Evaluating Phonological Processing Skills in Children With Prelingual Deafness Who Use Cochlear Implants

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This study investigated the phonological processing skills of 29 children with prelingual, profound hearing loss with 4 years of cochlear implant experience. Results were group matched with regard to word-reading ability and mother's educational level with the performance of 29 hearing children. Results revealed that it is possible to obtain a valid measure of phonological processing (PP) skills in children using CIs. They could complete rhyming tasks and were able to complete sound-based tasks using standard test materials provided by a commercial test distributor. The CI children completed tasks measuring PP, but there were performance differences between the CI users and the hearing children. The process of learning phonological awareness (PA) for the children with CIs was characterized by a longer, more protracted learning phase than their counterparts with hearing. Tests of phonological memory skills indicated that when the tasks were controlled for presentation method and response modality, there were no differences between the performance of children with CIs and their counterparts with hearing. Tests of rapid naming revealed that there were no differences between rapid letter and number naming between the two groups. Results yielded a possible PP test battery for children with CI experience.

For many years, people who are stakeholders in the task of fostering the communication skills of children with severe-to-profound hearing loss have described the relationship between intervention, language, and literacy outcomes. This descriptive research describes generally low achievement levels across communication skills including speech intelligibility, spoken English, and written English comprehension. In particular, children born with profound hearing loss typically graduate from high school reading at the fourth-grade level, given standardized assessments (Goetzinger & Rousey, 1957; Pinter & Patterson, 1916, 1917; Traxler, 2000). According to Ogle et al. (2003), the type of reading skills needed to perform at mean benchmark competencies for a fourth-grade reading level include the ability to (a) make elementary inferences, (b) locate specific parts of a text to retrieve information, and (c) make observations about whole texts.

On the other hand, *functional reading literacy* is defined as the ability to understand, use, and reflect on written texts in order to achieve one's goals, to develop one's knowledge and potential, and to participate effectively in society (Boudard & Jones, 2003). The skills involved in functional reading literacy include the following: (a) reading lengthy, complex, abstract prose texts as well as synthesizing information and making complex inferences, (b) integrating, synthesizing, and analyzing multiple pieces of information located in complex documents, and (c) locating more abstract quantitative information and using it to solve multistep problems when the arithmetic operations are not easily inferred and the problems are more complex (Kutner et al., 2007).

As such, we can conjecture that in the United States, current technological and societal demands necessitate a 10th- or 11th-grade reading ability for functional participation in society (Marschark & Harris, 1996). Allen (1986) estimated that more than 30% of deaf children graduate from high school functionally illiterate.

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There is evidence that some outcomes with regard to reading skills of some deaf children are changing, however. Studies of children who receive cochlear implants (CIs) reveal that they gain access to spoken language. This access is also associated with higher levels of speech intelligibility, better vocabulary skills, and better language skills than their peers with profound hearing loss who do not wear CIs (e.g., Geers, Nicholas, & Sedey, 2003; Peng, Spencer, & Tomblin, 2004; Vermeulen, Hoekstra, Brokx, & van den Broek, 1999). On the premise that reading skills are influenced by spoken language skills, investigators have likewise begun to document increased reading comprehension at the word and paragraph level in children who use CIs (Connor & Zwolan, 2004; Geers, 2003; Spencer, Barker, & Tomblin, 2003; Spencer, Tomblin, & Gantz, 1997).

In hearing children, we know that an intact phonological system provides an important foundation for learning to read (Nathan, Stackhouse, Goulandris, & Snowling, 2004; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001); however, little is known about the phonological skills of prelingually deaf children who use CIs. Phonological Awareness (PA) is defined as the ability to abstract and manipulate segments of spoken language (Bentin, 1992; Liberman, Shankweiler, Fischer, & Carter, 1974; Mattingly, 1972). In brief, the construct of PA is a composite of several abilities. Three distinct levels of PA are proposed: breaking individual words into smaller units from words to syllables, then into the onset-rime level, and finally into the phoneme level (Bradley & Bryant, 1991; Perfetti, Beck, Bell, & Hughes, 1987; Stahl & Murray, 1994). PA is part of a broader construct, PP, which incorporates phonological memory.

