e.g., Fischer, 1983). However, it is still widely reported that most deaf children and adults do not achieve reading levels above the 4th-grade level (Conrad, 1979; Karchmer, Milone, & Wolk, 1979; Moog & Geers, 1985; Paul, 2003). Research has established that, as in the normal-hearing population, the lower average reading abilities of deaf children and adults are not due to lower intelligence levels (Paul, 2003). Furthermore, the fact that some deaf individuals develop college-level reading skills (Hanson, 1991 cites Reynolds, 1975) indicates that deafness itself does not prevent the acquisition of advanced reading skills. Thus, the underlying nature of reading difficulties of children who are deaf is an important research problem that deserves attention.

In normal-hearing children, extensive research has revealed several well-established findings. Phonological processing skills, which include phonological awareness, phonological working memory skills, and lexical retrieval, have all been found to be related to reading development (Brady, 1991). Phonological awareness is the explicit knowledge that spoken language, while being a continuous acoustic stream, consists of sequences of smaller abstract units (e.g., syllables, onset-rimes, phonemes). Phonological working memory skills include working memory capacity (often indexed with digit span tasks) and verbal rehearsal speed (often indexed by speaking rate). Lexical retrieval is the ability to access and retrieve representations in the mental lexicon and can be indexed using speeded naming tasks or vocabulary tasks. In general, the type of phonological processing skills most closely associated with reading are tasks that assess phonological awareness skills.

Reading difficulties have been found to be associated with poor phonological awareness skills (e.g., Gillon, 2004). That is, children who have difficulty understanding the concept that a word can be decomposed into smaller abstract units (such as syllables or phonemes) often have difficulty learning to read as well. It is hypothesized that as children learn words in their language, the increased density of the lexical items encourages them to abstract smaller units (e.g., syllables, then phonemes) for which they develop representations in the mental lexicon (Juszcyk, Lube, & Charles-Luce, 1994). Their phonemic representations become stronger or more robust as their lexical representations increase and improve, that is, as they learn more words and gain more experience with language (Studdert-Kennedy, 2002). As their phonemic representations become more robust, the children in turn learn new words more easily, and also become more skilled at completing phonological awareness tasks that require the parsing of continuous speech into smaller linguistic units. In particular, the ability to parse speech into phonemic units is necessary in order for a child to be able to grasp the alphabetic principle: letters correspond to individual speech sounds (see Shankweiler, 1991). An understanding of the alphabetic principle is important for children when they are learning to read (Shankweiler, 1991). Thus, the correlation between phonological awareness and reading skills is hypothesized to be a reflection of the fact that more robust phonological representations in the mental lexicon underlie both sets of skills (e.g., Studdert-Kennedy, 2002).

The mental lexicons of adults and children also encode word frequency and phonotactic frequency. Previous research has shown that a word's frequency of occurrence, as well as the frequency of occurrence of the phonemic sequences (phonotactics) contained within a word or nonword, affect adults' and children's performance on a wide range of processing tasks such as lexical decision, lexical retrieval and nonword repetition (e.g., Edwards, Beckman, & Munson, 2004; Eukel, 1980; Newman & German, 2002; Vitevitch & Luce, 1998). In addition, the extent to which children's performance on nonword repetition reflects phonotactic knowledge has been shown to be related to their vocabulary knowledge (e.g., Munson, Edwards, & Beckman, 2005).

The present study was carried out on the premise that new insights into the skills that underlie reading abilities in deaf children with cochlear implants may be obtained through investigation of the same reading-related skills that have been examined in NH children. Chapter 2 summarizes the results of a preliminary study that was designed to test the feasibility of this hypothesis. We used existing data from 76 children with cochlear implants to investigate the relationship between reading skills and nonword repetition performance. We found that several different measures of reading were correlated with nonword repetition scores. These findings indicated that the reading tasks relied on some of the same underlying processes as the nonword repetition task. However, unexplained variance still remained in the children's reading scores. To identify other factors that might explain any of the remaining variance in reading scores, we also investigated demographic variables, communication mode, performance IQ, and "lexical diversity," a score based on the number of words the children used during an oral interview. We used lexical diversity because we did not have a direct measure of vocabulary knowledge and we speculated that lexical diversity may reflect vocabulary size. We computed partial correlations between reading and nonword repetition in which we factored out these additional variables. We found that demographic characteristics, communication mode and performance IQ were not underlying factors in the relationship between reading and nonword repetition but lexical diversity emerged as an important factor. That is, the correlations between reading and nonword repetition decreased when lexical diversity was partialled out, indicating that the children's reading skills relied both on skills involved in nonword repetition and on separate knowledge indexed by the lexical diversity measure. However, these two factors (nonword repetition and lexical diversity) still left unexplained variance in reading scores. To study these other variables, we completed further studies of the factors that underlie reading skills in deaf children with cochlear implants.

We recruited a new group of deaf children with CIs to participate in a set of closely-related studies designed to explore some possible factors underlying reading skills in deaf children with cochlear implants. Because phonological awareness has been found to be strongly related to reading development in NH children, we were particularly interested in exploring the extent to which reading and phonological awareness are related in our sample of children. In order to investigate other factors that underlie the relationship between reading and phonological awareness in this population, we also obtained scores from the children on several different measures of vocabulary, speech perception, nonword repetition, and working memory. We were able to use these scores not only in the correlational analyses with reading and phonological awareness, but also to investigate the children's performance on these measures as well.

In Chapter 3, we report the children's scores on measures of reading, phonological awareness and vocabulary. The reading tests included a single word reading measure (Reading Recognition subtest of the Peabody Individual Achievement Test – Third Edition; Dunn & Dunn, 1997); a nonword reading measure (Word Attack subtest of the Woodcock Reading Mastery Test – Revised; Woodcock, 1998); and a read-sentence comprehension measure (Reading Comprehension subtest of the Peabody Individual Achievement Test – Third Edition; Dunn & Dunn, 1997). The phonological awareness measure was obtained from the Lindamood Auditory Conceptualization Test – Third Edition (Lindamood & Lindamood, 2004), a standardized test that included several subtests. The subtests indexed different levels of phonological awareness: syllable-level, phoneme-level, and both together. The vocabulary measure was a standardized test of receptive vocabulary (Reading Comprehension subtest of the Peabody Individual Achievement Test – Third Edition; Dunn & Dunn, 1997). Because all of these tests have been standardized, we were able to compare the performance of the deaf children in our study with their NH peers using published norms based on the performance of large groups of NH children.

In Chapter 4, we report the children's performance on a nonword repetition task. The nonwords were a different set than in those used in the preliminary study reported in Chapter 2. However, we used the same scoring methods in order to be able to compare the preliminary results reported in Chapter 2 with those for the new set of participants. This new set of nonwords were developed by Edwards, Beckman, and Munson (2004) and contained nonwords with high phonotactic probability sequences and nonwords with low phonotactic probability sequences. These nonwords allowed us to investigate whether the children would demonstrate sensitivity to phonotactic probability by obtaining significantly different scores for the high phonotactic probability nonwords when compared to the low phonotactic probability nonwords. We did not compare the children's performance on the nonword repetition task to the scores of NH children on this task reported in the literature because we used a novel method of scoring the responses based on our earlier research (Dillon, Burkholder, Cleary, & Pisoni, 2004).

In Chapter 5, we report the children's performance on several processing tasks that were designed to measure phonological working memory. We obtained measures that indexed different components of phonological working memory. Forward digit spans were obtained as an index of the children's working memory capacity. A speaking rate measure based on the children's sentence durations was obtained as an index of verbal rehearsal speed. And, backward digit spans were obtained as an index of executive function. The children's performance on these tasks is summarized and compared with previously reported results from other groups of children with cochlear implants and NH children.

In addition to describing the children's performance on these various measures, we report the results of several correlational analyses. In Chapter 3 we present correlations between the children's reading scores and measures of phonological awareness. We found that reading and phonological awareness measures were strongly correlated, indicating that reading ability is closely related to phonological awareness in deaf children with cochlear implants. We also explored the degree to which demographic variables (Chapter 3), speech perception (Chapter 3), vocabulary (Chapter 3), a new nonword repetition measure (Chapter 4), and phonological working memory (Chapter 5) mediated in the relationship between reading and phonological awareness. To do this, we computed partial correlations between reading and phonological awareness in which we partialled out these other factors. In Chapter 6 we summarize the major findings, draw conclusions and provide some suggestions for future research directions.

In the present study, we provide the first report of phonological awareness in deaf children with cochlear implants. Until now research has not addressed whether or not deaf children with cochlear implants develop phonological awareness skills that are comparable with NH children. We also explored whether the deaf children displayed evidence of having made generalizations about the phonotactics of English, which would indicate that their experience with spoken English allowed them to develop and build sufficiently detailed abstractions of phonemes and phonemic sequences. The most important contribution made by the present study is the exploration of relationships between the children's performance on reading tasks and several other speech-processing tasks. We examined the degree to which reading and phonological awareness are related in this population, and the extent to which demographic characteristics, speech perception, nonword repetition, and phonological working memory mediated in that relationship. Our findings present an initial understanding of the relations between reading skills and these other factors in deaf children who are experienced cochlear implant users. These findings provide an initial basis for future studies that will further our understanding of the cognitive and linguistic processes used by deaf children with cochlear implants as they learn to read and gradually develop advanced reading skills.

CHAPTER II: NONWORD REPETITION AND READING SKILLS IN DEAF CHILDREN WHO USE COCHLEAR IMPLANTS: A PRELIMINARY REPORT

Abstract

The acquisition of reading and literacy skills in normal-hearing children has been found to be closely related to the development of phonological knowledge and the use of phonological processing skills. Phonological processing is often measured using a nonword repetition task in which a child relies on phonological knowledge and abstract phonological representations in order to decompose, encode, rehearse in working memory, and reproduce novel phonological patterns. In the present study of deaf children with cochlear implants, we found that nonword repetition performance was strongly correlated with several measures of reading skills and a measure of lexical diversity obtained from samples of spontaneous speech. These findings suggest that the phonological knowledge used in nonword repetition may be an important contributor to the acquisition of reading and literacy skills in this clinical population.

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, 2005). 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 speechreading 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 strongly 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. The present study was specifically designed to test this hypothesis.

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 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 2.1 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). 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).

Table 2.1. Summary of the demographic make-up of the 76 children.

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

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 2.2, 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.

Table 2.2. The 20 nonwords used in the present study (adapted from Gathercole et al., 1994; see also Carlson et al., 1998).

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

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 means of the demographic characteristics of this subset of children are provided in Carter, Dillon, & Pisoni, 2002). 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.

Scores Based on Perceptual Accuracy Ratings. In addition to these scores, the children's nonword responses were played back to naïve listeners to obtain perceptual goodness 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, 2005). A direct behavioral 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 and provided a sample of spontaneous speech (Geers, Nicholas, & Sedey, 2003). The number of different words used by each child during the interview was calculated, and used as 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.

Two studies have examined the relationship between vocabulary size (as measured by standardized vocabulary tests) and several different measures of spontaneous (elicited) speech. They provide some evidence that lexical diversity (number of different words used in a conversation) may be related to vocabulary size, but the correlations are not strong. Ukrainetz and Blomquist (2002) obtained several measures from a group of 28 NH typically-developing children approximately ages 4-6 years. They found that the number of different words produced in an elicited speech sample was correlated with the children's scores on the Peabody Picture Vocabulary Test-Revised (PPVT) (Dunn & Dunn, 1981), a measure of receptive vocabulary size ($r=+.36$, $p<.05$). In the task they used to elicit the speech sample from the children, most children described materials used as conversational prompts: a farm set (including animals, a tractor, etc.), pictures in a wordless storybook and drawings in an activity book; some children told stories about these prompts. In contrast, in the present study the examiner led the child in a conversation by asking him/her questions about many things including personal interests.

In a study of 15 NH typically-developing children ages 27-47 months, Silverman and Ratner (2002) found that a correlation between the children's PPVT scores and a measure of vocabulary diversity (based on a spontaneous speech sample) did not reach significance ($r=+.33$, $p=.08$). The speech sample was obtained from the children while they played with their parents using common toys (blocks, play food, etc.). The vocabulary diversity measure used was based on the application of an algorithm to type-token ratios in the children's speech. The type-token ratios themselves were not significantly correlated with the children's PPVT (receptive vocabulary) scores, nor with their scores on an expressive vocabulary test, the Expressive One-Word Picture Vocabulary Test (EOWPVT) (Gardner, 1990). The children's EOWPVT scores were correlated with the vocabulary diversity measure ($r=+.48$, $p=.01$). The number of different words in the speech sample was not calculated in either study.

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 (2004). The children's nonword responses varied in terms of suprasegmental, consonant, vowel, and overall perceptual accuracy. A summary is provided in Table 2.3.

Table 2.3. Summary of means, standard deviations (SD), and ranges for the nonword repetition scores.

Nonword Repetition Score	Mean (SD)	Range
% 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

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 2.4 the different methods of scoring the nonword repetition task yielded scores that were strongly intercorrelated with each other.

Table 2.4. Intercorrelations among the nonword repetition scores.

Nonword Repetition Score	1. Syls	2. Str	3. Cs 1	4. Cs 2	5. Vs 1	6. Vs 2	7. Ratings
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

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

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 2.5.

Table 2.5. Significant correlations between the children's demographic characteristics and their nonword repetition scores.

Nonword Repetition Score	**Age at Onset**	**Comm. Mode**	**PIQ**
% 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*

Reading Outcome Measures

A summary of the children's scores on the reading outcome measures is shown in Table 2.6. 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 4thgraders. 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, 1989).

Table 2.6. Summary of means, standard deviations (SD), and ranges for the reading outcome measures (N=76).

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

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 2.7. 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 2.8, scores on the reading outcome measures were all highly intercorrelated; the percentage of rhyme errors was moderately correlated with the other reading outcome measures.

Table 2.7. 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	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 2.8. Intercorrelations among the reading outcome measures (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

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 2.9).

Table 2.9. Significant correlations between the children's demographic characteristics and their scores on the reading outcome measures (N=76).

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

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. As shown in Table 2.10, 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, Burkholder, et al., 2004) 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.

Table 2.10. 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).

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

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

Discussion

Nonword repetition is a difficult information processing task because it 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 found to be 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 WRMT 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 existing 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. 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. However, 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 (Liberman, Shankweiler, & Liberman, 1989). In the present study, we found that the children's nonword repetition performance and their reading comprehension scores were also significantly correlated ($r = +.43$, $p < .001$). This finding 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 access and make use of abstract representations of the contrasting sounds of his/her ambient language; he/she must be able to map the visual graphemes onto abstract phonological units. The more robust their phonological representations were, the more reliably these children were able to decompose and reassemble spoken nonwords.

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. (2005) 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. Additional analyses of the effects of the wordlikeness and phonotactic probability of the target nonwords on the children's nonword repetition performance revealed 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, 2004).

However, we divided the children into two equal groups (N=38 for each): those who produced a smaller number of words for the spontaneous speech sample (the "low lexical diversity" group) and those who produced a high number of words for the spontaneous speech sample (the "high lexical diversity" group). We found that the nonword repetition ratings for the low diversity group were significantly correlated with wordlikeness and phonotactic probability when calculated by individual phoneme frequency (r = .49, p < .05; r = -.58, p < .01, respectively), and nearly significantly correlated with phonotactic probability when calculated by biphone frequency (r = -.43, p = .058). The nonword repetition ratings for the high diversity group were not significantly correlated with wordlikeness or phonotactic probability. These findings are consistent with Edwards et al.'s earlier results for NH adults and children, and indicate that among these deaf children with cochlear implants, the children with greater lexical diversity are less affected by frequency characteristics than children with poorer lexical diversity. Further investigation into lexical diversity (number of words in a spontaneous speech sample) as a measure of vocabulary is necessary. However, we also found that number of words *per minute* in the spontaneous speech sample was correlated with speaking rate (as measured by 7-syllable McGarr sentence durations) (r = -.73, p < .001), indicating that at least one measure obtained from the spontaneous speech sample is reliably related to results obtained using a well-established processing measure of performance (Pisoni & Cleary, 2003).

The recent findings reported by Edwards et al. (2004) and Munson et al. (2005) 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." Insomuch as nonword repetition involves segmentation and decomposition 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 poor specification of phonological representations, which stems from speech-specific processing operations 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 somewhat different views on the *source* of 'weak' or non-robust phonological representations, but their positions 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. (2005), and the present results lend converging support to the proposal that robust phonological representations are responsible for the better performance observed on tasks such as nonword repetition and phonemic awareness.

In summary, our results are consistent with the proposal that phonological processing and knowledge are important for both nonword repetition and reading performance in deaf children with cochlear implants. The correlation between nonword repetition performance and reading comprehension in this study suggests that the deaf children with cochlear implants were utilizing phonological processing skills in order to complete the reading comprehension task. 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. A child's ability to construct and make use of abstract phonological representations of the linguistically significant sound contrasts in his/her ambient language contributes to reading readiness and reading skills.

CHAPTER III: PHONOLOGICAL AWARENESS, READING SKILLS AND VOCABULARY KNOWLEDGE IN DEAF CHILDREN WHO USE COCHLEAR IMPLANTS

Abstract

Children who are deaf typically tend to have poor reading skills, and even deaf adults often do not achieve reading levels above the level of normal-hearing 4th-graders. In normal-hearing children, reading skills have been found to be closely related to phonological awareness. We investigated the reading and phonological awareness skills of 27 deaf school-age children who were experienced cochlear implant users. Over one-third of the children performed at or above the level of their normal-hearing peers on several standardized reading tests. The children also completed the Lindamood Auditory Conceptualization Test – Third Edition, a standardized test that is used to assess several phonological awareness skills. We found that most children exhibited some phonological awareness, with some children displaying phonological awareness skills that were at or above the levels of their normal-hearing peers. The children's reading scores were found to be strongly correlated with their phonological awareness. These correlations did not decrease when we statistically controlled for potentially confounding demographic variables such as age at testing or speech perception skills. However, these correlations decreased when we statistically controlled for vocabulary size, indicating that lexicon size is a mediating factor in the relationship between the children's phonological awareness and reading skills. These findings are consistent with the hypothesis that vocabulary development leads to more robust lexical representations, which in turn aid in the development of the phonological awareness skills that are crucial for reading.

Introduction

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; National Association of the Deaf, 2005). 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 (ASL) (Fischer, 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 the cochlear implant as a treatment for profound deafness has 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, Holden, Skinner, Tobey, Peterson, Gaggl, et al., 2004).

Despite progress 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). Studies of the reading skills of deaf children and adults over the past 50 years have repeatedly shown that their reading skills tend to be significantly delayed relative to their normal-hearing peers. Deaf adults' reading levels often do not exceed a 4th-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 NH peers, why do so many deaf children and adults have reading difficulties?

Research into the reading skills of normal-hearing children and adults can provide some initial insights into the answers to this question. First, in the normal-hearing population, poor reading skill is not generally related to low IQ (Bradley & Bryant, 1983; Brady, 1991 cites Jorm, Share, McLean, & Matthews, 1986; Fowler, 1991 cites Stanovich, 1988 and Stanovich, Cunningham, & Feeman, 1984; Morais, 1991 cites Siegel, 1988). Second, in the early 1970s, Isabelle Liberman and her co-workers demonstrated that the reading difficulties of normal-hearing individuals were generally not due to deficiencies in visual perception or visual scanning (Shankweiler, 1991: vix).

Researchers at Haskins Laboratories have been exploring the possible causes of difficulty in reading an alphabetic system. As Shankweiler (1991) explains, they focused on the fact that the alphabetic system is based on the use of graphemes which symbolize the individual sounds of a language. Sequences of graphemes are used to represent spoken words which can be broken down into sequences of individual sounds. However, explicit conscious knowledge of the existence of these individual sounds is not necessary for a person to speak or listen to language. Isabelle Liberman and her colleagues have argued that the source of poor readers' difficulty was the dissociation between the continuous nature of the acoustic speech signal of *spoken languag*e 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).

In speech, coarticulation of phonemes is extensive and pauses between successive phonemes do not occur. In alphabetic writing, however, phrases are represented as words separated by spaces, and words are represented as discrete sequences of isolated graphemes which do not overlap. Liberman called the idea that the acoustic speech signal can be broken down into discrete units *the alphabetic principle*. A person's awareness of the alphabetic principle is referred to as his/her *phonemic awareness*. Liberman and her colleagues hypothesized that phonemic awareness is strongly related to reading ability. Research findings over the past 30 years have repeatedly confirmed this original hypothesis, consistently finding high levels of phonemic awareness to be "the best single predictor of reading success" (Shankweiler, 1991: xvi) in the normal-hearing population (e.g., Liberman et al., 1974; Liberman, Shankweiler, & Liberman, 1989).

Phonemic awareness is one level of *phonological awareness*. Phonological awareness is the conscious awareness that individual words have an internal phonological structure and are composed of sequences of sound units (see also Abler, 1989). These units can be syllables, onsets/rimes, or phonemes, knowledge of which reflects knowledge of phonological structure at the syllable level, the level of onsets and rimes, or the phoneme level, respectively (Brady, 1991; Gillon, 2004; Treiman & Zukowski, 1991). *Phonological awareness at the syllable level* – knowledge that a word can be decomposed into syllables – can be assessed with 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* is knowledge that words consist of collated onsets and rimes. 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*, 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 tasks, 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).

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 2nd-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 5-7 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 relationship between and among measures of 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 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 vs. 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 clear and 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). Results reported in Carter, Dillon, and Pisoni (2002) on deaf children with cochlear implants are also consistent with this finding. 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 when viewed from the perspective of Liberman's alphabetic principle: the representation of spoken language with an alphabet hinges critically on the graphic representation of *phonemes*, not syllables.

Deaf children who receive little or no benefit from sensory aids have been shown to develop 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, while it is not necessary to know the mappings between graphemes and phonemes nor even that words have phonological structure in order to read, even children with little or no hearing do not just memorize the visual/graphemic/orthographic 'shape' of each word, but benefit from their (articulatory) knowledge of the phonological units of their language.

Many of the research methods that have been used to study reading skills in NH children are also applicable to the study of reading skills in deaf children as well. Geers (2003) investigated the reading skills of a large group 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 the 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. In a study of the same children, we found that the children's reading scores were strongly correlated with their performance on a nonword repetition task (Chapter 2). This finding suggested that the children used the phonological processing skills in the reading tasks that they used in nonword repetition. 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.

Several recent studies of normal-hearing children have reported that phonological processing skills used in nonword repetition are related to vocabulary size (e.g., Edwards, Beckman, & Munson, 2004; Munson, Edwards, & Beckman, 2005). Dillon and Pisoni also examined the role of vocabulary size in their study. A standardized vocabulary measure was not available for the children in their study. However, a novel measure of 'lexical diversity' was computed based on the number of different words the children used in an oral interview. Dillon and Pisoni found that when the children's lexical diversity scores were statistically controlled, the correlations between the children's reading scores and nonword repetition scores decreased substantially. This finding suggested that the children who had larger vocabularies also developed more robust phonological processing and reading skills.

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 the preliminary investigation (Chapter 2).

The specific research questions addressed in this investigation are the following. First, how do deaf children with cochlear implants compare to their normal-hearing peers on the 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, as NH often do? Third, to what extent are phonological awareness measures in deaf children indicative of their reading skills? Fourth, to what extent is the relationship between phonological processing skills and reading skills mediated by the children's demographic characteristics, speech perception, and vocabulary size?

Method

Participants

Twenty-seven profoundly deaf children (seventeen boys and ten girls) who use cochlear implants participated in this study. Eleven children were contacted to participate because they received their cochlear implants in Indianapolis, Indiana at Riley Hospital for Children. Six children were current or former students at Child's Voice Oral School in Wood Dale, Illinois. Six participants were current or former students in the hearing impaired program at Sylvester Elementary School in Berrien Springs, Michigan. Four participants were current or former students in the hearing impaired program at Shawnee Park Elementary School in Grand Rapids, Michigan. All of the children used oral communication (spoken English). Three children were deaf due to Mondini malformations, one child became deaf due to meningitis, and two 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 3.1 shows a summary of the demographic characteristics of the sample. Twenty of the children were deaf for less than 3 years before implantation. None of the children received their implant before age 1 year. Ten 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. Three more children received their implant before age 5. Two 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 children were 7 years old, 6 children were 8 years old, 1 child was 9 years old, 2 children were 10 years old, 4 children were 11 years old, 2 children were 12 years old, 1 child was 13 years old, and 1 child was 14 years old.

Table 3.1. Demographic characteristics of the twenty-seven children who participated in the present study. The number of children (N) used to calculate the mean, SD and range for each characteristics is shown in parentheses in column 1.

Demographic Variable	**Mean**	**SD**	**Range**
Age at Onset of Deafness in years (N=24)	0.23	0.76	0.0-3.5
Duration of Deafness in years (N=24)	2.3	1.4	0.5-6.0
Age at Implantation in years (N=24)	2.5	1.3	1.0-6.0
Duration of Implant Use in years (N=24)	6.7	2.2	3.7-11.8
Chronological Age in years (N=25)	9.1	2.5	6.2-14.0

Procedure

Each child was tested in a quiet room over a period of approximately 1.0 to 1.5 hours. 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 Lab t-shirt for his/her participation. The responses provided by the children during all tasks were recorded onto digital audio tape and transferred to a computer for storage and later analysis.

Tasks and Stimuli

The tasks that the children completed for this study are shown in Table 3.2 and are described in greater detail in the paragraphs below.

Table 3.2. The skills/processes measured and the tasks included in the present study.

	Process/Skill Being Measured	Test/Task
Phonological Awareness Task	Phonological Awareness: Syllable and Phoneme Levels	Lindamood Auditory Conceptualization Test – Third Edition (LAC3) (Lindamood & Lindamood, 2004)
Reading Tasks	Reading Recognition: Letter/ Phoneme Matching and Single Word Reading	Peabody Individual Achievement Test-Revised (PIAT-R) Reading Recognition (Markwardt, 1998)
	Nonword Reading	Woodcock Reading Mastery Test-Revised (WRMT-R) Word Attack (Woodcock, 1998)
	Read-Sentence Comprehension	Peabody Individual Achievement Test-Revised (PIAT-R) Reading Comprehension (Markwardt, 1998)
Other Related Tasks	Speech Perception	The Phonetically-Balanced Kindergarten Test (PBK) (Haskins, 1949)
	Vocabulary	Peabody Picture Vocabulary Test (PPVT-III) (Dunn & Dunn, 1997)

Phonological Awareness Skills. In order to examine the children's phonological awareness skills, we administered the Lindamood Auditory Conceptualization Test-Third Edition (LAC3; Lindamood & Lindamood, 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*, 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 Isolated Phoneme Patterns subtest is to test 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.

The second subtest, *Tracking Phonemes (Monosyllables)*, tests the child's ability to track the number and order of phonemes within a syllable. The syllables in these test items are never real words. 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, e.g., "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*, the child is asked to listen to a nonword stimulus and indicate the number of syllables in the nonword by placing that number of colored felt squares (not blocks) in a row in front of him/her. The fourth subtest, *Tracking Syllables*, 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*, 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 rather than any of the other available phonological awareness tests 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 norms and age- and grade-level equivalent scores for 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 PIAT (Peabody Individual Achievement Test-Revised; Markwardt, 1998). The Reading Recognition subtest of the PIAT-R includes 100 items. The first 16 items consist of four-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); or, 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, e.g., 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, e.g., *and*, *height*, *statistics*, and *vitiate*. 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. The PPVT items are shown in the Appendix.

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: 6). The children received one point for each nonword that was pronounced correctly. The test is administered until the child incorrectly produces 6 consecutive items (within a subgroup of nonwords). The nonwords included in the WRMT Word Attack (Form G) are shown in Table 3.3.

Each nonword is shown in its orthographic form followed by its phonemic transcription in brackets.

Table 3.3. The nonwords included in the WRMT Word Attack (Woodcock, 1998).

Word Attack Stimuli	
Ex. A. tat [tΘt]	22. sy /sa□I/
Ex. B. op [□p]	23. straced /stre□Ist/
	24. chad / t□ΣΘd/
1. dee /di/	25. than't /ΔΘnt/
2. ap /Θp/	26. tadding /tΘ.dIN/
3. ift /Ift/	27. twem /twEm/
4. raff /rΘf/	28. laip /le□Ip/
5. bim /bIm/	29. adjeks /Θ.d□ZEks/
6. nan /nΘn/	30. gouch /ga□Yt□Σ/
7. un /℘n/	31. yeng /jEN/
8. fay /fe□I/	32. zirdn't /z↔∏.d↔nt/
9. gat /gΘt/	33. gaked /ge□Ikt/
10. roo /ru/	34. knoink /no□INk/
11. oss /□s/	35. cigbet /cIg.bEt/
12. pog /p□g/	36. mancingful /mΘn.cIN.f↔l/
13. poe /po□Y/	37. wrey /re□I/
14. weat /wit/	38. bafmotbem /bΘf.m□t.bEm/
15. plip /plIp/	39. translibsodge /trΘnz.lIb.s□d□Z/
16. dud's /d℘dz/	40. monglustamer /m□n.gl℘s.t↔.m↔∏/
17. shab /ΣΘb/	41. vauge /va□Yd□Z/
18. whie /hwa□I/	42. gnouthe /na□YT/
19. vunhip /v℘nhIp/	43. quiles /kwa□Ilz/
20. nigh /na□I/	44. cyr /s↔∏/
21. bufty /b℘fti/	45. pnomocher /no□Y.mo□Y.t□Σ↔∏/

Reading 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, e.g., 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 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. 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 (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-III) (Dunn & Dunn, 1997). The PPVT has been shown to be reliable and valid, and is normed for participants ages 2-90^{+} years. The test includes standard scores and age-equivalent and grade-equivalent scores. 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 Analysis

We calculated raw scores and percent correct scores for the LAC3, PIAT Reading Recognition, WRMT Word Attack, 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 NH children (research question 1), we used the children's raw scores to determine their standard scores on the LAC3, PIAT Reading Recognition, WRMT Word Attack, 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 one standard deviation below the mean, and a standard score of 115 is one standard deviation above the mean. We also used the raw scores to compute age-equivalent and/or grade-equivalent scores, and then we calculated the proportion of children who performed below, at, and above age and/or grade level on each test. 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 normal hearing age- or grade-mates obtained lower scores than the children who participated in the present study.

To address research question 2, we calculated LAC3 subtest scores and compared the percent-correct subtest scores across and within the individual children. To address research question 3, we computed correlations between the LAC3 and the reading tests in order to investigate the extent to which measures of the children's phonological awareness indicated their ability to complete the reading tasks. Finally, we further investigated the relationship between the children's performance on the reading tests and the LAC3 by statistically controlling for potentially confounding demographic characteristics, speech perception, and vocabulary to address research question 4. In order to know which demographic variables to control in addressing question 4, we first computed bivariate correlations between the test scores and the children's demographic characteristics.

Results

General Performance on Tests

The children's mean raw scores and mean percent correct scores on the phonological awareness (LAC3), single word reading (PIAT Reading Recognition), nonword reading (WRMT Word Attack), read-sentence comprehension (PIAT Reading comprehension), total reading, and vocabulary (PPVT) are shown in Table 3.4. A wide range of scores were obtained from the children on all of the tests. In answer to our first research question, most of the children performed with some success on the phonological awareness, reading and vocabulary tests, though several young 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.

On the speech perception test (PBK), the children exhibited a wide range of scores. No children received scores lower than 30% words correct. When the PBK was scored as percent words correct, the highest score was 85%. When the PBK was scored as percent phonemes correct, only two children obtained scores lower than 81%; these two children still obtained relatively high percent phonemes correct scores, 61% and 63%. Thus, the children in this sample exhibit fairly good speech perception abilities in quiet conditions.

Table 3.4. The children's raw scores and percent correct scores for the phonological awareness, reading, speech perception and vocabulary tests. The number of children's scores (N) reported for each test is shown in column 1.

		Raw Scores (% Correct Scores)		
Test	N	Mean	SD	Range
LAC3 Total (Phonological Awareness) (max=66)	27	25 (38%)	10 (15%)	3-46 (5-70%)
PIAT Reading Recognition (max=100)	26	40 (40%)	21 (21%)	7-78 (7-78%)
PIAT Reading Comprehension (max=100)	26	40 (40%)	23 (23%)	0-80 (0-80%)
PIAT Total Reading (max=200)	27	77 (39%)	43 (22%)	14-158 (7-79%)
WRMT Word Attack (max=45)	26	20 (44%)	12 (27%)	0-40 (0-89%)
PBK (Speech Perception) (max=50 words correct)	25	34 (68%)	7 (14%)	15-94 (30-84%)
PBK (Speech Perception) (max=140 phonemes correct)	25	121 (86%)	12 (9%)	85-132 (61-94%)
PPVT-III (Vocabulary) (max=204)	26	87 (43%)	35 (17%)	26-157 (13-77%)

Performance Relative to Normal-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 Word Attack, and PPVT are shown in Table 3.5. Standard scores corresponding to the distribution of scores obtained from normal-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 in the present study. As described in the Analyses section above, a standard score of 100 corresponds to the mean raw score obtained from the normalization sample (a large group of normal-hearing children; specific Ns vary across the tests). One standard deviation 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 normal-hearing, typically-developing children who are his/her age. (Standard scores based on grade level are not available for the LAC3 and the PPVT).

Table 3.5. Standard scores based on the children's ages and grades for the phonological awareness, reading, and vocabulary tests.

	Standard Scores based on Child's Age				Standard Scores based on Child's Grade			
Test	N	Mean	SD	Range	N	Mean	SD	Range
LAC3 Total (Phonological Awareness) (max=66)	25	88	13	55-111	(not available)			
PIAT Reading Recognition (max=100)	24	95	15	72-128	23	100	17	75-132
PIAT Reading Comprehension (max=100)	24	94	20	55-132	22	99	22	55-136
PIAT Total Reading (max=200)	25	94	18	55-130	23	99	20	57-134
WRMT Word Attack (max=45)	23	101	15	70-125	23	103	22	39-133
PPVT-III (Vocabulary) (max=204)	24	81	19	40-117	(not available)			

As shown in Table 3.5, the mean score obtained by the children in the present study for the LAC3 falls just within the normal range (85 is one standard deviation below the mean). The children's vocabulary knowledge as measured by the PPVT was also just under one standard deviation below the mean, indicating that as a group, the children in the present study had lower than average vocabularies compared to normal-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 normal-hearing sample populations of children their ages and grades. However, as discussed above, the children's scores varied widely on all of these tasks.

Table 3.6 shows the number of children whose standard scores fall within 1 standard deviation bins with respect to the mean. At least three children scored more than one standard deviation 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 one standard deviation of the mean or higher for all tests except the PPVT.

Table 3.6. The percent of children whose standard scores on the LAC3, PIAT subtests, WRMT Word Attack and PPVT were within various standard deviation bins of the mean. Standard scores within normal range (i.e., within one standard deviation of the mean) are shown in bold.

Outcome Measure		Standard Scores					
		< -2 SD	-2 to -1 SD	**-1 to 0 SD**	**0 to +1 SD**	+1 to +2 SD	> +2 SD
		<70	70-84	**85-99**	**100-114**	115-129	>129
Standard Scores based on age	LAC3 (N=25)	8%	24%	**52%**	**16%**	0%	0%
	PIAT Reading Recognition (N=24)	0%	21%	**50%**	**17%**	13%	0%
	PIAT Reading Comprehension (N=24)	13%	13%	**33%**	**25%**	13%	4%
	PIAT Total Reading (N=24)	4%	17%	**50%**	**13%**	13%	4%
	WRMT Word Attack (N=23)	0%	13%	**35%**	**35%**	17%	0%
	PPVT (N=24)	29%	29%	**25%**	**13%**	4%	0%
Standard Scores based on grade	PIAT Reading Recognition (N=23)	0%	22%	**43%**	**9%**	22%	4%
	PIAT Reading Comprehension (N=22)	9%	5%	**45%**	**9%**	23%	9%
	PIAT Total Reading (N=22)	5%	14%	**41%**	**9%**	27%	5%
	WRMT Word Attack (N=23)	9%	4%	**22%**	**43%**	4%	17%

Percentile Ranks. The standard scores presented above reveal how the children's performance on the various tests was distributed around the mean obtained from normal-hearing, typically developing children in their age groups and grade levels. The percentile ranks shown below indicate the proportion of the normal-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 or grade level as the child in question). Percentile ranks are useful because they provide a benchmark as to where a child would fall within an average group of his/her normal-hearing peers (based on age or grade).

The individual percentile ranks shown in Figures 3.1–3.5 indicate the percentage of the children's normal-hearing peers whose standard scores would be lower than the standard score obtained from the deaf child (based on age or grade as labeled). For instance, as shown in Figure 3.1, the 6-year-old child C11 obtained a higher score than approximately 75% of normal-hearing 6-year-olds on the LAC3. She was one of only 4 children in the present study whose performance on the LAC3 was better than 50% of their normal-hearing age peers (the others are children C10, C24 and C07, as shown in Figure 3.1).

The percentile ranks are shown as a function of the children's age, and also as a function of grade when grade-based ranks were available. On the PIAT subtests and the WRMT Word Attack, for which grade-based percentile ranks were available, more deaf children obtained scores in the top half of scores obtained from their *grade-level* peers than from their *age* peers (nine children for the PIAT Reading Recognition subtest, 15 children for the WRMT Word Attack, and nine children for the PIAT Reading Comprehension subtest). This finding indicates that some children did not perform as well in comparison to NH children their age as in comparison to NH children in their grade. As shown in Figure 3.4, the percentile ranks for the PPVT reveal that only three children's performance fell within the top half of the scores obtained by their normal-hearing age peers.

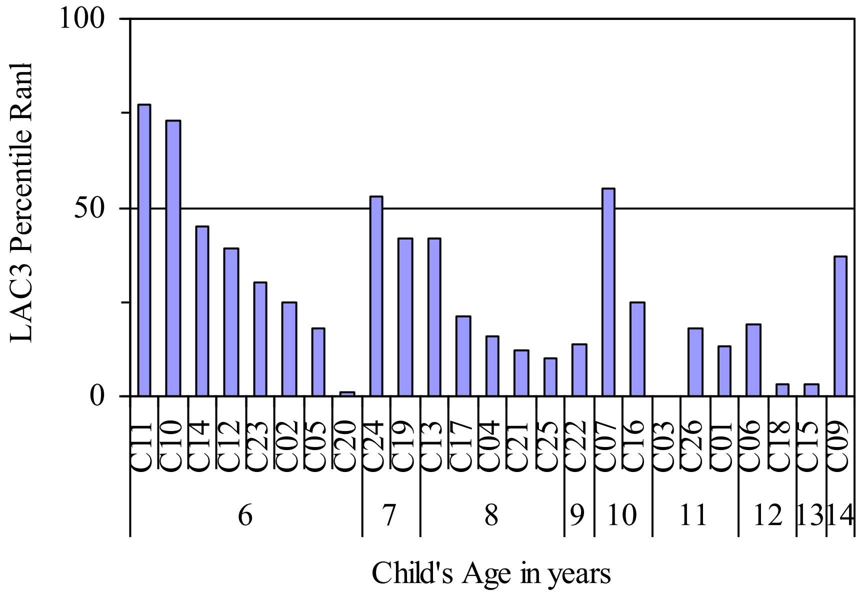

Figure 3.1. LAC3 percentile ranks derived from the children's standard scores based on age, shown as a function of the child's age.