A final, albeit controversial skill possibly involved with Phonological Processing (PP) is rapid naming, which involves retrieving sound information from long-term (permanent) memory to name pictures, letters, or numbers. Wagner, Torgesen, and Rashotte (1999) proposed that young readers first retrieve sounds associated with letters or letter pairs, then they retrieve the pronunciations of common word segments, and finally they retrieve the whole word. In this view, rapid naming is predictive of early reading skill. This is because rapid naming measures the efficiency of retrieving phonological codes associated with phonemes, word parts, or entire words (Shankweiler & Crain, 1986; Share, 1995; Torgesen & Burgess, 1998). Rapid naming predicts reading skills; yet, the nature of its relationship to assessment of phonological skills is unclear. Wagner and Torgesen (1987) originally believed that rapid naming was a phonologically based skill. Subsequently, researchers have proposed that rapid naming is a measure of several skills including PP and executive functioning (Denckla & Cutting, 1999), and/or the ability to detect and represent orthographic redundancy (Bowers & Wolf, 1993; Wolf, 1999). Alternatively, rapid naming has been proposed to measure global processing efficiency (Kail, Hall, & Caskey, 1999) and is an index of attention skill (Neuhaus, Foorman, Francis, & Carlson, 2001).

In this article, the term PP indicates the broader, more encompassing construct that includes a phonological memory and naming component. There are numerous tasks that can be used to assess PP, but there are four common operations used during assessment procedures (McBride-Chang, 1995). The operations include (a) listening and perceiving the words that are typically presented in an oral modality; (b) holding the phonological representation in memory; (c) performing a manipulation on the speech segment (e.g., deletion, identification); and (d) communicating the result of the operation they performed, usually with a spoken response.

Valid assessment of PA or PP skills of children with profound hearing loss is challenging because their performance on assessment tasks is confounded by their ability to listen to and hear the test items and then to produce accurate spoken responses. Furthermore, it is often assumed that these PP skills are not well developed in children with hearing loss. Consequently, in many cases, explicit reading instruction does not build on or emphasize those skills. Thus, teachers of the deaf and hard of hearing (D/HH) have tended used basal reader approaches that favor "whole word" reading (Webster, 2000).

Instructional methods for children with profound hearing loss have been criticized in the past for failure to incorporate phonological or "sound-based" reading strategies into the reading curriculum (Hanson, 1989; Nielsen & Luetke-Stahlman, 2002). LaSasso and Mobley (1997) surveyed reading instructional methods and materials used by teachers of the deaf and found that very few teachers used sound-based (phonological) reading strategies. Furthermore, only 22% of teachers rated their knowledge of reading theory as up-to-date, and only 24% rated their knowledge of instructional strategies and variables that affect reading development as current. Schirmer and McGough (2005) noted that there was little research documenting the effectiveness of instructional interventions in deaf children, particularly using the topic of phonics instruction.

There is, however, indirect support for using sound-based reading instruction with deaf learners. Skilled reading among deaf readers who do not use CIs is predicted by knowledge of print-to-sound correspondence, speech intelligibility, speech reading skills, and ability to extract phonological information from print (Hanson, 1982; Hanson & Lichtenstein, 1990). Two recent studies have provided direct support for using sound-based reading instruction for children who are D/HH. Trezek and Malmgren (2005) evaluated a phonics treatment package that was used with middle school–aged children who were D/HH. Results of this study demonstrated a treatment effect of phonemic awareness instruction. Additionally, Trezek and Wang (2006) found that D/HH clients who received 1 year of a phonics-based curriculum that was supplemented by Visual Phonics (which is a system that combines written and hand signs to augment grapheme-to-phoneme teaching) demonstrated improvements in reading skills. The reading improvement was documented by statistically higher scores on standardized tests of word reading, pseudoword decoding, and reading comprehension after they received intervention with the Visual Phonics treatment program.

The widespread use of CIs in children provides additional justification for incorporating more sound-based instructional strategies into the reading curriculum for children born with profound hearing loss. Researchers have documented that children with congenital, bilateral, profound loss who use CIs develop better speech perception (Boothroyd & Eran, 1997; Geers & Brenner, 1994; McKinley & Warren, 2000; Vermeulen et al., 1997) and speech production skills (Geers & Tobey, 1992; Peng et al., 2004; Tobey, Geers, & Brenner, 1994; Tye-Murray, Spencer, & Woodworth, 1995) than their profoundly deaf peers who wear hearing aids. Many CI users also attain higher levels of language and reading comprehension than their peers with profound hearing loss who do not use CIs (Spencer, Tye-Murray, & Tomblin, 1998; Spencer et al., 2003; Spencer et al., 1997; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999).