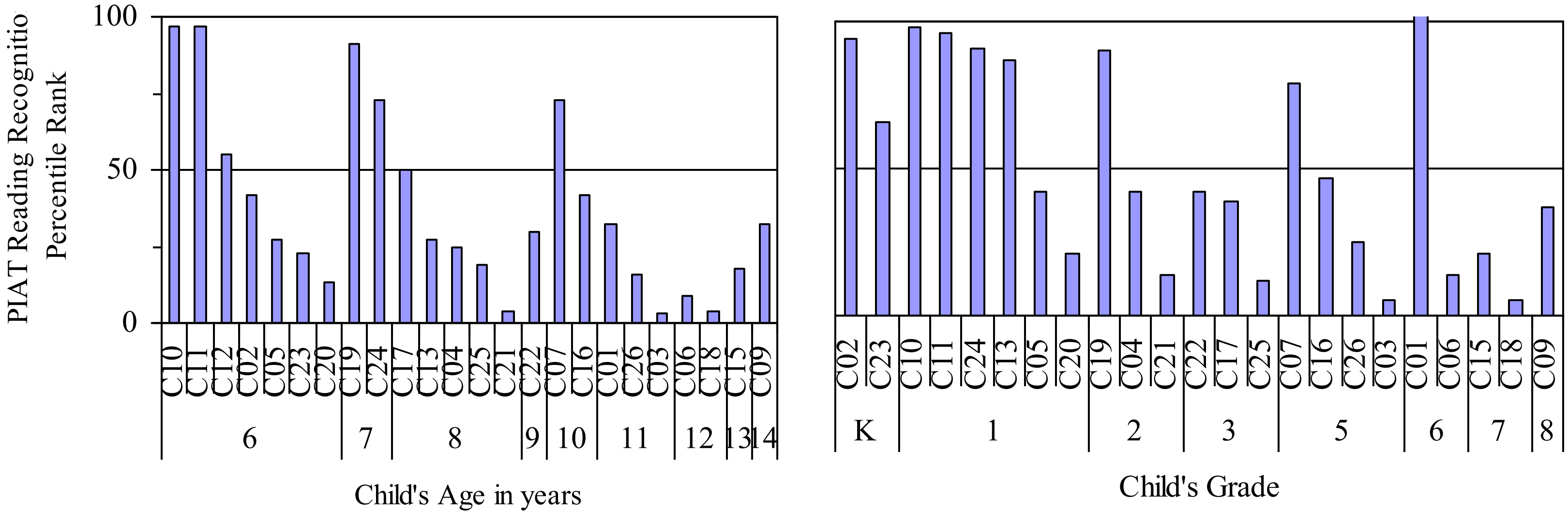

Figure 3.2. PIAT Reading Recognition percentile ranks derived from the children's standard scores based on age, shown as a function of the child's age (left panel) and percentile ranks derived from the children's standard scores based on grade, shown as a function of the child's grade (right panel).

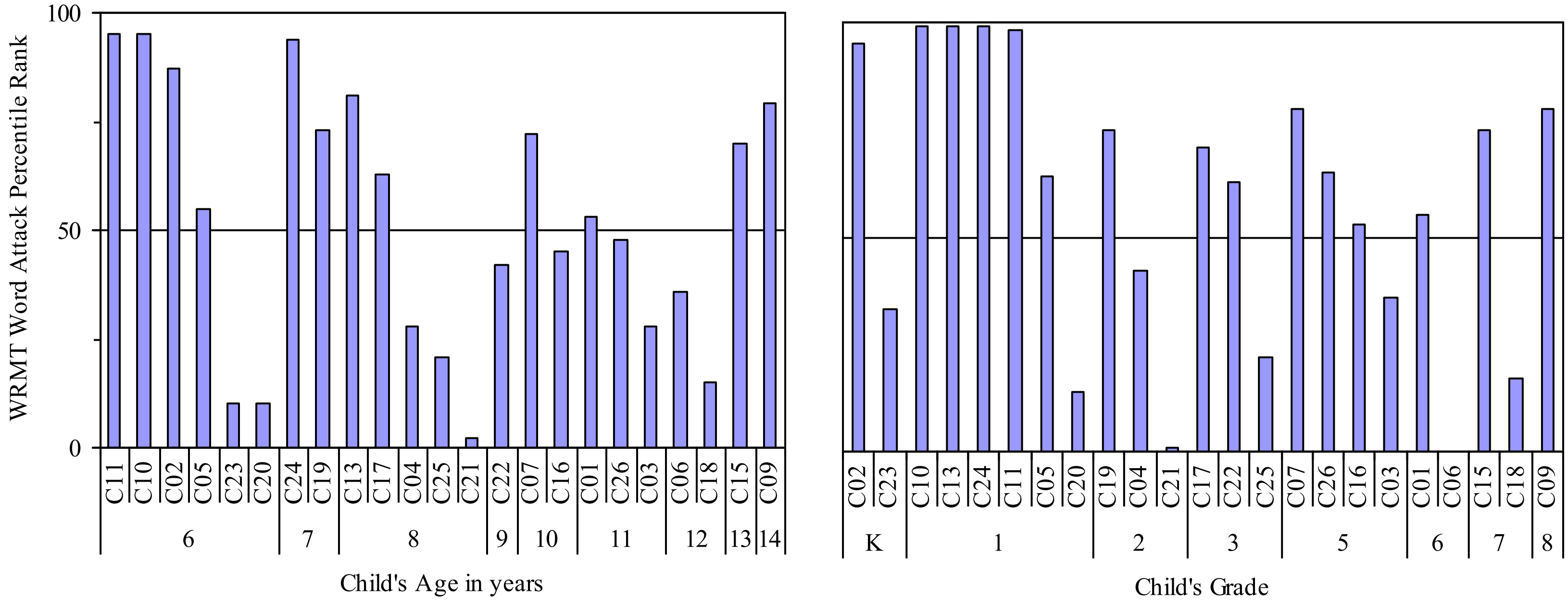

Figure 3.3. WRMT Word Attack percentile ranks derived from the children's standard scores based on age, shown as a function of the child's age (left panel) and percentile ranks derived from the children's standard scores based on grade, shown as a function of the child's grade (right panel).

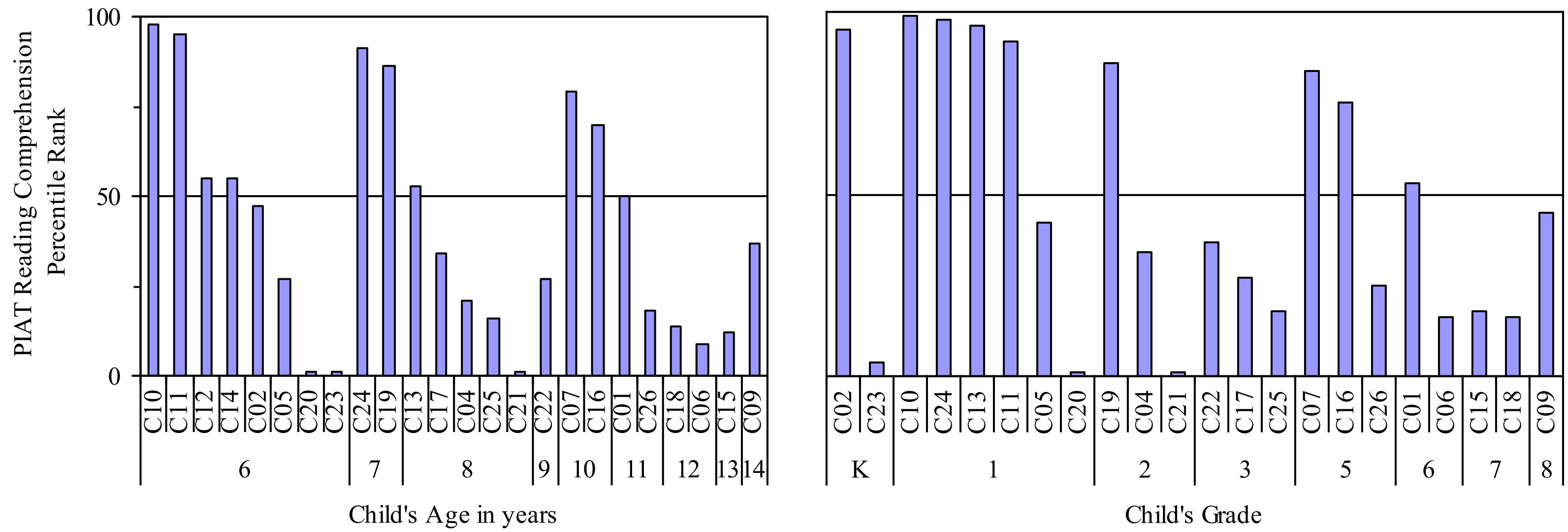

Figure 3.4. PIAT Reading Comprehension percentile ranks derived from the children's standard scores based on age, shown as a function of the child's age.

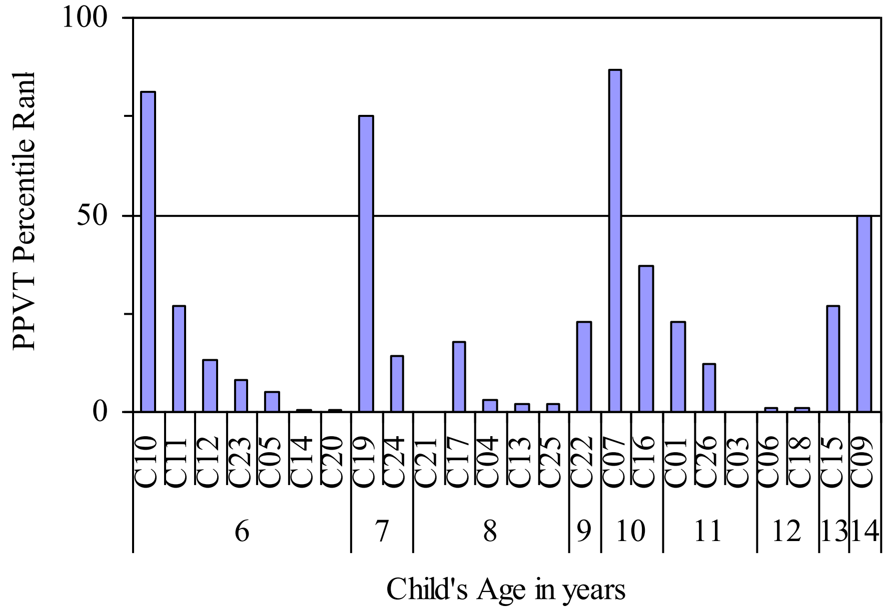

Figure 3.5. PPVT percentile ranks derived from the children's standard scores based on age, shown as a function of the child's age.

Age- and Grade-Equivalent Scores. The final descriptions of the children's performance relative to the normal-hearing population as measured in the standardized tests are the children's age- and grade-equivalent scores, shown in Figure 3.6 and Figure 3.7. While the standard scores and percentile ranks showed where a deaf child's score fell within the distribution of *normal nearing (NH) children their age or grade*, the age- or grade-equivalent scores show *which NH children* (as an age group or grade level) obtained scores closest to the deaf child's score. That is, for the PIAT subtests, the age- or grade-equivalent score is the age or grade of the normal-hearing children in the norming sample whose *average* score was in the same age year or grade level as the deaf child's score on the particular test in question. For the WRMT Word Attack and the PPVT, a child's equivalent score is the age or grade level for which the *median* raw score obtained by the normative sample is the same age year or grade level as the child's raw score. The metric on which the LAC3 equivalent scores are based is unclear; the LAC3 age- and grade-equivalent scores indicate that the child's score is "consistent with the majority of students" who are the age or grade of the equivalent score (Lindamood & Lindamood, 2004: 34).

Figure 3.6 and Figure 3.7 show the percentage of children in the present study whose age- or grade-*equivalent* scores were below, at, or above the child's *actual* age or grade (respectively). As shown in these figures, for most tests in the present study, over half of the participating children obtained scores that were equivalent to the mean/median scores of normal-hearing younger children or children in lower grades. Overall, more children performed at or above the average performance of their normal-hearing age or grade peers on the PIAT Reading Comprehension subtest and the WRMT Word Attack than on the other tests.

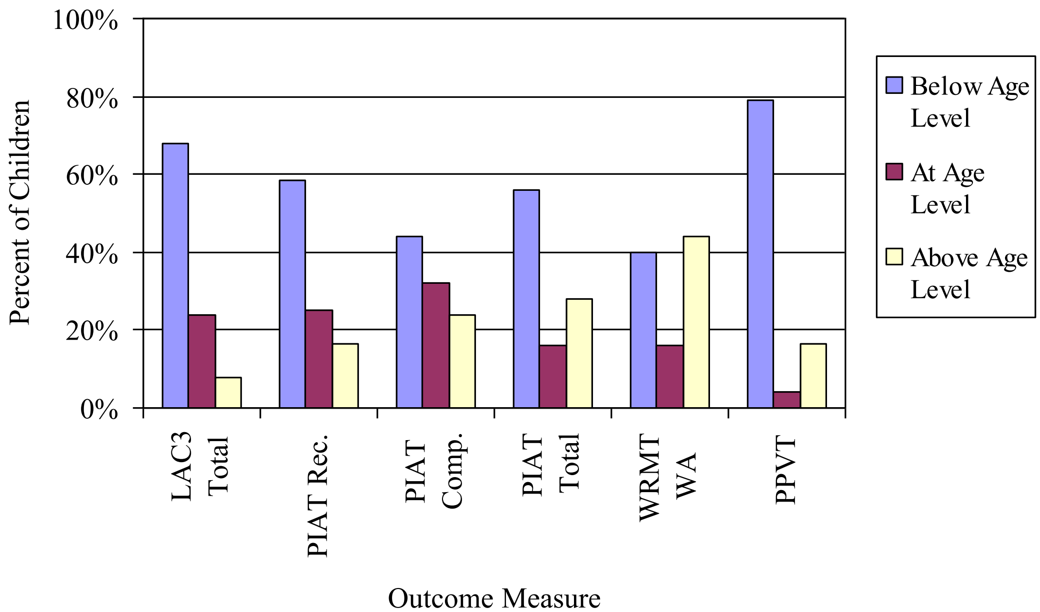

Figure 3.6. Percent of children who scored below, at, and above age level on the phonological awareness, reading and vocabulary tests.

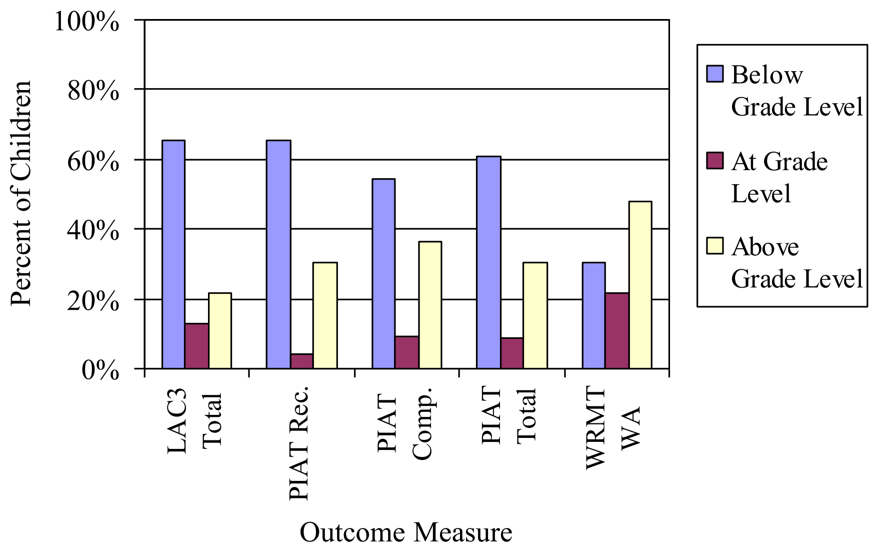

Figure 3.7. Percent of children who scored below, at, and above grade level on the phonological awareness, reading and vocabulary tests.

Levels of 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 the 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[1]. 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, 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 Word Attack, PIAT Reading Comprehension, and PIAT Total Reading scores). The phonological awareness scores were strongly correlated with all of the reading scores (*r*'s = +.82, +.74, +.86, +.85, respectively; shown in Table 3.8 below).

Factors Related to Phonological Awareness and Reading

Given that the children's phonological awareness and reading skills were related, we also investigated the extent to which this relationship was mediated by other factors. First, any significantly correlated demographic characteristics were potentially confounding variables when investigating the relationship between any of the outcome measures.

Correlations between the children's demographic characteristics and their scores on the phonological awareness, reading, vocabulary and speech perception tests are shown in Table 3.7. 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 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.

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 (α = .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 3.7).

[1] Child C26 was eligible to be given the TCP because he earned a score of 50% on the TP subtest, but due to time constraints Child C26 did not complete the TCP. 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 subjects.

Table 3.7. Correlations between the children's demographic characteristics and their scores on the outcome measures. The number of children for which data were available (N) for each correlation is shown in the bottom half of each cell. 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). We found that the corrected alpha was .00119. Correlations that were significant using the Bonferroni corrected alpha value are shown in bold.

	LAC3 Total	PIAT Rec	WRMT WA	PIAT Comp	PIAT Total	PPVT	PBK
Age at Onset	ns N=24	ns N=24	ns N=24	ns N=23	ns N=24	ns N=23	ns N=22
Duration of Deafness prior to Implantation	ns N=24	ns N=24	ns N=24	ns N=23	ns N=24	ns N=23	ns N=22
Age at Implantation	ns N=24	ns N=24	+.41* N=24	+.43* N=23	ns N=24	ns N=23	ns N=22
Duration of CI use	+.48* N=24	**+.63**** N=24	+.49* N=24	+.56** N=23	+.60** N=24	+.61** N=23	ns N=22
Age at Testing	+.45* N=25	**+.70***** N=25	**+.66***** N=25	**+.69***** N=24	**+.64***** N=25	**+.63***** N=24	ns N=23
Child's Grade Level	+.47* N=23	**+.75***** N=23	**+.65***** N=23	**+.72***** N=22	**+.69***** N=23	**+.68***** N=22	ns N=21

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

Thus, it was important to statistically control for these variables using partial correlations. The demographic variables that emerged as possible 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. Thus, these demographic characteristics were potentially confounding variables. These variables were strongly intercorrelated with each other (r's = +.98, +.85, +.86; p's < .001); thus it was not necessary to control for all variables. 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 3.8, the correlations between the LAC3 and the reading measures did not decrease when age at testing was controlled (r's = +.80, +.74, +.77, +.82).

Second, because the children in this study were hearing impaired and because speech perception has been shown to play a role in phonological awareness (McBride-Chang, 1995), we were interested in the extent to which their speech perception skills (as measured with the PBK) played a role in the relationship between their phonological awareness and reading skills. Thus, we computed partial correlations between the LAC3 and reading scores, partialling out the children's PBK scores. The 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 3.8. Again, we found that these partial correlations were not smaller than the bivariate correlations (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 3.8 (*r*'s = +.63, +.56, +.58, +.63, respectively). This decrease in the correlations indicates that the correlation between the children's reading and phonological awareness is partially affected by their vocabulary size. That is, vocabulary size 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 relationship between reading and vocabulary. As shown in the right half of Table 3.8, the results were very similar to the first set of correlations. The children's reading test scores and vocabulary knowledge were very strongly correlated (*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 factored out, the correlations between reading and vocabulary decreased but remained significant. This finding indicates that phonological awareness mediates in the relationship between reading and vocabulary size.

Taken together, the correlations shown in Table 3.8 show that reading is strongly related to phonological awareness, and reading is also strongly related to vocabulary knowledge. However, the decrease in correlations when either of these measures is factored out indicates that there is partial overlap in the contributions made to reading skills by these two factors. That is, phonological awareness and vocabulary are both independently related to reading, but they also affect each other's relationship with reading.