Additionally, a recent study (Spencer & Oleson, 2008) found that early speech perception and production skills predicted later reading skills in prelingually deaf children who used CIs. Findings such as these indicate that children with CIs may well develop a more intact phonology, their phonologies may be more testable, and they make more use of their phonology for reading. The limited extant literature suggests that these children develop phonological systems that are stronger than those of their deaf peers without CIs but weaker than those of their hearing peers.

It is important to understand the way children with CIs develop PP skills because of the association between PP and reading achievement in hearing children. One obstacle in assessing these skills in children who use CIs is that there are no standardized testing instruments. To date, there is no valid assessment battery that can potentially identify those CI users who are significantly below their peers with respect to their phonological abilities. If such a battery existed, clinicians could subsequently use PP test information to identify the strengths and weakness regarding the phonological skill development of their clients. The information derived from this testing could, in turn, have implications for remediation of speech, language, and literacy skills, and could guide clinicians and teachers in choosing goals for rehabilitation.

One goal of this article was to investigate whether it was possible to establish the validity of a series of tasks to measure the PA and PP skills of CI users. A second goal of the study was to document the range of PA skills in children with more than 3 years of CI experience and to compare this range with peers who have hearing, but are matched with regard to word-reading level. The final goal of the study was to examine in a preliminary way the relationship between PP skills and reading skills.

Method

Participants

CI users. Twenty-nine children with CIs participated in this study. They met the following criteria:

prelingual, bilateral hearing loss with no other identified cognitive or learning disability; they received a CI at the University of Iowa Hospital and Clinics before the age of 7; they had at least 3 years of CI experience when examined, and they were younger than 18 years. Participants were paid $15.00 for their participation. The average age of implantation was 3 years 7 months (SD = 2 years 5 months), with an age range of 1 year 6 months to 10 years 8 months. The average age at testing was 11 years 9 months (SD = 3 years 6 months), with an age range between 7 years 2 months and 17 years 8 months. Etiologies of deafness included nonspecified heredity component, identified GJBT mutation (connexin 26), meningitis, cytomegalovirus infection, cochlear malformation, Usher Type 1, complications from receiving ototoxic drugs, and unknown etiology. All CI users were educated in public school systems (21 within the state of Iowa, 1 in North Dakota, 1 in Illinois, 2 in Wisconsin, and 3 in Missouri). Parental report indicated that 28 participants were educated using a Total Communication (TC) philosophy. For the purpose of this article, "TC" indicates that the educational programs employed "the combined use of aural, manual and oral modalities in communicating with and teaching hearing impaired individuals" (Garretson, 1976). One child used an Auditory–Verbal approach to aural habilitation but was educated in a mainstream public school setting where the educators were using a TC philosophy.

All participants underwent CI surgery at the University of Iowa Hospitals and Clinics. The type of CI processors used by the participants included 2 Nucleus 22-channel Spectras, 9 Nucleus 22-channel Sprints, 5 Nucleus 22-channel Esprits, and 12 Nucleus 3Gs. Processing strategies included the following: 22 Nucleus ACE strategies, 1 MPEAK strategy, and 6 SPEAK strategies. Demographic information for the CI participants is given in Appendix A.

Hearing controls. Thirty-two children with hearing (hearing controls [HC]) were recruited from two area education agencies (AEAs) within Iowa, including the Grant Wood AEA and the Mississippi Bend AEA. These children were recruited to be matched with the CI group on mother's education and word comprehension ability. We performed group matching as a way to experimentally control the variance of performance and to remove age effects. Thus, we matched the groups with respect to word comprehension level rather than for chronological age. This allowed us to assess *skills* that are associated with *relative* reading ability, rather than age-related abilities. The average age at testing was 9 years 7 months (SD = 2 years 8 months), with an age range between 6 years 2 months and 17 years 9 months.