Table 3.8. 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.

	Correlations with Phonological Awareness (LAC3 Total Raw Scores)				**Correlations with Vocabulary (PPVT Raw scores)**			
Outcome Measure	Bivariate	Partial 1 (Age or Grade)	Partial 2 (Speech Perc.)	Partial 3 (Vocab.)	Bivariate	Partial 1 (Age or Grade)	Partial 2 (Speech Perc.)	Partial 3 (Phon. Awar.)
Single Word Reading & Reading Readiness (PIAT Reading Recognition Raw Scores) (N=26)	+.82***	+.80***	+.87***	+.63***	+.93***	+.88***	+.93***	+.85**
Nonword Reading (WRMT Word Attack Raw Scores) (N=26)	+.74***	+.74***	+.82***	+.56**	+.83***	+.73***	+.86***	+.61**
Read-Sentence Comprehension (PIAT Reading Comprehension Raw Scores) (N=26)	+.86***	+.77***	+.88***	+.58**	+.91***	+.84***	+.87***	+.76**
PIAT Total Reading Raw Scores	+.85***	+.82***	+.89***	+.63***	+.94***	+.90***	+.92***	+.86***

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

Discussion

Twenty-seven experienced cochlear implant users ages six to 14 participated in the present study. The children completed a phonological awareness test, several reading tests, 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.

Phonological Awareness

The phonological awareness test included five subtests of varying phonological levels. We expected that the children's performance would vary across the subtests. Specifically, based on reports in the literature regarding the performance of NH children (discussed in the Introduction) we expected that the relative difficulty of the subtests, from least difficult (highest %-correct scores) to most difficult (lowest %-correct scores) would be:

Counting Syllables ≥ *Isolated Phoneme Patterns* ≥ *Tracking Syllables* > *Tracking Phonemes* > *Tracking Syllables & 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 Counting Syllables subtest than the Isolated Phoneme Patterns (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 Counting Syllables (CS) subtest, the child had to parse a continous 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 children's syllable-level awareness seems to precede phoneme-level awareness, as discussed in the Introduction), 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.

The children performed with the highest levels of accuracy on the subtest that did not require them to explicitly parse a continuous signal into individual phonological units (the Isolated Phonemes subtest). In addition, the fact that the children performed better on the Isolated Phonemes and Counting Syllables subtests than both Tracking subtests suggests that the development of their phonological awareness may follow a similar general pattern of development to that of NH children. That is, similar to normal-hearing children, these children performed better when the task did not require them to manipulate the phonological units in question as the Tracking tasks did (as discussed in the Introduction; e.g., Schatschneider et al., 1999; Stahl and Murray, 1994).

The findings that all children performed with some accuracy on the Isolated Phonemes subtest, and most children performed above floor on the first four subtests of the LAC3, suggests that this group of children has developed some phonological awareness skills. However, the fact that each of the Counting and Tracking subtests elicited at least one score of zero indicates that some of the children were not able to exhibit phonological awareness beyond the most basic level tapped by the Isolated Phonemes task. On the other hand, high scores were obtained on all of the subtests by some children. Overall, the LAC3 results indicate that the children in the present study have been 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.

Reading

The reading tests used in the present investigation included one test that was primarily single word reading (PIAT Reading Recognition), a nonword reading task (WRMT Word Attack), and a read-sentence comprehension test (PIAT Reading Comprehension). Profoundly deaf children have typically performed below the age/grade level of their normal-hearing peers, with their reading skills asymptoting at about a 3rd- or 4th-grade level. In the present study, we found that at least three children obtained above-normal scores for their age or grade on every one of the standardized tests (which measured phonological awareness, reading skills and vocabulary). In addition, the majority of children scored within the normal range of NH children their age or grade level. These results are encouraging because they suggest that the deaf children who use cochlear implants in the present study are already developing foundational linguistic analysis skills that may help them acquire average or higher literacy skills as they continue through school into adulthood.

Comparisons to Normal-hearing Children

The children's standard scores on the reading measures indicated that they were slightly behind the average scores of their NH peers, but were well within the range of normal variation. Their 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 NH peers. Although the children's average standard scores are encouraging, the range of scores is notably skewed to the bottom end, indicating that some of the children have lower than average phonological awareness, vocabulary, and reading skills. We were surprised by the children's 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.

For the age- and grade-equivalent scores, while about half of the children in the present study obtained scores that were equivalent to the mean/median scores of normal-hearing younger children or children in lower grades on the standardized tests, about a quarter of the children performed above age or grade level on most tests as well. This finding indicates that the speech signal received by these children through their cochlear implant provides them with information that they are able to use in conjunction with visual and tactile information to develop phonological representations, with varying degrees of robustness.

The percentile rank results 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 NH peer groups on the phonological awareness and reading tests. The present study does not provide any detailed insights into the cause of this decrease in performance relative to NH peers as the children 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 with the present group of participants. Another possibility is that the difference is related to differences in the educational environments of the children. A larger proportion of the younger children were enrolled in oral schools for the deaf rather than mainstream classroom programs. 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 average nearly on par with their NH peers as they get older; or whether the younger children's phonological awareness and reading skills will not improve on pace with their NH peers, causing them to fall increasingly behind the NH population as they get older. A longitudinal study in which children's phonological awareness and reading skills are measured over time is the only means by which we will be able to explore the developmental trajectory of the children's phonological awareness and reading skills.

In addition, although many of the younger children performed quite well relative to their NH peers on the LAC3 and reading measures, the younger children who did not perform as well tended to perform quite 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. Future research should explore the relative performance of children who are in different school environments and/or exposed to different educational approaches.

Relations between Phonological Awareness and Reading Skills

We found that the children's reading skills were strongly correlated with their phonological awareness skills. This finding suggests that, at least to some extent, the children relied on the phonological processing skills that they use to process auditory speech input, in order to decode written English. This is an important finding because it is consistent with an extensive body of research findings obtained from normal-hearing children: like NH children, children who use cochlear implants and 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 small sample size of 27. In normal-hearing children, phonological processing abilities and reading and literacy development have been found to be closely linked, with development in each causing further development in the other (see Brady, 1997; Troia, 2004). 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. Numerous studies have reported that normal-hearing children's reading skills can benefit from 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, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Treiman & Baron, 1983; see Ehri, Nunes, Willows, Schuster, Yaghoub-Zadeh, & Shanahan, 2001 for a review). Future explicit phonological awareness training studies of deaf children with cochlear implants would be invaluable to assess these claims.

The Role of Demographic Characteristics. We partialled out the children's age at testing from the correlations between reading and phonological awareness and between reading and vocabulary because these variables were the only demographic characteristics that were significantly correlated with the outcome measures. 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 a small effect on this relationship.

It was somewhat surprising that age at testing and grade level in school were the only variables that were found to be significantly correlated with the outcome measures. However, 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, nullifying the significance of variability across subjects. 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 received early intervention and were experienced cochlear implant users at the time of their participation in the present study. Perhaps their extensive experience with a cochlear implant provided these children with sufficient early linguistic experience that the variability that existed in their demographic characteristics was not strong enough to be significantly related to their outcome performance. However, it is also noteworthy that children within the same age groups sometimes exhibited extensive 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.

The Role of Speech Perception. Our finding that the correlations between reading and phonological awareness and the correlations between reading and vocabulary did not decrease when speech perception was statistically controlled 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. Perhaps this finding is 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 83% phonemes correct and the lowest score was 61% phonemes correct. The percent words correct scores were lower (M = 66%, lowest score = 14%) but these scores were higher than previously reported scores for another group of deaf children. 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 somewhat later ages, and had less experience with their implants at the time of testing. Cleary et al. found that the children in their study obtained an average score of only 46% words correct on the PBK, with a standard deviation of 23% and a range of 8-88% percent words correct.

In comparison to the results reported in Cleary et al. (2000), the children in the present study obtained substantially higher overall scores on the PBK (possibly due to the demographic differences stated above). It is encouraging that the children in the present study demonstrated remarkably high open-set speech perception scores despite profound pre-lingual deafness. Furthermore, 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 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 mediating factor in the relationship between phonological awareness and reading.

The Role of Vocabulary Size. 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 NH children). The fact that the correlations between phonological awareness and reading decreased when vocabulary was statistically controlled suggests that the children with larger vocabularies also have more robust phonological representations (as hypothesized by Studdert-Kennedy, 2002, and supported by Edwards, Beckman, & Munson, 2004, and Munson, Edwards, & Beckman, 2005). Brady (1991) suggests that "If one gets better at encoding, more resources will be available for memory." (p. 133) In line with Brady (1991), perhaps the children with more robust phonological representations were able 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 relationship between phonological working memory skills, phonological awareness skills and reading development.

On the other hand, we also found that correlations between reading and vocabulary decreased when phonological awareness was 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 NH children: improvement or training in one corresponds with improvement in the other as well (Perfetti, Beck, Bell, & Hughes, 1987). A longitudinal phonological awareness training study of children with cochlear implants could provide further insights into the development of and relationship between these skills and reading and vocabulary knowledge in this clinical population.

CHAPTER IV: NONWORD REPETITION, PHONOLOGICAL AWARENESS AND READING SKILLS IN DEAF CHILDREN WITH COCHLEAR IMPLANTS

Abstract

Previous research with children has shown that nonword repetition performance is strongly correlated with reading skills and vocabulary knowledge. We investigated the nonword repetition skills of deaf children who use cochlear implants, in order to determine the extent to which the phonological processing skills assessed by the nonword repetition task in normal hearing children are also displayed by deaf children. We also wanted to determine whether nonword repetition skills are related to reading skills and vocabulary knowledge in this population. Twenty-seven experienced cochlear implant users ages 6-13 participated in the present study. The nonword stimuli varied in terms of syllable length and phonotactic probability. The children produced better nonword responses to shorter targets than to longer targets. However, no significant difference was observed in performance between phonotactically frequent and phonotactically infrequent nonwords. Children with larger vocabularies produced better responses overall than children with smaller vocabularies, but neither vocabulary group differed in terms of phonotactic frequency. A previous study of these children found that their reading skills were strongly related to their phonological awareness. In this study, we found that this relationship was not mediated by their nonword repetition skills, indicating that the phonological processing skills indexed by nonword repetition do not independently contribute to the reading skills of children who use cochlear implants beyond the contributions made by phonological awareness.

Introduction

The adult mental lexicon encodes the frequency of occurrence of lexical items in the ambient language. For instance, Howes (1957) demonstrated that high frequency words have lower intelligibility thresholds than low frequency words when the words are presented in wide-spectrum noise. In addition, when adults are asked to decide whether a stimulus is a real word or nonword (a lexical decision task), they respond more quickly to higher frequency words than to lower frequency words, independently of whether the words are members of high or low density neighborhoods (e.g., Luce & Pisoni, 1998). Another robust finding in the spoken word recognition literature is that adults respond more quickly during lexical decision tasks to real words than to nonwords (Forster, 1978).

Word frequency has also been found to play an important role in the development of children's mental lexicons as well. In learning words of their ambient language, children must first learn to parse the words from a continuous speech signal. Children learn to parse highly familiar words such as their own name from the speech signal very early, as young as 6 months of age (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005). Similarly, Mandel, Jusczyk, and Pisoni (1995) found that infants preferred their own names over different sound patterns with either the same or opposite stress pattern. One likely reason that children are able to parse their own name from a continuous speech signal earlier than other words is that a child's own name is spoken very frequently in the language learning environment. Later in children's development, early-acquired words tend to be very high frequency words (Storkel, 2004). The use of high frequency words has been found to produce more facilitation than low frequency words in treating children with phonological delays (Gierut, Morrisette, & Champion, 1999). Newman and German (2002) also found that in a lexical retrieval task, high frequency words were easier to retrieve in speech production by both typically-developing children and children with word-retrieval difficulties.

Adults and children have also been shown to be sensitive to the phonotactic frequency of the component segments of words. In adults, Luce and Large (2001) found that real words composed of high phonotactic probability sequences elicited faster responses than real words composed of low phonotactic probability sequences. This finding was obtained for correct same responses in a same-different task. Using a head-turn preference procedure, Jusczyk, Luce, and Charles-Luce (1994) found that infants preferred syllables constructed with high frequency phonotactic sequences.

In a pioneering study, Eukel (1980) found that adults were also sensitive to the phonotactic characteristics of *nonwords*. Judgments of the 'frequency' of nonwords was found to be related to the frequency of phonotactically similar real words. The listeners in Eukel's study used the frequency of the phonotactic sequences in the nonwords to make their responses. Similarly, Vitevitch and Luce (1998) found that adults demonstrated faster reaction times in judging the lexicality of nonwords containing high-probability phonotactics than nonwords containing low-probability phonotactics.

Similar findings have been reported regarding repetition of spoken nonwords. Although nonword repetition may appear to be a simple task, it is a complex procedure that requires the participant to integrate several speech and memory-related skills that involve speech perception, encoding, rehearsal, and retrieval of phonological representations from working memory as well as reassembly for speech production, phonetic implementation and speech-motor control. Recently, Coady and Aslin (2004) found that normal-hearing (NH) typically-developing (TD) children were able to repeat nonwords more accurately when the nonword stimuli contained high frequency phonotactic frequency sequences than when the nonword stimuli contained low frequency phonotactic sequences. Edwards, Beckman and Munson (2004), using a different set of high and low frequency nonwords, found that adults and typically-developing NH children performed better when they were asked to repeat high frequency nonwords than low frequency nonwords.

In addition, Edwards' et al.'s results demonstrated that frequency effects also reflect the overall size of a child's lexicon. They found that children who have larger vocabularies demonstrated a smaller frequency effect than children who have smaller vocabularies. In another study, Munson, Edwards, and Beckman (2005) found that TD children and children with phonological disorders (PD) repeated high frequency nonwords more accurately than low frequency nonwords. Although the PD children performed the nonword repetition task more poorly than the TD children, the PD children displayed the same phonotactic frequency effects as the TD children. Munson et al. also found in both groups that children with larger vocabularies repeated the nonwords more accurately than the children with smaller vocabularies. Thus, the accuracy and efficiency with which normal-hearing children complete nonword repetition tasks is not only a function of the frequency of sound sequences in the nonword stimuli, but is also a function of how many words are in the children's lexicons.

In the present study, we investigated the nonword repetition skills of children who are deaf and use cochlear implants. We were interested in whether the lexical factors observed in nonword repetition performance by normal-hearing children (such as phonotactic frequency and vocabulary size) also affect nonword repetition in deaf children who use cochlear implants. In broader terms, we were interested in measuring about the phonological processing skills of deaf children and investigating the effects of vocabulary knowledge in order to gain insight into the processes that underlie their reading abilities.

In a preliminary investigation of this problem, we studied the relationship between nonword repetition skills and reading development in deaf children with cochlear implants. We found that nonword repetition was strongly related to reading abilities; children who displayed higher nonword repetition scores were better readers. This finding was observed even when demographic variables and speech perception skills were factored out. In addition, we also found that the children's performance on the nonword repetition and reading tasks could be partially explained by another measure that assessed lexical diversity (number of different words used in a spontaneous speech sample), which we used to index vocabulary size. When lexical diversity was factored out, the correlations between nonword repetition and reading decreased but still remained significant. This finding suggested that the children used some of the same phonological processing skills in both the nonword repetition task and the reading tasks.

In a follow-up study, we investigated the phonological awareness skills, reading skills and vocabulary knowledge in a new group of deaf children who use cochlear implants. The children in this study were administered the Lindamood Auditory Conceptualization Test – Third Edition (LAC3; Lindamood & Lindamood, 2004). Several reading tests were also administered, including the Reading Recognition and Reading Comprehension subtests of the Peabody Individual Achievement Test – Revised (PIAT-Rec, PIAT-Comp; Markwardt, 1998); and the Word Attack subtest of the Woodcock Reading Mastery Test (WRMT-WA; Woodcock, 1998). We also obtained a measure of the children's receptive vocabulary size using the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997).

Phonological awareness and reading were found to be strongly correlated. When demographic variables and speech perception were statistically controlled, the relationship between phonological awareness and reading still remained essentially unaffected. However, when vocabulary knowledge was factored out by partialling out the children's PPVT scores, the correlations between phonological awareness and reading decreased in magnitude but remained significant. This finding suggests that although phonological awareness skills and vocabulary knowledge are related, both contribute independently to the reading abilities of deaf children who use cochlear implants.

The findings from these two studies indicated that the phonological processing skills required to complete nonword repetition, phonological awareness, and vocabulary tests are all associated with the development of reading skills in deaf children with cochlear implants. In the present study, we further investigated the relationships among the children's performance on these tests. We examined whether deaf children with cochlear implants exhibit differential performance in their responses to nonwords containing phonotactically high frequency sequences compared to nonwords containing low frequency sequences. Sensitivity to phonotactic frequency would indicate that deaf children with cochlear implants, similarly to NH children, encode generalizations about the phonotactic patterns in their ambient language and make use of this knowledge in repeating nonwords. In addition, we investigated the extent to which this relationship was mediated by the cognitive and linguistic processes used to carry out nonword repetition.

Specifically, we asked the following research questions: first, do deaf children with CIs demonstrate a phonotactic probability ("frequency") or syllable length effect in their nonword repetition performance? Second, is the extent to which deaf children who use CIs demonstrate a nonword frequency effect related to their vocabulary size, as found in NH children? And third, is the relationship between phonological awareness and reading skills mediated by the same processes used in nonword repetition? (That is, does nonword repetition account for any of the variability in the children's reading skills beyond the variability that phonological awareness accounts for?)

Method

Participants

The participants in the present study were 27 deaf children with cochlear implants who all used oral communication. The children were recruited from the DeVault Research Laboratory at Riley Hospital for Children in Indianapolis, Indiana; Child's Voice Oral School in Wood Dale, Illinois; the Hearing Impaired Program at Sylvester Elementary school in Berrien Springs, Michigan; and the Hearing Impaired Program at Shawnee Park Elementary School in Grand Rapids, Michigan. Seventeen males and 10 females participated. Table 4.1 shows a summary of the children's demographic characteristics. 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. Twenty-two of the children received their implant before age 5. All of the children had used their implant for at least 3.5 years. The children were between the ages of 6 and 14 at the time of testing.

Table 4.1. Demographic characteristics of the 27 children who participated in the present study. The number of children (N) used to calculate the mean, SD and range for each characteristic is shown in parentheses in column 1.

Demographic Variable	Mean	SD	Range
Age at Onset of Deafness in years (N=24)	0.23	0.76	0.0-3.5
Duration of Deafness in years (N=24)	2.3	1.4	0.5-6.0
Age at Implantation in years (N=24)	2.5	1.3	1.0-6.0
Duration of Implant Use in years (N=24)	6.7	2.2	3.7-11.8
Chronological Age in years (N=25)	9.1	2.5	6.2-14.0

Procedure

The children completed the nonword repetition task and several other information processing tasks as part of a larger study. The tests were administered in a quiet room over a period of approximately 1.5 to 2.5 hours, including breaks taken as necessary. Each child received $28 and an Indiana Speech Research Lab t-shirt for his/her participation in the larger study. The responses provided by the children during the tasks were recorded onto digital audio tape and transferred to a computer for storage and later scoring.

Tasks and Stimuli

Nonword Repetition

Nonword Repetition Task. All of the children in the present study completed a nonword repetition task. They listened to 44 novel nonwords, played one at a time in auditory-only modality through a loudspeaker at approximately 70 dB SPL. The children were asked to repeat each nonword aloud back to the experimenter. Each child was given two practice nonwords to ensure that they understood the task. During the procedure, the children were only permitted to listen to each nonword target once.

Nonword Stimuli. The nonwords used in the present study were originally created by Edwards et al. (2004) and are shown in Table 4.2. The stimuli include 22 pairs of nonwords in which both nonwords contain the same or closely related phonemes. One nonword in each pair includes phonotactic sequences that occur with low frequency in English ("low frequency nonwords") and one includes phonotactic sequences that occur with high frequency in English ("high frequency nonwords"). Both sets of nonwords were balanced for wordlikeness (based on ratings obtained from adult listeners of how "wordlike" each nonword was). The nonword pairs include 11 2-syllable pairs and 11 3-syllable pairs. The nonwords developed by Edwards et al. not only provided nonword repetition scores and the potential to further investigate the effect of syllable length, but these materials also allowed investigation of the effects of phonotactic frequency on the children's performance. During the nonword repetition task, the stimuli and responses were recorded onto DAT and later transferred to a computer for storage and analysis.

Each listener was assigned to one of nine groups. Each group consisted of five listeners. All five listeners within a group heard all of the nonword repetition responses that were provided by three children, two times (once in a first block, and another time in a second block). The responses provided by the three children were randomized in a block, and played back in a different random order in each block. Each child's responses were heard by every listener within one group, and by no listeners from any other group. In this way, five listeners provided accuracy ratings for each child twice (once in each block).

We calculated a mean rating for each child by averaging the ratings provided by all five listeners in a block for all of that child's repetition responses. We also calculated a 'low frequency mean rating' and a 'high frequency mean rating' for each child by averaging the ratings provided by all 5 listeners for the responses provided by a child for the nonwords that contained low phonotactic probability sequences and high phonotactic probability sequences (respectively). Similarly, we calculated separate mean ratings for each child's responses to the 2-syllable nonwords and the 3-syllable nonwords.

In earlier previous studies of nonword repetition performance by deaf children with cochlear implants, we found that mean nonword repetition accuracy ratings were strongly correlated with several other measures of nonword repetition performance based on transcriptions (Chapter 2). We used the accuracy ratings in the present study because the children's nonword repetition performance was at floor when the conventional accuracy scoring methods were used. The children provided correct responses to only 9.6% of the nonword stimuli when calculated out of the total number of target stimuli (114/1122). They provided correct responses to 9.9% of the nonword stimuli when calculated out of the total number of repetition responses that they provided (114/1188). However, the children failed to provide any response to only 5.6% (66/1188) of the target nonword stimuli.

Table 4.2. Nonword stimuli. Low frequency nonwords contain less frequently occurring phonotactic sequences while high frequency nonwords contain similar segments in more frequently occurring phonotactic sequences (Edwards et al., 2004).

Syllable Length	Low Frequency	High Frequency
	/jugoin/	/bogib/
	/moip↔d/	/mΘbEp/
	/vugim/	/vIdΘg/
	/motauk/	/petik/
	/donug/	/bedΘg/
2	/tedaum/	/podaud/
	/aupt↔d/	/ipt↔n/
	/n↔fΘmb/	/mInΘmp/
	/pwAg↔b/	/twEkEt/
	/bufkit/	/kiften/
	/dogdet/	/tΘktut/
	/bod↔jau/	/med↔ju/
	/vukAtEm/	/vIt↔gAp/
	/gaun↔pEk/	/git↔mok/
	/nYb↔m↔n/	/nId↔bIp/
	/dugn↔ted/	/t℘gn↔dit/
3	/aukp↔de/	/ikb↔ni/
	/auft↔gA/	/aunt↔ko/
	/kEd↔w↔mb/	/fIk↔tΘmp/
	/pwEn↔tEp/	/twed↔mIn/
	/nΘfk↔tu/	/g℘ft↔daI/
	/dEgd↔n↔/	/tikt↔po/

Nonword Repetition Scoring. The children's nonword repetition responses were segmented into individual sound files and amplitude leveled using Level16 (Tice & Carrell, 1998). The model nonword stimuli that the children heard, followed by the children's actual vocal responses, were then played back to 45 normal-hearing naïve adult listeners. The listeners were asked to rate the children's nonword repetitions for accuracy in comparison to the model nonword on a scale of 1 to 7 (1=poor, 7=perfectly accurate).

Phonological Awareness Measure

The children in the present study also completed the Lindamood Auditory Conceptualization Test-Third Edition (LAC3; Lindamood & Lindamood, 2004). The LAC3 is a standardized phonological awareness test that is normed for NH typically-developing participants. The test items in the LAC3 were designed for children ages 5–18; this wide age range meant that it was unlikely to elicit ceiling performance from the children in the present study. The LAC3 consists of five subtests which assess the child's knowledge of different levels of phonological awareness (see Chapter 3). Items on the LAC3 consist of nonwords which minimized the child's ability to rely on lexical knowledge during the task. In addition, the LAC3 test items do not require a potentially-confounding spoken response. Description and summary of the children's performance on the LAC3 is provided in Chapter 3.

Reading Measures

A detailed description of the children's performance on the reading tests that are described below is provided in Chapter 3.

Reading Recognition: Letter/Phoneme Matching and Single Word Reading. All of the children also completed the Reading Recognition subtest of the Peabody Individual Achievement Test-Revised (PIAT-R; Markwardt, 1998), which consists of 100 test items. The first 16 items consist of four-alternative forced choice questions requiring a pointing response (including items that involve letter-matching, initial-phoneme matching, and 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. Children received one point for every word that they read aloud correctly. The test was administered until the child provided an incorrect response for five consecutive items.

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 one at a time to the experimenter. The child received one point for every nonword that he/she pronounced correctly and the test is scored immediately in real time by the examiner.

Reading Comprehension. The children also completed a read-sentence comprehension task using single sentences, the Reading Comprehension subtest of the PIAT-R (Markwardt, 1998). The test includes 82 meaningful narrative sentences which the child was told to read once silently to him/herself. After reading each sentence, the child was shown a page with four pictures and was asked to point to the alternative that best represented the meaning of the sentence. The items increased in difficulty throughout the test, which was administered until the child provided an incorrect response to five consecutive items. The child was given one point for each correct response.

Total Reading Score. In addition to these separate subtests, a total reading score (PIAT-Total) was computed for each child by summing the PIAT-Rec score and the PIAT-Comp score.

Vocabulary Knowledge Measure

All children in the present study also completed the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997). The PPVT is a standardized vocabulary knowledge test that is appropriate for use with children and adults ages 2 – 90^+ years. The PPVT is a four-alternative forced choice task administered in live-voice auditory-visual modality. Participants are asked to listen to the administrator say a single real English word and to provide a pointing response to the one of four pictures that best represents the meaning of the word. The PPVT includes 17 sets of items that increase in difficulty throughout the test. Each set contains 12 vocabulary items. The PPVT is administered until the child responds incorrectly to 8 out of 12 items within a set. A child's score on the PPVT consisted of the total number of items that he/she responded to correctly.

Results

All children provided nonword repetition responses to almost all of the nonword targets. After the exclusion of responses that were real words or phrases (such as "I don't know", "weird one", "you going"), 23 children provided a response to more than 40 out of the 44 stimuli, two children provided responses to 39 stimuli, one child provided 37 responses, and one child provided 29 responses. Overall, the children provided responses to 94% of the nonword stimuli. None of the children exhibited any difficulty understanding the procedure or carrying out the nonword repetition task.

Reliability of the Nonword Repetition Accuracy Ratings

As described above, five listeners comprised each of nine listener groups. Within a listener group, each listener provided ratings of all repetition responses obtained from the same three children. Each listener provided ratings of all repetition responses twice, once in a first block and a second time in a second block. The two blocks contained the same repetition responses randomized in different orders.

The reliability of the ratings provided by the listeners was assessed in several different ways. First, in order to investigate inter-block reliability, we calculated the mean rating provided by the listeners for each of the 2 blocks and measured the correlation between these two scores. The mean ratings provided by the listeners in the first block ($M = 3.60$, $SD = .51$) were highly correlated ($r = +.77$, $p < .001$) with the mean ratings provided by the listeners in the second block ($M = 3.63$, $SD = .59$). In addition, a paired-samples *t*-test revealed that the mean ratings in the first block were not significantly different from the mean ratings in the second block. This finding indicates that as a group, the listeners provided accuracy ratings that were consistent from the first time they heard the children's responses to the second time. All results reported below are based on the ratings obtained in the first block of trials.

We also calculated individual correlations in order to compare each listener's ratings provided in block 1 with his/her ratings provided in block 2. Because 45 listeners participated in the ratings experiment, 45 correlations were calculated. We corrected the desired alpha values using a Bonferroni correction[2]. We found that 43 of the 45 listeners provided ratings across the 2 blocks that were significantly correlated with each other. Twelve of the correlations were +.80 or greater (all *p*'s < .00002), an additional 22 of the correlations were between +.60 and +.80 (all *p*'s < .00002), six *r*-values were between +.40 and +.60 (all *p*'s < .00002), and three correlations were between +.29 and +.40 (*p*'s < .00111). These findings indicate that most of the individual listeners provided ratings that were consistent across the two blocks.

In order to investigate whether the listeners within a group provided ratings similar to each other, we used a measure of internal consistency based on inter-item correlations across listeners (Cronbach's alpha; Norusis, 2004). The listeners within each group provided ratings similar to each other in block 1 (all α's > .74) and also in block 2 (all α's > .71). This finding indicates that the ratings provided by the listeners in the present study would be replicable if other groups of listeners participated in this same task. Thus, the nonword repetition ratings provided by the listeners in this study were highly reliable and consistent both within-listener and between listeners.

---

[2] Thus, for an uncorrected *p*-value of +.05, the corrected *p*-value was (+.05/45) +.00111; for an uncorrected *p*-value of +.01, the corrected *p*-value was (+.01/45) +.00022; for an uncorrected *p*-value of +.001, the corrected *p*-value was (+.001/45) +.00002.

Nonword Repetition Ratings

The children's mean ratings ranged from 1.52 to 5.45 on the scale of 1 to 7 (*M* = 3.57 *SD* = .95). Overall, the distribution of the children's mean nonword repetition accuracy ratings was normal although slightly skewed toward the lower end of the rating scale. The individual children's overall mean accuracy ratings are shown in the lefthand panel of Figure 4.1. Although overall performance was skewed toward the lower scores, none of the children displayed a floor effect. Figure 4.1 includes a histogram of the number of children who received overall mean nonword repetition accuracy ratings in 1-unit bins.

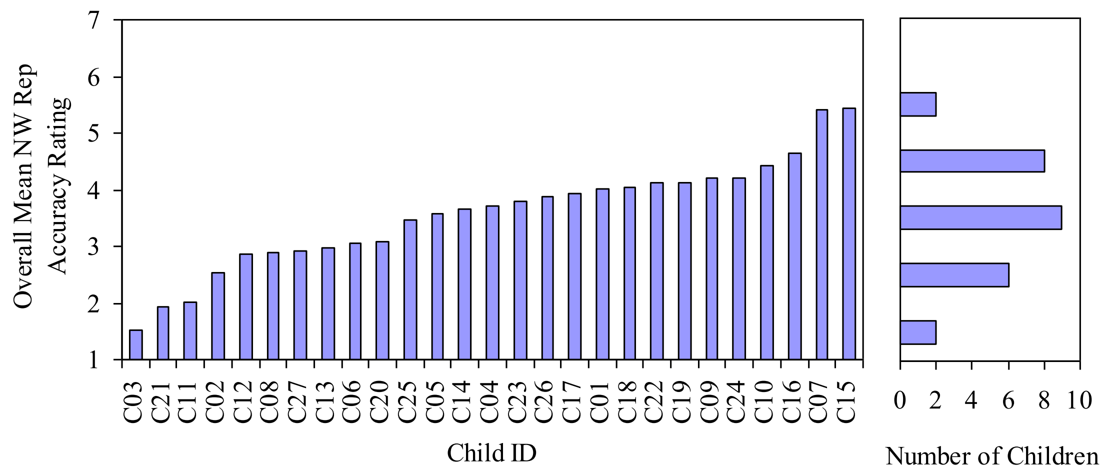

Figure 4.1. The lefthand panel shows the individual children's overall mean nonword repetition accuracy ratings, in order from the lowest mean rating to the highest mean rating. The righthand panel is a histogram of the number of children who received overall mean nonword repetition accuracy ratings in 1-unit bins from 1 to 7.

We computed a 2-way ANOVA in which mean ratings was the dependent factor, and the two independent factors were syllable length and phonotactic frequency. There was no significant main effect of phonotactic frequency. The children as a group did not receive different mean ratings for high and low frequency nonwords (low: *M* = 3.51, *SD* = 1.03; high: *M* = 3.60, *SD* = 1.08; *F*(1, 104) = .23, *p* = .64). However, the ANOVA revealed a significant main effect of syllable length. The children received significantly higher ratings (*F*(1,104) = 6.13, *p* < .05) for their responses to 2-syllable target nonwords (*M* = 3.80, *SD* = 1.05) than for their responses to 3-syllable target nonwords (*M* = 3.31, *SD* = 1.00). The interaction between syllable number and phonotactic frequency was not significant (*F*(1, 104) = .52, *p* = .47).

In addition, to confirm the lack of difference between the children's performance on the low versus high frequency nonwords, we computed 27 pairwise t-tests (one for each individual child) comparing the mean rating for each child's responses to the low frequency nonwords and the high frequency nonwords. With an uncorrected alpha value of +.05, only two children received significantly different ratings for the low versus high frequency nonwords. One of these children, C13, received a mean rating of 2.60 (*SD* = 1.07) for the low frequency nonwords and 3.37 (*SD* = 1.35) for the high frequency nonwords (*t* = 2.16, *p* = .04). The other child, C06, however, received a lower rating for the high frequency nonwords (*M* = 2.69, *SD* = 1.16) than for the low frequency nonwords (*M* = 3.33, *SD* = 1.11) ($t = 2.09$, $p = .05$). With a corrected alpha value of (α=.05/27) +.002 (using a Bonferroni correction), none of the individual children received significantly different mean ratings for the low and high frequency nonwords. Using the corrected alpha value, independent samples t-tests also showed that no children received significantly different mean ratings for the low versus high frequency nonwords.

Intercorrelations among the Nonword Repetition Scores

We also computed intercorrelations among the various nonword repetition scores. These are shown in Table 4.3. All of the nonword repetition scores were strongly correlated with each other. This finding indicates that the children who performed better on the nonword repetition task overall also tended to receive higher nonword ratings regardless of the target characteristics of the nonwords (high or low frequency, two or three syllables).

Table 4.3. Intercorrelations among the nonword repetition scores.

NW Rep Score	Mean Rating for Low Freq NWs	Mean Rating for High Freq NWs	Mean Rating for 2-syllable NWs	Mean Rating for 3-syllable NWs
Overall Mean Rating	+.97***	+.98***	+.97***	+.96***
Mean Rating for Low Freq NWs		+.90***	+.93***	+.94***
Mean Rating for High Freq NWs			+.95***	+.93***
Mean Rating for 2-syllable NWs				+.85***

***$p < .0001$

Nonword Repetition Performance as a Function of Vocabulary Size

In order to investigate the relationship between the children's nonword repetition performance and vocabulary knowledge, we split the children into two groups based on their PPVT scores. The 14 children with lower PPVT scores (*M* = 59.0, *SD* = 14.8, range = 26 – 77) comprised the low vocabulary group and the 12 children with higher PPVT scores (*M* = 118.5, *SD* = 22.6, range = 93 – 157) comprised the high vocabulary group. (We did not split the children into two groups of 13 because the middle two children both scored 77 on the PPVT.) A significant difference was observed ($t(24) = 4.32$, $p < .001$) between the overall nonword repetition ratings received by the low vocabulary group (*M* = 3.04, *SD* = .78) and the ratings received by the high vocabulary group (*M* = 4.27, *SD* = .66). This difference is consistent with earlier findings that the children's PPVT scores were significantly correlated with their nonword repetition scores ($r = +.76$, $p < .01$). The low vocabulary knowledge group received significantly lower ratings (*M* = 3.13, *SD* = .86) than the high vocabulary knowledge group (*M* = 4.31, *SD* = .69) for their responses to the high frequency nonwords ($t(24) = 3.81$, $p < .001$). Similarly, for their responses to the low frequency nonwords, the low vocabulary group (*M* = 2.94, *SD* = .79) also received significantly lower ratings ($t(24) = 4.48$, $p < .001$) than the high vocabulary group (*M* = 4.23, *SD* = .66).

A series of t-tests revealed that neither group received significantly different ratings for the low frequency nonwords than for the high frequency nonwords. Within the high vocabulary group, no significant difference was observed in the ratings between low frequency nonwords and high frequency nonwords. Similarly, within the low vocabulary group, no significant difference between low and high frequency nonwords was observed.[3]

Correlations with Demographic Characteristics

Finally, we investigated the relationship between nonword repetition performance and the children's demographic characteristics. We computed correlations between age at onset of deafness, duration of deafness prior to implantation, age at implantation, duration of CI use, age at time of testing, and grade in school and their overall mean nonword repetition ratings. Except for age at onset of deafness which was moderately corrrelated with the children's overall mean nonword repetition ratings ($r = +.42$, $p < .05$), none of the other correlations between the children's demographic characteristics and nonword repetition performance reached significance.

A "Replication" of Previous Results

In a different group of deaf children discussed in Chapter 2, we found that reading and nonword repetition were significantly correlated, and that 'lexical diversity' (based on a spontaneous speech sample) was an important factor in the relationship between reading and nonword repetition. In the present study, we used the new results from our group of 27 to compute correlations between reading nonword repetition (using different stimuli than in the study reported in Chapter 2), and to factor out vocabulary. The results are shown in Table 4.4.

In general, the results shown in Table 4.4 are similar to the earlier preliminary findings summarized in Chapter 2. Reading and nonword repetition were still significantly correlated. However, when we factored out vocabulary knowledge, the correlations between reading and nonword repetition were no longer signficant. The only exception was the finding that the single word reading scores were marginally significantly correlated with nonword repetition. This result indicates that the skills used in nonword repetition do not underlie reading skills independently of vocabulary knowledge.

[3] We also calculated overall phonological probability for the nonwords using Vitevitch and Luce's (2004) probability calculator, which is based on Jusczyk, Charles-Luce, & Luce (1998). The phonological probability calculated was the combined probability of all of the biphone sequences in each nonword. We then computed overall mean ratings for each child for their responses to the 22 target nonwords with higher phonotactic probability (high pp) and overall mean ratings for each child for their responses to the 22 target nonwords with lower phonotactic probability (low pp). An independent samples t-test revealed no difference between the mean ratings per child (N=27) for the high pp nonwords and the mean ratings per child (N=27) for the low pp nonwords. Another t-test revealed no difference between the mean ratings per nonword for the 22 high pp nonwords compared to the mean ratings per nonword for the 22 low pp nonwords. A paired samples t-test (with each child's high and low scores paired) neared significance ($t(26) = 1.92$, $p = .066$) but the direction of the difference was the opposite of what would be expected: the children's mean ratings for the high pp nonwords were lower ($M = 3.48$, $SD = .92$) than their mean ratings for the low pp nonwords ($M = 3.65$, $SD = 1.03$).

Table 4.4. Correlations between nonword repetition accuracy ratings and reading outcome measures: simple bivariate correlations, partial correlations 1 (controlling for age at onset of deafness) and partial correlations 2 (controlling for vocabulary).

Reading Outcome Measure	**Bivariate**	**Partial 1 (Age at Onset)**	**Partial 2 (Vocab.)**
Single Word Reading	+.62***	+.58**	- .47*
Nonword Reading	+.47*	+.42 ($p < .051$)	ns
Sentence Comprehension	+.66***	+.65**	ns
Total Reading (Single Word Reading + Sentence Comp.)	+.69***	+.63**	ns

Do the Phonological Processing Skills Measured by Nonword Repetition Contribute to the Relationship between Reading Skills and Phonological Awareness?

The simple bivariate correlations between phonological awareness and reading skills that were summarized in Chapter 3 are shown in Table 4.5. In our earlier study, the children's phonological awareness skills were found to be strongly correlated with their reading scores. In the present study we were interested in investigating whether nonword repetition performance was also a factor mediating in this relationship. To answer this question, we statistically controlled the children's nonword repetition skills using partial correlations, as shown in Table 4.5. When nonword repetition mean ratings were factored out of the correlations between reading and phonological awareness, the correlations did not decrease. This finding indicates that the skills used for nonword repetition performance did not affect the relationship between reading and phonological awareness. As reported in Chapter 3, when vocabulary knowledge was factored out, the correlations between reading and phonological awareness decreased in magnitude but still remained significant, indicating that vocabulary size did play a role in the relationship between reading and phonological awareness.

Bivariate correlations between reading and nonword repetition are also shown again in Table 4.5 (repeated from Table 4.4). These correlations indicate that nonword repetition is indeed related to reading, even though nonword repetition skills do not affect the relationship between reading and phonological awareness. When phonological awareness was factored out of the correlations between reading and nonword repetition (as shown in the right half of Table 4.5), the correlations remained approximately the same.

These findings indicate that the children's phonological awareness did not contribute to the relationship between nonword repetition and reading. However, when we factored out vocabulary size from the correlations between reading and nonword repetition, the correlations decreased and they were no longer significant. Thus, the relationship between reading and nonword repetition is heavily dependent on vocabulary knowledge. This finding suggests that vocabulary knowledge and the size of the children's mental lexicons is a substantial contributing factor to the link between their nonword repetition performance and reading skills.

In summary, phonological awareness, vocabulary knowledge, and nonword repetition performance are all related to reading skills. While phonological awareness and vocabulary size partially overlap in their contribution to reading skills (see Chapter 3), phonological awareness and nonword repetition skills are not overlapping in their contribution to reading skills. The skills used in nonword repetition do not affect the relationship between reading skills and phonological awareness. That is, after partialling out nonword repetition skills, the correlations between phonological awareness and reading was unaffected, indicating that the phonological processing skills indexed by nonword repetition are not an underlying factor in the relationship between phonological awareness and reading skills. Vocabulary knowledge appears to be a very important underlying factor in the relationship between reading and nonword repetition.

Table 4.5. The left half of the table shows bivariate correlations between reading scores and phonological awareness followed by partial correlations in which we factored out nonword repetition skills or vocabulary. The right half of the table shows bivariate correlations between reading scores and nonword repetition followed by partial correlations in which we factored out phonological awareness or vocabulary.

	Correlations with Phonological Awareness (LAC3)			**Correlations with Nonword Repetition Mean Ratings**		
Reading Outcome Measure	Bivariate	Partial 1 (NW Rep.)	Partial 2 (Vocab.)	Bivariate	Partial 1 (Phon. Awar.)	Partial 2 (Vocab.)
Single Word Reading & Reading Readiness (PIAT Reading Recognition Raw Scores) (N=27)	+.82***	+.86***	+.65***	+.62***	+.61**	-.47*
Nonword Reading (WRMT Word Attack Raw Scores) (N=27)	+.72***	+.77***	+.52**	+.47*	(+.37**, *p*=.07)	ns
Read-Sentence Comprehension (PIAT Reading Comprehension Raw Scores) (N=26)	+.86***	+.85***	+.60**	+.66***	+.64***	ns
PIAT Total Reading Raw Scores (N=27)	+.86***	+.87***	+.67***	+.69***	+.68***	ns

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

Discussion

Overall, the 27 children tested in this study were able to complete the nonword repetition task and the vocabulary test without performing at floor or ceiling levels. The nonword repetition accuracy ratings that we collected from adult listeners were found to be highly reliable both within and between listeners. The overall mean ratings of the children's nonword repetition responses were found to be strongly correlated with the mean ratings of the subsets of nonwords (high frequency, low frequency, 2-syllable, and 3-syllable). These intercorrelations indicate that the children who provided better nonword repetition responses overall tended to provide better responses to all nonword subtypes (high frequency, low frequency, 2-syllable, and 3-syllable).

The children's nonword repetition responses were found to be significantly correlated with their age at onset of deafness. This finding is consistent with previous research that has shown that children who become deaf at later ages demonstrate better performance on speech and language outcome measures (e.g., Geers et al., 2003). However, this correlation should be viewed with some caution because most of the children who participated in this study were congenitally deaf. Other studies that have used larger sample sizes than the present study provide more details about the relationship between demographic characteristics and outcome measures (e.g., see Geers & Brenner, 2003).

Because other researchers have found that NH children provide more accurate repetition responses to high phonotactic frequency nonwords than to low phonotactic frequency nonwords (e.g., Coady et al., 2001; Edwards et al., 2004; Munson et al., 2005), we expected that the deaf children studied here would also receive higher mean accuracy ratings for their responses to the high phonotactic frequency nonwords than to the low phonotactic frequency nonwords. We expected that the children who had sufficient experience listening to English would have made use of the generalizations about the frequency of phonotactic sequences. We also expected that even if the children as a group did not demonstrate a difference in performance for the high and low frequency nonwords, then at least the subset of children with higher vocabulary scores would display this pattern.

However, the present results were not consistent with these expectations. The children as a group and taken as individuals did not repeat the high frequency nonwords more accurately than the low frequency nonwords, at least when the responses were scored using the ratings method. Furthermore, after we split the children into a high vocabulary group and a low vocabulary group, we found that although the higher vocabulary group received higher mean ratings overall than the lower vocabulary group, neither group demonstrated a difference in performance on the high versus low phonotactic frequency nonwords. Thus, the children did not display evidence of being differentially sensitive to high and low frequency phonotactic sequences in English.

Several factors may have been responsible for the absence of a phonotactic frequency effect in the nonword repetition task. One factor may have been our method of scoring the children's nonword repetition responses. Previous nonword repetition studies have used transcription-based scores to compare children's responses to high and low frequency nonwords, but we used perceptual accuracy ratings obtained from naïve listeners. However, we have found that transcription-based scores and perceptual accuracy ratings of nonword repetition responses provided by deaf children with cochlear implants were strongly intercorrelated (Chapter 2).

A second possible cause may be task-related. Perhaps a component or components of the nonword repetition task were difficult enough that they prevented a phonotactic frequency effect from surfacing. For instance, difficulty with the speech production component of nonword repetition may have overridden any phonotactic frequency effects, and a different task that did not require a spoken response may reveal effects of phonotactic frequency.

A third possible cause of the lack of phonotactic frequency effect may be related to the children's abstract representations. It is possible that the level of phonetic detail encoded and utilized by NH children in their representations (and repetitions) of high phonotactic frequency sequences is not present in the phonological representations encoded by deaf children with cochlear implants. It may be necessary for the children to acquire more vocabulary knowledge and experience with spoken language in order to develop detailed and robust representations that are sufficiently specified for the children to make broader generalizations across the lexicon regarding phonotactic sequences.

Although the children in this study did not demonstrate a phonotactic frequency effect, they did display a syllable length effect. The children received higher accuracy ratings for their responses to the 2-syllable nonwords than to the 3-syllable nonwords. This result is consistent with earlier findings that deaf children tend to repeat shorter nonwords more accurately than longer nonwords. Both Carter et al. (2002) and Dillon, Pisoni, et al. (2004) reported this finding for deaf children who use cochlear implants in their studies on the nonword repetition responses to 2- to 5-syllable nonwords from the Children's Test of Nonword Repetition (Gathercole et al., 1994).

Gathercole, Willis, Emslie and Baddeley (1992) also found that NH children repeated shorter nonwords more accurately than longer nonwords. Gathercole et al. (1992) suggested that the length effect that NH children exhibit in their nonword repetition performance is related to phonological working memory limitations (see also Dillon, Burkholder, et al., 2004). Children have more difficulty maintaining longer nonwords in phonological working memory (Burkholder & Pisoni, 2003), and thus provide poorer repetition responses to longer target nonword stimuli. Similarly, normal-hearing children also display better recall of lists of shorter words than longer words (Baddeley, Thomson, & Buchanan, 1975; see also Cowan, Wood, Nugent, & Treisman, 1997).

Our earlier findings indicated that the reading skills of children who are deaf and use cochlear implants are related to nonword repetition performance (Chapter 2) and that their reading skills are strongly related to both phonological awareness and vocabulary knowledge (Chapter 3). The present study revealed that the children's reading scores were signficantly correlated with their nonword repetition performance. However, correlations between phonological awareness and reading skills did not decrease when nonword repetition accuracy was factored out. This finding suggests that the phonological processing skills assessed by nonword repetition performance do not affect the relationship between reading skills and phonological awareness in deaf children who use cochlear implants. Similarly, we found that correlations between nonword repetition and reading did not decrease when we factored out phonological awareness. Thus, phonological awareness is not a mediating factor in the relationship between reading nonword repetition. Taken together, these findings indicate that while nonword repetition and phonological awareness both contribute to reading, their contributions are independent of each other. Furthermore, our finding that correlations between reading and nonword repetition become weaker and non-significant when vocabulary is factored out indicates that the relationship between nonword repetition and reading relies very heavily on the children's vocabulary knowledge.

Nonword repetition is a phonological processing task that requires several types of phonological processing skills. The nonword repetition task required each child to parse novel speech patterns into a sequence of phonological units that he/she could encode, rehearse, and reassemble for speech production. The phonological awareness task also required the child to parse a continous speech signal, but it did not require reassembly of the phonological units in the speech signal speech production. Thus, the phonological awareness task is also a phonological processing task, but with different components than the nonword repetition task.

Nonword repetition and phonological working memory skills have been found to be closely related in normal-hearing children and adults (Gathercole et al., 1994; Gupta, 2003). However, the nonword repetition task also requires speech perception and speech production skills (see Dillon, Burkholder, et al., 2004). In Chapter 5 we use "purer" measures of phonological working memory (digit spans, speaking rate) to investigate whether phonological working memory skills are a mediating factor in the relationship between phonological awareness and reading skills.

CHAPTER V: PHONOLOGICAL PROCESSING SKILLS AND READING SKILLS IN DEAF CHILDREN WITH COCHLEAR IMPLANTS

Abstract

This study investigated the relationship between phonological awareness and reading skills in children who use cochlear implants. Specifically, we investigated the extent to which this relationship may be due to differences in phonological working memory (forward and backward digit span, speaking rate based on sentence durations) and vocabulary knowledge. Forward digit span scores and sentence durations were significantly correlated with each other and not with backward digit span. Phonological awareness was not significantly correlated with forward digit span, was moderately correlated with sentence durations, and was strongly correlated with backward digit span. When we statistically controlled for forward digit span, speaking rate, and backward digit span, we found that none of these process measures was a mediating factor in the relationship between phonological awareness and reading. This finding indicates that although phonological working memory skills may contribute to a child's phonological awareness skills, phonological working memory skills do not independently contribute to the variation in reading beyond what can be explained by phonological awareness skills.

Introduction

Phonological processing refers to several cognitive operations that are routinely used in the processing of speech. Brady (1991) discusses these cognitive operations as three classes of abilities that draw on phonological representation. These operations include phonological awareness (parsing of a continuous speech signal into discrete abstract individual phonological segments, or phonemes), encoding items in phonological working memory, and retrieval of phonological representations from the lexicon (Troia, 2004; Wagner & Torgeson, 1987; Brady, 1991). Many studies have shown that these three different phonological processing abilities are related to each other and are related to reading skills in children and adults, but further research is still needed if we are to understand the nature and structure of these relationships (Brady, 1991). In the present study, we obtained measures of these phonological processing skills and examined their relationship to reading in deaf children with cochlear implants.

Phonological awareness is defined in various ways by different researchers. Moreover, many different tasks have been used to measure phonological awareness. In general, phonological awareness refers to a person's knowledge that individual words can be parsed and decomposed into smaller units such as phonemes, onsets-rimes, or syllables. In the present study, the phonological awareness of deaf children who use cochlear implants was assessed using a task that included several subtests which indexed phoneme and/or syllable-level phonological awareness. In addition, we obtained three different measures of phonological working memory. Working memory is assumed to consist of two subcomponents: a "temporary storage system" that holds memory traces for a matter of seconds, and a "subvocal rehearsal system" through which the initial memory traces are maintained in order to delay their rapid decay (Baddeley, 2003). To assess the temporary storage system subcomponent of phonological working memory, a forward digit span measure was obtained. In order to assess the subvocal rehearsal system subcomponent of phonological working memory, a measure of speaking rate was obtained from each child. The rate at which items are subvocally (or verbally) rehearsed in phonological working memory is widely accepted to be reflected in the speaking rates of both children and adults (see Baddeley, Thompson, & Buchanan, 1975; Burkholder & Pisoni, 2003). In the present study, measurements of sentence durations were used to quantify speaking rate.

We also obtained a measure of receptive vocabulary from the children in the present study. This measure provides an estimate of vocabulary size, or the number of items in the child's mental lexicon. We used a measure of vocabulary knowledge rather than lexical retrieval (the third phonological processing operation) because we were interested in investigating the more basic question of how many items were in the children's lexicon before conducting a possible future study of the children's skill in retrieving these items from the lexicon by completing tasks such as speeding naming.

In addition, we also obtained a measure of backward digit span from the children. While backward digit span tasks require children to maintain a sequence of digits in phonological working memory, the manipulation of digits required in this task draws on more general cognitive processing skills ("executive function"). Thus, backward digit span performance tends not to be correlated with forward digit span performance and other measures that index the same processing skills as forward digit span (see, e.g., Rosen and Engle, 1997).

The relationship between backward digit span on the one hand and phonological working memory skills (indexed by both forward digit span and speaking rate) and vocabulary on the other hand, has been explored in children who use cochlear implants (Burkholder & Pisoni, 2003; Cleary, Pisoni, & Kirk, 2000). However, the relationship between backward digit span and phonological awareness has not been previously investigated in deaf children who use cochlear implants. Thus, we obtained a measure of backward digit span in the present study in order to investigate whether backward digit span performance mediated in the relationship between the children's phonological awareness and reading skills. The phonological working memory tasks (forward digit span and sentence durations) and backward digit span task used in the present study have proven to be useful in previous studies because they provide "process" measures of the children's phonological/cognitive skills. Process measures assess aspects of the process or task that a child completes, as opposed to product measures in which the child's score is based more directly on the final result of his/her cognitive processing (such as nonword repetition or receptive vocabulary responses). One important aspect of process measures is that children do not reach ceiling on such tasks (see Burkholder & Pisoni, 2003).

In our earlier study we investigated the relationship between the children's reading skills and phonological awareness (Chapter 3). We found that the children's phonological awareness and reading skills were strongly correlated (r's = +.72 to +.86, all p's < .001). In addition, after we statistically controlled for the children's demographic characteristics and speech perception skills, we found that the correlations between phonological awareness and reading skills did not decrease. That is, differences in the children's demographic characteristics and speech perception skills did not explain the relationship between phonological awareness and reading. Regardless of their demographic characteristics or speech perception skills, children with poor phonological awareness also tended to display poor reading, and vice versa.

In the present study, we further investigated the relations between phonological processing skills and reading in deaf children who use cochlear implants. Specifically, we examined the relations between phonological awareness and reading skills. To assess the extent to which this relationship may be due to differences in phonological working memory processes and vocabulary knowledge, we asked whether phonological working memory skills independently contribute to the relationship between reading skills and phonological awareness in children who are deaf and use cochlear implants.

Method

Participants

The participants included seventeen boys and 10 girls who were profoundly deaf and used cochlear implants. The children's demographic characteristics are summarized in Table 5.1. The children who participated in the present study are described in more detail in Chapters 3 and 4.

Table 5.1. The demographic characteristics of the 27 children who participated in the present study.

Demographic Variable	Mean	SD	Range
Age at Onset of Deafness in years (N=24)	0.23	0.76	0.0-3.5
Duration of Deafness in years (N=24)	2.3	1.4	0.5-6.0
Age at Implantation in years (N=24)	2.5	1.3	1.0-6.0
Duration of Implant Use in years (N=24)	6.7	2.2	3.7-11.8
Chronological Age in years (N=25)	9.1	2.5	6.2-14.0

Tasks and Stimuli

Phonological Processing Skills

Phonological Awareness. We obtained a measure of the children's phonological awareness using the standardized Lindamood Auditory Conceptualization Test-Third Edition (LAC3; Lindamood & Lindamood, 2004). The LAC3 is designed to test 5- to 18-year-old participants' ability to parse a speech signal into phonological units (phonemes or syllables) and does not require spoken responses. The children's performance on this task is reported in detail in Chapter 3.

Phonological Working Memory. ***Immediate Memory Capacity: Forward Digit Span.*** A forward digit span measure was obtained from the children using a subtest of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991). This task measures the capacity of the temporary storage system subcomponent of phonological working memory (Pisoni & Cleary, 2003; Pisoni & Geers, 2000). Each child was asked to listen to and then repeat back lists of spoken digits read live-voice in auditory-visual modality to the child at a rate of approximately 1 digit per second. The list length began at 2 digits and two lists were given at each list length. If the child correctly repeated at least one list at a given list length, then the list length on the next trial was increased by one until the child did not correctly repeat either list at a given list length. The child received one point for each list that he/she repeated correctly. The number of points received by each child was his/her 'total' score. Each child was also assigned a 'longest list length' score. This score was equal to the number of digits in the longest list that he/she repeated correctly.

Phonological Working Memory. ***Verbal Rehearsal: Speaking Rate.*** Spoken productions of twelve 7-syllable sentences from the McGarr Speech Intelligibility Test (McGarr, 1981; see also Tobey, Geers, Brenner, Altuna, & Gabbert, 2003) were obtained from the children. Each sentence was printed in 36 point Times New Roman font and displayed on a notecard. The sentences were spoken aloud by the examiner (with lip-reading cues available) and then the notecard with the printed version of the sentence was placed in front of the child[4]. The children were asked to repeat the sentences in their "best speaking voice." If the examiner noted any incomplete or incorrect portions of the sentences during testing, the child was asked to repeat the utterance up to three times. This procedure was followed in order to elicit the best speech sample possible (Burkholder & Pisoni, 2003). The children's responses were recorded onto digital audio tape and the duration of each sentence was measured. An average sentence duration was calculated for each child. This procedure has been used previously to measure speaking rate and verbal rehearsal speed in school-age deaf children with cochlear implants (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003).

Phonological Working Memory. ***Backward Digit Span.*** Backward digit span measures were obtained from the children using the Wechsler Intelligence Scale for Children – Third Edition (WISC-III; Wechsler, 1991). The procedure used for backward digit span was the same as the procedure used for forward digit span except that the children were asked to repeat the digits in each list in reverse order. Although backward digit span is not a phonological working memory measure per se, it is discussed along with the phonological working memory measures below.

Vocabulary Knowledge

We used a standardized receptive vocabulary test, the Peabody Picture Vocabulary Test – Third Edition (PPVT; Dunn & Dunn, 1997), to measure vocabulary knowledge in the present study. For each item on the PPVT, the child listened to a word presented live-voice in auditory-visual modality. He/she then pointed to one of four pictures that best represented the meaning of the word. The children received one point for every correct response. The PPVT includes 12 sets of 17 items each. The sets increase in difficulty from kindergarten level to twelfth-grade level. The test was administered until the child responded incorrectly to at least 8 out of 12 items in a set. A summary of the children's performance on the PPVT is provided in Chapter 4.

Reading Skills

The children completed two subtests of the Peabody Individual Achievement Test-Revised (PIAT-R; Markwardt, 1998). The Reading Recognition subtest included 16 items that consisted of four-alternative forced choice questions requiring a pointing response (including items that involve letter-matching, initial-phoneme matching, and matching of initial-phonemes to letters), followed by 84 single real-word reading items. The Reading Comprehension subtest of the PIAT-R consisted of 82 sentences which each child read once silently to him/herself. The child was then asked to provide a pointing response to indicate which one of four pictures on a page best represented the meaning of the sentence. For each subtest of the PIAT-R, children received one point for every item to which they responded correctly. Each subtest was administered until the child responded incorrectly to five consecutive items. A "PIAT-Total" score was calculated for each child by adding their PIAT-Rec and PIAT-Comp score. The children's performance on the reading tests is reported in detail in Chapter 3.

The children also completed a nonword reading task, the Word Attack subtest of the Woodcock Reading Mastery Tests - Revised (WRMT; Form G; Woodcock, 1998). For this task, each child was asked to read 45 nonwords aloud one at a time. The child received one point for every nonword that he/she pronounced correctly.

[4] The extent to which children appeared to use the notecard to read aloud the written version of the sentence, rather than or in addition to repeating the spoken version, varied across the children.

Analyses

We calculated means, standard deviations, and ranges of the children's performance on the phonological working memory tasks. These descriptive results, in addition to correlations among the phonological working memory tasks, are reported below. We also investigated the relationships between phonological awareness, phonological working memory, vocabulary knowledge and speech perception by calculating simple bivariate correlations among these measures. Finally, we examined the extent to which the relationship between phonological awareness and reading (already reported in Chapter 3) was mediated by demographic characteristics, speech perception, phonological working memory, and/or vocabulary skills.

Results

Phonological Working Memory Measures

The results of the children's digit span performance and sentence durations are shown in Table 5.2. As shown, the individual children displayed a wide range of variability on these tasks. Forward digit span scores ranged from 3 to 9 (M = 5.4, SD = 1.5). Backward digit span scores ranged from 0 to 6 (M = 3.0, SD = 1.6). Sentence durations ranged from 1.48 seconds to 7.74 seconds (M = 2.91, SD = 1.45). Overall, the memory spans obtained in the present study tended to be shorter than those reported in the literature for normal-hearing children.

Table 5.2. Results of the phonological working memory measures.

Phonological Working Memory Measure	Mean	SD	Range
Forward Digit Span (N=27)	5.4	1.5	3-9
Backward Digit Span (N=25)	3.0	1.6	0-6
McGarr 7-syl. Sentence Durations (in sec) (N=23)	2.91	1.45	1.48-7.74

The two measures of phonological working memory, forward digit span and speaking rate (as indexed by sentence durations), were negatively correlated (r = -.63, p < .01, N=23). This finding indicates that the children who demonstrated higher working memory capacity (on the digit span task) also had shorter sentence durations (which reflect faster verbal rehearsal speeds). The children's backward digit span scores, however, were not significantly correlated with either forward digit span (N=25) or speaking rate (N=21). This finding suggests that backward digit span assesses different cognitive processing abilities than forward digit span and mean sentence durations.

Correlations between Phonological Working Memory and Demographic Characteristics

We investigated the relations between the children's phonological working memory (and backward digit span) scores and their demographic characteristics. As shown in Table 5.3, several of these correlations reached significance using standard uncorrected alpha values (p < .05, p < .01). However, because this analysis involved the calculation of a large number of correlations (18), it was necessary to use corrected alpha values. Thus, for a desired alpha of .05, the corrected alpha was (.05/18) .003. None of the correlations reached significance using the corrected alpha value.

Table 5.3. Correlations between the children's phonological working memory measures (and backward digit span) and their demographic characteristics. The number of children (N) whose scores and demographic characteristics were used to calculate each correlation is shown in the bottom row of each cell. Correlations that reached significance using uncorrected alpha values are shown with their *p*-values.

	Age at Onset	Duration of Deafness	Age at Implant-ation	Duration of CI Use	Age at Time of Testing	Child's Grade in School
Forward Digit Span	+.55	ns	ns	ns	+.46	+.47
	N=24	N=24	N=24	N=24	N=25	N=23
Mean Sent. Durations	ns	ns	ns	ns	-.46	-.48
	N=21	N=21	N=21	N=21	N=22	N=20
Backward Digit Span	ns	ns	ns	+.43	ns	ns
	N=22	N=22	N=22	N=22	N=23	N=21

Partial Correlations between Phonological Awareness and Reading Skills

In the present study, we also examined the relationship between reading skills and phonological awareness by statistically controlling for measures of the children's phonological working memory. In order to explore which aspects of phonological working memory were possible mediating factors, we computed correlations between the working memory measures and phonological awareness, and the working memory measures and reading (Table 5.4). We found that forward digit span and phonological awareness were not significantly correlated, but that the children's mean sentence durations were moderately correlated with phonological awareness. Children with longer forward digit spans tended to display faster speaking rates (which were reflected in shorter mean sentence durations). Backward digit span was found to be strongly correlated with phonological awareness. These findings suggest that the skills involved in the phonological awareness tasks in the LAC3 draw on the general cognitive processing skills involved in backward digit span ("executive function"; see Hester, Kinsella, & Ong, 2004), but do not heavily rely on phonological working memory capacity.

Correlations between the children's reading test scores and phonological working memory performance tended to be strong as well, as shown in Table 5.4. Unlike the correlations with phonological awareness, none of the working memory measures were more closely related to reading than any of the other working memory measures. The only exception to this generalization is that nonword reading was more strongly correlated with forward digit span and sentence durations but was not significantly correlated with backward digit span. This finding indicates that in order to decode novel words perhaps the children relied more on phonological working memory skills than on executive function or the more general cognitive processing skills indexed by backward digit span.

Table 5.4. Correlations between the children's phonological working memory performance on the one hand and phonological awareness and reading scores on the other hand.

	Phono. Awar.	Single Word Reading	Nonword Reading	Sentence Comp.	Total Reading (Single Word + Sent. Comp.)
Fwd Digit Span	ns	+.53**	+.59**	+.57**	+.54**
Sentence Durations	-.45*	-.58**	-.70***	-.59**	-.60**
Bwd Digit Span	+.64***	+.53**	ns	+.51*	+.55**

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

The relationship between phonological awareness and reading skills did not become weaker when we controlled for phonological working memory capacity by partialing out the children's forward digit spans (as shown in Table 5.5). This finding was not surprising given that that forward digit span and phonological awareness were not significantly correlated. Similarly, when the children's speaking rates (an index of verbal rehearsal speed) were controlled, the correlations between the reading measures and phonological awareness also did not decrease. In addition, we also found that backward digit span was not a mediating factor in the relationship between phonological awareness and reading skills. However, as reported in Chapter 3, the correlations between the children's phonological awareness and reading skills decreased when we statistically controlled for their vocabulary size.

Table 5.5. Correlations between reading scores and phonological awareness, bivariate and partials after controlling for phonological working memory measures and lexical size.

	Correlations with Phonological Awareness (LAC3)				
Reading Outcome Measure	Bivariate	Partial 1 (Forward Digit Spans)	Partial 2 (Sentence Durations)	Partial 3 (Backward Digit Spans)	Partial 4 (Lexicon Size)
Single Word Reading & Reading Readiness (PIAT Reading Recognition Raw Scores) (N=27)	.82***	.85***	.81***	.81***	.65***
Nonword Reading (WRMT Word Attack Raw Scores) (N=27)	.72***	.79***	.77**	.78***	.52**
Read-Sentence Comprehension (PIAT Reading Comprehension Raw Scores) (N=26)	.86***	.85***	.83**	.80***	.60**
PIAT Total Reading Raw Scores (N=27)	.86***	.86***	.84***	.82***	.67***

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

Thus, vocabulary knowledge appears to be a contributing factor that mediates in the relationship between reading and phonological awareness, but phonological working memory is not a mediating factor in the relationship between reading and phonological awareness. It is important to note that although phonological working memory is not a latent variable underlying the correlation between reading and phonological awareness, phonological working memory is nevertheless related to reading ability.

Discussion

Twenty-seven deaf children with cochlear implants participated in the present study. They completed several processing tasks that were designed to measure their phonological working memory skills: forward digit spans which index phonological working memory capacity; sentence durations which measure speaking rate, which provides an index of verbal rehearsal speed in phonological working memory; and backward digit spans, a more general cognitive processing task that assesses executive function in working memory.

Overall, the children's performance was very similar to the performance of a demographically-comparable group of children with cochlear implants whose phonological working memory skills were reported in Cleary, Pisoni, and Kirk (2000). Cleary et al. studied a group of 32 deaf children ages 5 to 13 who use cochlear implants and oral communication. They found that the mean forward digit span was approximately 5.5 and the mean backward digit span was slightly over 3. Burkholder and Pisoni (2003) also studied another group of 37 children who used cochlear implants. Twenty-two of these children used oral communication. This group of children was more homogeneous in terms of their demographic characteristics than the group of children in the present study or in the earlier study by Cleary et al. (e.g., all of the children in the Burkholder and Pisoni study were 8 or 9 years old), although their mean demographic characteristics were again similar to the children in the present study.

The mean forward digit span for the oral communication group (N=22) was 5.14, while the mean backward digit span score was 3.32. Burkholder and Pisoni (2003) found that age-matched normal-hearing children had significantly longer forward and backward digit spans than the deaf children with cochlear implants. These previous findings suggest that the group of children in the present study performed similarly to other groups of demographically-comparable groups of deaf children who use cochlear implants. Thus, it is likely that digit spans of the deaf children in the present study would be shorter than those of age-matched NH children.

In addition, the children who used cochlear implants and oral communication in Burkholder and Pisoni also produced mean sentence durations (for the McGarr 7-syllable sentences) that were slightly less than 3 seconds, which is again similar to our findings in the present study. The children in Burkholder and Pisoni (2003) had significantly longer sentence durations (slower speaking rates) than the age-matched NH group of children. Thus, based on the findings of Burkholder and Pisoni (2003), it is also likely that the children in the present study demonstrated slower speaking rates than age-matched NH children would have demonstrated.

We found that forward digit span and sentence duration, an index of speaking rate, were significantly correlated with each other, but they were not significantly correlated with backward digit span. This pattern of correlations indicated that completion of the backward digit span task does not rely on the same cognitive processing resources as forward digit span and speaking rate. The children's scores on the phonological working memory tasks were significantly related to their demographic characteristics. This finding is consistent with previous findings from our laboratory obtained from deaf children with cochlear implants (e.g., Burkholder & Pisoni, 2003; Dillon, Cleary, et al., 2004) and other results obtained from normal-hearing typically-developing populations (see Rosen & Engle, 1997), which have shown that backward digit span measures fundamentally different cognitive processing skills than forward digit span.

In the present study, we found that when phonological working memory skills were factored out of correlations between reading and phonological awareness, the correlations still remained strong and highly significant. Although phonological working memory skills are related to phonological awareness and to reading, the relationship between phonological awareness and reading is strong and is separate from the relationship between reading and phonological working memory skills. Taken together, our recent studies (Chapters 3 and 4) and the results of the present investigation demonstrate that the phonological processing skills involved in phonological awareness, nonword repetition, and phonological working memory skills are related to reading skills. However, reading skills are more strongly correlated with phonological awareness than to nonword repetition skills, phonological working memory skills and other potentially confounding variables such as demographic characteristics and speech perception.

In the present study, we also found that children who displayed large backward digit spans also tended to demonstrate strong phonological awareness skills, possibly because both skills rely on some general cognitive processing ability related to executive function. This is not surprising, considering that several of the measures of phonological awareness require children to reverse the order of elements, similar to the task required in backward digit recall. However, although phonological working memory skills may contribute to a child's phonological awareness measures, the correlations between reading skills and phonological awareness are not simply a reflection of variation in phonological working memory. The speech-related processing skills involved in phonological awareness (such as parsing and decomposition of a continuous speech signal into a sequence of discrete units), rather than the more general processing skills involved in the working memory tasks or backward digit span, appear to contribute more directly to the development of children's reading skills.

CHAPTER VI: SUMMARY AND CONCLUSIONS

In the present study, we investigated several cognitive and linguistic skills that underlie reading in deaf children who use cochlear implants. We obtained measures of phonological processing that have been found to be related to reading in normal-hearing (NH) children. In an initial study of existing data obtained from 76 experienced pediatric cochlear implant users (Chapter 2), we found that nonword repetition, a phonological processing task that relies on phonological working memory, was related to the children's reading skills and to their lexical knowledge as indexed by the number of different words used in a spontaneous speech interview. These preliminary findings suggested that these deaf children used some of the same phonological processing skills to complete nonword repetition and reading tasks that NH children use, and further that both of these processes are related to a measure of the size of the child's lexical knowledge.

In a follow-up investigation summarized in Chapters 3–5, we studied a group of 27 deaf children who used cochlear implants and oral communication. 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. This group of children completed a series of tasks including several reading tests, a phonological awareness test, a receptive vocabulary test, a speech perception test, and a nonword repetition task.

On the standardized tests of reading, phonological awareness and vocabulary, we found that approximately 40% to 75% of the children in the present study obtained scores that were within the normal range (one standard deviation above or below the mean) of NH children. About a quarter of the children performed below normal for NH children their age. Up to approximately 25% of the children performed above the norm compared to their NH peers. A greater proportion of the older children who used cochlear implants (compared to the younger children) performed in the bottom half of their NH 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 NH peers.

In the nonword repetition task, the nonword stimuli were balanced for phonotactic frequency (high versus low) and syllable length (two versus three). The children received higher mean accuracy ratings for their responses to 2-syllable target nonwords than to 3-syllable target nonwords. This finding is consistent with earlier reports in the literature that NH children and children with cochlear implants tend to repeat shorter nonwords more accurately than longer nonwords (Carter, Dillon, & Pisoni, 2002; Dillon, Pisoni, Cleary, & Carter, 2004; Gathercole, Willis, Emslie, & Baddeley, 1992).

However, the deaf children in this study did not exhibit a phonotactic frequency effect in the nonword repetition task. This finding may be related to the finding that the children also obtained lower vocabulary scores than would be expected given their good performance on the reading tests; about 60% of the children had vocabulary sizes that were more than one standard deviation below the mean of their NH peers. We split the children into two groups based on their vocabulary scores and found that children with higher vocabulary scores performed better overall on nonword repetition than children with lower vocabulary scores. However, neither vocabulary group exhibited a phonotactic frequency effect.

We found that the children's reading skills were strongly correlated with their phonological awareness. However, some variability in the children's reading scores was left unexplained by phonological awareness. This finding, along with our interest in whether the outcome of phonological awareness tests and their correlations with reading were due to some other latent variable(s), led us to explore the contribution of several other variables in the relationship between reading and phonological awareness. We found that demographic variables and speech perception did not independently contribute to reading skills beyond the contribution of the phonological awareness measure.

We examined the contribution of nonword repetition skills to reading, partialing out nonword repetition scores from the correlations between the reading measures and phonological awareness. We found that nonword repetition performance was correlated with the reading test scores, but partial correlations revealed that the phonological processing skills involved in nonword repetition did not mediate in the relationship between reading skills and phonological awareness. Similarly, we found that while phonological awareness did not contribute to the relationship between reading and nonword repetition, vocabulary size was a very important underlying factor in this relationship. That is, the relationship between reading skills and nonword repetition performance relies heavily on the children's vocabulary knowledge.

We also investigated the degree to which phonological working memory resources were related to reading and phonological awareness. First, we found that in general the working memory measures were related to reading. Phonological awareness on the other hand was correlated with sentence durations which are an index of verbal rehearsal speed and with backward digit span, but not with forward digit span. We again computed partial correlations, factoring out the children's scores on the working memory measures from the correlations between reading and phonological awareness. We found that the correlations between reading and phonological awareness did not decrease when we partialled out the phonological working memory measures. These findings suggest that the processing resources the children used to complete the phonological working memory tasks did not overlap with those used to carry out the phonological awareness task.

Future Studies

Our findings indicate that phonological awareness and vocabulary independently contribute to reading skills in deaf children with cochlear implants, although their contributions to the children's reading skills partially overlap. Each contributes to the development of reading skills, but even when taken together they leave some variance in reading performance unexplained. Future studies should further explore the cognitive and linguistic skills that underlie reading in deaf children with cochlear implants. Several other areas for future research also arise out of the present findings, as described below.

In the present study, we found that deaf children with cochlear implants could carry out a nonword repetition task, but that their responses did not display sensitivity to the phonotactic probability in the nonword stimuli. Furthermore, even the subset of children who had higher vocabulary scores did not demonstrate a phonotactic probability effect, although these children received higher overall nonword repetition ratings than the children with smaller vocabularies. Although this finding may reflect lack of knowledge of the phonotactic patterns of English, such a conclusion would be premature. It is possible that any phonotactic frequency sensitivity that the children may have was masked by the processing demands of speech production or speech perception components of the nonword repetition task. Perhaps the use of a different information processing task would reveal differences in the robustness of phonological representations of high and low frequency phonotactic patterns. For instance, it is possible that if deaf children with cochlear implants were asked to complete a task that did not require speech production (such as providing wordlikeness judgments of nonwords), they would display sensitivity to the phonotactic probabilities of these patterns.

The finding that most of the children had substantially smaller lexicons than their NH peers could partially explain the lack of phonotactic frequency effect in the nonword repetition task. If the child's mental lexicon does not contain as many items to use in making generalizations across the lexicon, then perhaps their nonword productions are of such a low quality that frequency effects are not evident. That is, poorly specified lexical representations may be reflected in the lack of phonotactic frequency effect and smaller relative vocabulary sizes. The children may have had lexicons that were a sufficient size to allow development of phonological awareness which in turn helped them develop reading skills, but not a sufficiently large lexicon to enable them to demonstrate a phonotactic frequency effect in the nonword repetition task.

The results of the present investigation revealed a strong relationship between the deaf children's reading skills (single-word reading, nonword reading, and read-sentence comprehension) and phonological awareness skills. This relationship was not mediated by any of the children's demographic characteristics or their speech perception skills, 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 may 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 that enabled them to obtain higher scores on the phonological awareness and reading tests. Brady's (1991) conceptualization of this hypothesis is that more robust and detailed phonological representations may 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. The children's phonological representations are strengthened with the acquisition of additional vocabulary items in their lexicons, which is consistent with Beckman and Pierrehumbert's (2003) views of the 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 the phonological awareness task and better reading skills on tasks that rely on phonological representations.

Further research is warranted regarding the *sources* of the development of 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 oral communication or total communication environments). Insights into the development of phonological representations should come from further behavioral research, and may also come from genetic studies. Several recent studies have reported 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 children's sentence comprehension scores tended to be closer to those of their NH peers than their vocabulary scores were. This finding suggests that deaf children may make greater use of sentence context in order to interpret sentences for meaning on the sentence comprehension task than NH children did, allowing them to perform at a relatively higher level on the sentence comprehension task than on the PPVT compared to NH children. Another interpretation of this finding rests on the fact that the PPVT 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 were generally high, and speech perception did not appear to be a direct cause of difficulty for the children on the PPVT.

The children's phonological awareness as indexed by the various subtests of the LAC3 phonological awareness test also followed a similar pattern of development as might be predicted for NH children in that they performed more poorly on phonological awareness tasks that required them to explicitly manipulate the phonological units in question. This finding, taken together with the finding that phonological awareness, reading, and vocabulary knowledge are strongly related skills in these children, indicates that explicit training methods that have been shown to benefit NH children with poor reading skills may be beneficial to deaf children who use cochlear implants as well. Further investigation is needed 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 investigation is also warranted by the fact that numerous studies have found that NH children's reading skills can benefit significantly from explicit 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. 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.

While 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 ranks showed that most of the children were not within the top 50th percentile of their age or grade peers on these tests. For the phonological awareness and reading subtests, we observed that the younger children's performance relative to their NH peers was better than the older children's performance relative to their NH peers. In addition, the finding that the younger deaf children's performance relative to their NH peers was better than the older deaf children's performance relative to their NH peers is difficult to explain with the cross-sectional data available in the present study. A longitudinal study in which the phonological awareness, vocabulary and reading skills of children with cochlear implants are tracked from pre-reading (preschool) age to adulthood 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 mental lexicon.

Overall, the present study was an initial contribution to research that we hope will help lead to increased literacy skills in children who are deaf. Additional studies are needed 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 NH 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 eye movements during reading. In addition, further investigation into 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 basic linguistic skills that underlie reading in deaf children who use cochlear implants.

In the present investigation, we reported the first full study of phonological awareness in deaf children with cochlear implants. We obtained substantial information about the reading and speech-related skills of a group of deaf children with cochlear implants that allowed us to explore relationships among the children's performance on these tasks. The findings from the present study provide a more detailed understanding of the cognitive and linguistic processes used by deaf children with cochlear implants as they develop and acquire reading skills.

REFERENCES

Abler, W.L. (1989). On the particulate principle of self-diversifying systems. *Journal of Social and Biological Structures, 12*, 1-13.

Adams, M.J. (1990). *Beginning to Read*. Cambridge, MA: MIT Press.

Armstrong, D.F., Karchmer, M.A., Van Cleve, J.V., & Stokoe, W.C. (2002). The Study of Signed Languages: Essays in Honor of William Stokoe. Washington, D.C.: Gallaudet University Press.

Baddeley, A. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36*, 189-208.

Baddeley, A. D., Thompson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Behavior, 14*(6), 575-589.

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.

Ball, E., & Blachman, B. (1988). Phoneme segmentation training: Effect on reading readiness. *Annals of Dyslexia, 38*, 208-225.

Beckman, M.E., & Pierrehumbert, J. (2003). Interpreting 'phonetic interpretation' over the lexicon. *Papers in Laboratory Phonology VI* (pp. 13-37). Cambridge UK: Cambridge University Press.

Bortfeld, H., Morgan, J.L., Golinkoff, R.M., & Rathbun, K. (2005). Mommy and me: Familiar names help launch babies into speech stream segmentation. *Psychological Science, 16*, 298-304.

Bradley, L., & Bryant, P.E. (1983). Categorizing sounds and learning to read - a causal connection. *Nature, 301*, 419-421.

Brady, S., Fowler, A., Stone, B., & Winbury, N. (1994). Training phonological awareness: A study with inner-city kindergarten children. *Annals of Dyslexia, 44*, 26-59.

Brady, S.A. (1991). The role of working memory in reading disability. In S.A. Brady & D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. 129-151). Hillsdale, NJ: Lawrence Erlbaum Associates.

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.

Burkholder, R.A., & Pisoni, D.B. (2003). Speech timing measures and working memory in profoundly deaf children after cochlear implantation. *Journal of Experimental Child Psychology, 85,* 63-88.

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, NY: The Guilford Press.

Cleary, M., Dillon, C.M., & Pisoni, D.B. (2002). Imitation of nonwords by deaf children after cochlear implantation: Preliminary findings. *Annals of Otology, Rhinology & Laryngology, 111*, 91-96.

Cleary, M., Pisoni, D.B., & Kirk, K.I. (2000). Working memory spans as predictors of spoken word recognition and receptive vocabulary in children with cochlear implants. *The Volta Review, 102 (monograph)*, 259-280.

Coady, J.A., & Aslin, R.N. (2004). Young children's sensitivity to probabilistic phonotactics in the developing lexicon. *Journal of Experimental Child Psychology, 89*, 183-213.

Conrad, R. (1979). Deafness and reading. In R. Conrad (Ed.), *The Deaf Schoolchild* (pp. 140-175). London: Harper and Row.

Cowan, N., Wood, N.L., Nugent, L.D., & Treisman, M. (1997). There are two word-length effects in verbal short-term memory: opposed effects of duration and complexity. *Psychological Science, 8*, 290-295.

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., & Pisoni, D.B. (2004). Nonword repetition and reading in deaf children with cochlear implants. *International Congress Series, 1273*, 304-307.

Dillon, C.M., Burkholder, R.A., Cleary, M., & Pisoni, D.B. (2004). Perceptual ratings of nonword repetition responses by children who are deaf after cochlear implantation. *Journal of Speech, Language, and Hearing Research, 47*, 1103-1116.

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.

Ehri, L.C., Nunes, S., Willows, D., Schuster, B., Yaghoub-Zadeh, & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly, 36*, 250-287.

Eukel, B. (1980). A phonotactic basis for word frequency effects: Implications for automatic speech recognition. *Journal of the Acoustic Society of America, 68*, S33.

Firszt, J.B., Holden, L.K., Skinner, M.W., Tobey, E.A., Peterson, A., Gaggl, W., Runge-Samuelson, C.L., & Wackym, P.A. (2004). Recognition of speech presented at soft to loud levels by adult cochlear implant recipients of three cochlear implant systems. *Ear & Hearing, 25*, 375-387.

Fischer, L.J., & de Lorenzo, D.L., Eds. (1983). *History of the College for the Deaf 1857-1907 by Edward Minor Gallaudet*. Washington, D.C.: Gallaudet College Press.

Forster, K.I. (1978). Assessing the mental lexicon. In E. Walker (Ed.), *Explorations in the Biology of Language* (pp. 139-174). Montgomery, VT: Bradford.

Fowler, A.E. (1991). How early phonological development might set the stage for phoneme awareness. In S.A. Brady & D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. 97-117). Hillsdale, NJ: Lawrence Erlbaum Associates.

Freeberg, E. (2001). *The Education of Laura Bridgman: First Deaf and Blind Person to Learn Language*. Cambridge, MA: Harvard University Press.

Gannon, J. (1981). *Deaf Heritage: A Narrative History of Deaf America*. Silver Spring, MD: National Association of the Deaf.

Gathercole, S.E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory and Cognition, 23*, 83-84.

Gathercole, S.E., & Baddeley, A. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28*, 200-213.

Gathercole, S., & Baddeley, A. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning arbitrary names of toys. *British Journal of Psychology, 81*, 439-454.

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.

Gathercole, S.E., Willis, C.S., Emslie, H., & Baddeley, A.D. (1992). Phonological memory and vocabulary development during the early school years – a longitudinal study. *Developmental Psychology, 28*, 887-898.

Geers, A.E. (2003). Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing, 24*, 59S-68S.

Geers, A. (2004). Speech, language and reading skills after early cochlear implantation. *Archives of Otolaryngology, Head and Neck Surgery, 130*, 634-638.

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., Morrisette, M.L., & Champion, A.H. (1999). Lexical constraints in phonological acquisition. *Journal of Child Language, 26*, 261-294.

Gillon, G.T. (2004). *Phonological Awareness: From Research to Practice*. New York: Guilford Press.

Gordon, J.C. (1892). *Education of Deaf Children: Evidence of Edward Miner Gallaudet and Alexander Graham Bell, presented to the Royal Commission of the United Kingdom on the Condition of the Blind, Deaf, and Dumb, etc., with the accompanying papers, postscripts, and an index.* Washington, D.C.: Volta Bureau; Gibson Brothers.

Gupta, P. (2003). Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 56*, 1213-1236.

Hanson, V.L. (1991). Phonological processing without sound. In S.A. Brady & D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. 153-161). Hillsdale, NJ: Lawrence Erlbaum Associates.

Haskins, H. (1949). A phonetically balanced test of speech discrimination for children. Unpublished master's thesis, Northwestern University, Evanston IL.

Hester, R.L., Kinsella, G.J., & Ong, B. (2004). Effect of age on forward and backward span tasks. *Journal of the International Neuropsychological Society, 10*, 475-481.

Howes, D. (1957). On the relation between the intelligibility and frequency of occurrence of English words. *Journal of the Acoustical Society of America, 29*, 296-305.

Jorm, A.F., Share, D.L., Maclean, R., & Matthews, R. (1986). Cognitive factors at school entry predictive of specific reading retardation and general reading backwardness: A research note. *Journal of Child Psychology and Psychiatry, 27*, 45-55.

Jusczyk, P.W., Luce, P.A., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory & Language*, 33, 630-645.

Karchmer, M.A., Milone, M.N., Jr., & Wolk, S. (1979). Educational significance of hearing loss at three levels of severity. *American Annals of the Deaf, 124*, 97-109.

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. (1971). Basic research in speech and lateralization of language: Some implications for reading disability. *Bulletin of the Orton Society, 21*¸7-87.

Liberman, I.Y., Shankweiler, D., & Liberman, A.M. (1989). The alphabetic principle and learning to read. In D. Shankweiler and I.Y. Liberman (Eds). *Phonology and Reading Disability: Solving the Reading Puzzle* (IARLD Monograph Series) (p.1-33). Ann Arbor, MI: University of Michigan Press.

Liberman, I.Y., Shankweiler, D., Fischer, F.W., & Carter, B. (1974). Explicit syllable and phoneme segmentation in the young child. *Journal of Experimental Child Psychology, 18*, 201-212.

Lindamood, P.C., & Lindamood, P. (2004). *Lindamood Auditory Conceptualization Test, third Edition*. Austin, TX: Pro-Ed.

Lonigan, C., Burgess, S., Anthony, J., & Barker, T. (1998). Development of phonological sensitivity in 2- to 5-year-old children. *Journal of Educational Psychology, 90*, 294-311.

Luce, P.A., & Large, N.R. (2001). Phonotactics, density, and entropy in spoken word recognition. *Language and Cognitive Processes, 16*, 565-581.

Luce, P.A., & Pisoni, D.B. (1998). Recognizing spoken words: The Neighborhood Activation Model. *Ear & Hearing, 19*, 1-36.

Lundberg, I., Olofsson, A., & Wall, S. (1980). Reading and spelling skills in the first years predicted from phonemic awareness skills in kindergarten. *Scandanavian Journal of Psychology, 21*, 159-173.

Maher, J. (1996). *Seeing Language in Sign: The Work of William C. Stokoe*. Washington, D.C.: Gallaudet University Press.

Mandel, D.R., Jusczyk, P.W., & Pisoni, D.B. (1995). Infants' recognition of the sound patterns of their own names. *Psychological Science, 6*, 314-317.

Markwardt, F.C. (1998). *Peabody Individual Achievement Test – Revised*. Circle Pines, MN: American Guidance Service.

Marschark, M. (2003). Interactions of language and cognition in deaf learners: From research to practice. *International Journal of Audiology, 42*, S41-S48.

McBride-Chang, C. (1995). What is phonological awareness? *Journal of Educational Psychology, 87*, 179-192.

McGarr, N. (1981). The effect of context on the intelligibility of hearing and deaf children's speech. *Language and Speech, 24*, 255-263.

Meyer, T.A., & Pisoni, D.B. (1999). Some computational analyses of the PBK Test: effects of frequency and lexical density on spoken word recognition. *Ear & Hearing, 20*, 363-371.

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.

Moog, J.S., & Geers, A. (1985). EPIC: A program to accelerate academic progress in profoundly hearing-impaired children. *Volta Review, 87*, 259-277.

Moog, J.S., & Geers, A.E. (2003). Epilogue: Major Findings, Conclusions, and Implications for Deaf Education. *Ear & Hearing, 24*, 121S-125S.

Morais, J. (1991). Constraints on the development of phonological awareness. In S.A. Brady and D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. 5-27). Hillsdale, NJ: Lawrence Erlbaum Associates.

Munson, B., Edwards, J., & Beckman, M.E. (2005). Relationships between nonword repetition accuracy and other measures of linguistic development in children with phonological disorders. *Journal of Speech, Language, and Hearing Research, 48*, 61-78.

National Association of the Deaf. Accessed January 28, 2005. http://www.nad.org/site/pp.asp?c=foINKQMBF&b=103786

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.

Newman, R.S., & German, D.J. (2002). Effects of lexical factors on lexical access among typical language-learning children and children with word-finding difficulties. *Language and Speech, 45*, 285-317.

Norusis, M.J. (2004). SPSS 13.0 advanced statistical procedures companion. Upper Saddle River, NJ: Prentice Hall.

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.

Perfetti, C.A., Beck, I., Bell, L.C., & Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal. *Merrill-Palmer Quarterly, 33*, 283-319.

Pisoni, D.B. (2005). Speech perception skills of deaf children with cochlear implants. In D.B. Pisoni & R.A. Remez (Eds.) *Handbook of Speech Perception* (pp. 494-523). Blackwell Publishers : Oxford UK.

Pisoni, D.B., & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children following cochlear implantation. *Ear & Hearing, 24*, 106S-120S.

Pisoni, D.B., & Geers, A.E., (2000). Working memory in deaf children with cochlear implants: Correlations between digit span and measures of spoken language processing. *Annals of Otology, Rhinology, & Otolaryngology, 18*(Suppl. 185), 592-593.

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.

Read, C. (1991). Access to syllable structure in language and learning. In S.A. Brady and D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. 119-124). Hillsdale, NJ: Lawrence Erlbaum Associates.

Reynolds, H.N. (1975). Development of reading ability in relation to deafness. World Congress of the World Federation of the Deaf: Full citizenship for all deaf people (pp. 273-284). Washington, D.C.: National Association for the Deaf.

Rosen, V.M., & Engle, R.W. (1997). Forward and backward serial recall. *Intelligence, 25*, 37-47.

Schatschneider, C., Francis, D.J., Foorman, B.R., Fletcher, J.M., & Mehta, P. (1999). The dimensionality of phonological awareness: An application of item response theory. *Journal of Educational Psychology, 91*, 439-449.

Shankweiler, D. (1991). The Contribution of Isabelle Y. Liberman. In S.A. Brady and D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. xiii-xvii). Hillsdale, NJ: Lawrence Erlbaum Associates.

Siegel, L.S. (1988). Evidence that IQ scores are irrelevant to the definition and analysis of reading disability. *Canadian Journal of Psychology, 42*, 201-205.

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.

Stahl, S.A., & Murray, B.A. (1994). Defining phonological awareness and its relationship to early reading. *Journal of Educational Psychology, 86*, 221-234.

Stanovich, K.E. (1988). The right and the wrong places to look for the cognitive locus of reading disability. *Annals of Dyslexia, 38*, 175-190.

Stanovich, K.E., Cunningham, A.E., & Feeman, D.J. (1984). Intelligence, cognitive skills, and early reading progress. *Reading Research Quarterly, 19*, 278-303.

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.

Stone, B.H., & Brady, S.A. (1995). Evidence for phonological processing deficits in less-skilled readers. *Annals of Dyslexia, 45*, 51-78.

Storkel, H.L. (2004). Do children acquire dense neighborhoods? An investigation of similarity neighborhoods in lexical acquisition. *Applied Psycholinguistics, 25*, 201-221.

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 preeminenc 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 Acaedmy 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.

Tice, R., & Carrell, T. (1998). Level 16, Version 2.0.3, University of Nebraska.

Tobey, E.A., Geers, A.E., Brenner, C., Altuna, D., & Gabbert, G. (2003). Factors associated with development of speech production skills in children implanted by age five. *Ear & Hearing, 24,* 36S-45S.

Treiman, R., & Baron, J. (1983). Phonemic-analysis training helps children benefit from spelling-sound rules. *Memory & Cognition, 11*, 382-389.

Treiman, R., & Zukowski, A. (1991). Levels of phonological awareness. In S.A. Brady and D.P. Shankweiler (Eds.), *Phonological Processes in Literacy: A Tribute to Isabelle Liberman* (pp. 67-83). Hillsdale, NJ: Lawrence Erlbaum Associates.

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, NY: The Guilford Press.

Vitevitch, M.S., & Luce, P.A. (1998). When words compete: Levels of processing in perception of spoken words. *Psychological Science, 9*, 325-329.

Vitevitch, M.S., & Luce, P.A. (2004). A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments & Computers. Special web-based archive of norms, stimuli, and data: Part 1, 36*, 481-487.

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.

Waters, G.S., & Doehring, D.G. (1990). Reading acquisition in congenitally deaf children who communicate orally: Insights from an analysis of component reading, language, and memory skills. In T.H. Carr & B.A. Levy, *Reading and its Development: Component Skills Approaches* (pp. 323-373). San Diego, CA: Academic Press.

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 – Third Edition*. San Antonio, TX: Psychological Corporation.

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

Yopp, H. (1988). The validity and reliability of phonemic awareness tests. *Reading Research Quarterly, 23*, 159-177.

APPENDIX

Peabody Picture Vocabulary Test – Third Edition (PPVT-III)
Training Items and Test Items
Dunn & Dunn (1997)

Training Items

For Children Ages 2;6 – 7;11
1. Ball
2. Dog
3. Crying
4. Sleeping

For Children Ages 8 and older
1. Parrot
2. Scissors
3. Mowing
4. Riding

Test Items

Set 1
1. bus
2. drinking
3. hand
4. climbing
5. key
6. reading
7. closet
8. jumping
9. lamp
10. helicopter
11. smelling
12. fly

Set 2
13. digging
14. cow
15. drum
16. feather
17. painting
18. cage
19. knee
20. wrapping
21. fence
22. elbow
23. garbage
24. exercising

Set 3
25. empty
26. shoulder
27. square
28. measuring
29. porcupine
30. arrow
31. peeling
32. fountain
33. accident
34. penguin
35. decorated
36. nest

Set 4
37. castle
38. sawing
39. cactus
40. farm
41. going
42. harp
43. astronaut
44. raccoon
45. juggling
46. envelope
47. tearing
48. claw

Set 5
49. parachute
50. delivering
51. rectangle
52. diving
53. camper
54. target
55. writing
56. furry
57. drilling
58. hook
59. group

60. dripping

Set 6
61. vehicle
62. oval
63. luggage
64. awarding
65. hydrant
66. swamp
67. calculator
68. signal
69. squash
70. globe
71. vegetable
72. frame

Set 7
73. gigantic
74. nostril
75. vase
76. knight
77. towing
78. horrified
79. trunk
80. selecting
81. island
82. camcorder
83. heart
84. wrench

Set 8
85. flamingo
86. tambourine
87. palm
88. surprised
89. canoe
90. interviewing
91. clarinet
92. exhausted
93. pitcher
94. reptile
95. polluting
96. vine

Set 9
97. pedal
98. dissecting
99. bouquet
100. rodent
101. inhaling
102. valley
103. tubular
104. demolishing
105. tusk
106. adjustable
107. fern
108. hurdling

Set 10
109. solo
110. citrus
111. inflated
112. lecturing
113. timer
114. injecting
115. links
116. cooperating
117. microscope
118. archery
119. garment
120. fragile

Set 11
121. carpenter
122. dilapidated
123. hazardous
124. adapter
125. valve
126. isolation
127. feline
128. wailing
129. coast
130. appliance
131. foundation
132. hatchet

Set 12
133. blazing
134. mammal
135. reprimanding
136. upholstery
137. hoisting
138. exterior
139. consuming
140. pastry
141. cornea

142. constrained
143. pedestrian
144. colt

Set 13
145. syringe
146. transparent
147. ladle
148. replenishing
149. abrasive
150. parallelogram
151. cascade
152. lever
153. detonation
154. pillar
155. cultivating
156. aquatic

Set 14
157. indigent
158. oasis
159. disappointed
160. perpendicular
161. poultry
162. confiding
163. periodical
164. filtration
165. primate
166. spherical
167. talon
168. octagon

Set 15
169. incandescent
170. pilfering
171. trajectory
172. mercantile
173. derrick
174. ascending
175. monetary
176. entomologist
177. gaff
178. quintet
179. nautical
180. incarcerating

Set 16
181. coniferous
182. wildebeest
183. caster
184. reposing
185. convex
186. gourmand
187. dromedary
188. diverging
189. incertitude
190. quiescent
191. honing
192. cupola

Set 17
193. embossed
194. perambulating
195. arable
196. importunity
197. cenotaph
198. tonsorial
199. nidificating
200. terpsichorean
201. cairn
202. osculating
203. vitreous
204. lugubrious

Reference

Dunn, L.M., & Dunn, L.M. (1997). *Peabody Picture Vocabulary Test – Third Edition*. Circle Pines, MN: American Guidance Service.