Participants met the following criteria: they had no known hearing loss as noted by passing a hearing screening by their local AEA; they had no identified cognitive or learning disabilities as per parent report; and they had not repeated a grade. Participants were paid $15.00 for their participation. Twenty-nine hearing participants were matched with the CI users according to the mother's education and to their word comprehension grade levels. A t test revealed no significant difference in the mother's education measure between the CI group ($M = 4.24$, $SD = 0.95$) and the hearing group ($M = 4.41$, $SD = 1.05$), $t(28) = -.65$, $p = .52$. There was no significant word comprehension grade equivalency difference between the CI group on the Woodcock Reading Mastery Tests Revised Form (WRMT; Woodcock, 1987) ($M = 5.21$, $SD = 4.01$) and the hearing group ($M = 5.15$, $SD = 4.01$), $t(28) = .06$, $p = .95$.

The average age of the HC group was nearly 2 years younger than the CI users and was 9 years 7 months (SD = 2 years 8 months), with an age range between 6 years 2 months and 17 years 9 months. Given the age difference between the two groups, it is important to realize that this study is examining the skills related to *relative ability* levels, not the skills of a particular age-group. Future studies could investigate skill differences between CI children and their age-mates with hearing. Demographic information for the hearing children is given in Appendix B. All participants were tested individually, in a quiet room.

Rationale for Choosing Tasks as Test Measures

Many children with profound hearing loss are receiving CIs, which provide considerable access to auditory stimuli, and in turn, gains are seen with speech production ability. Thus, phonological skills for speaking and listening are substantially affected. In concert with improved speaking and listening skills, we would expect to see improved PP skills in these children, which should be important for reading. Measuring PP skills in children who are D/HH or who wear CIs can be affected by the child's listening and possibly speech production ability. Therefore, we need to examine the validity of PP measures in CI children.

One of the purposes of the first portion of the study was to produce a set of tasks to obtain a valid measure PP skills of CI users. To do this, we wanted to minimize the influence of hearing on performance. It is hypothesized that if poorer hearing in the CI children is influencing their PP performance, then their performance on parallel tasks that vary in auditory demands will be effected more than what we would find in hearing children with comparable reading abilities. Also, it is hypothesized that if hearing levels affect performance, then the correlations between these parallel tests will differ between the CI and HC children. With this in mind, we wanted to assess whether using audition only was a valid way to measure PP skills in children with CIs, so we had to determine whether performance was related to decreased PP skills or to an inability to perceive the stimuli using auditory-only (A/O) condition. Appendix C contains a summary table of the tasks used.

PP tasks—PA. The Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 2001) was adapted and administered to both the CI and the HC children. The CTOPP was designed for hearing children and took about 30 min to administer. It had six subtests that assessed PA, phonological memory, and rapid naming. PA was tested by elision and blending tasks. The Elision subtest required the child to listen to the examiner and delete a sound from the stimulus word. Responses were scored as either correct or incorrect. The Blending Words subtest of the CTOPP required the child to listen to stimuli presented on an audio file of a CD played through a personal computer. The protocol involved a cue sentence, "What words do these sounds make?" followed by the test item "can dee." The child was then supposed to put the word together and say "candy." Responses were scored as either correct or incorrect. All raw scores were used to derive a standard score and a grade equivalency score.

A third PA task was administered via a rhyme test that was adapted from James et al. (2005). This task contained 24 trials that were presented on a personal computer and E-Run software (E-Prime, 2005). Each trial comprised four photos presented on the computer screen (a cue, a target, and two distracters). The choices for the cues contained a target (which rhymed with the cue item) and two distracters that were chosen to have either a semantic relationship or a phonological relationship with the cue. For example, the cue *hair* had the target *pear,* with a distracter of *bow* (semantically related) and *hill*. Alternatively, the cue *wall* had the target *ball,* with the distracter of *tie* and *wig* (which started with the same phoneme). Half of the targets were either orthographically congruent (sock, clock) or orthographically incongruent (fruit, boot) to the cue. The cue was the photo on the top of the computer screen. The target and the two distracters were the three photos just under the cue photo. All the photos remained on the computer display. The examiner named each picture on the screen and the child was to pick the photo that rhymed with the cue photo. If a child missed more than 10% of the items (three or more), a vocabulary verification procedure was performed where the child identified the picture that represented a missed vocabulary item from a field of three. Ten CI children had to perform the verification procedure, and three of the HC children performed the verification procedure. All did so with 100% accuracy.

PP tasks—phonological memory. All participants completed two versions of a Digit Repetition task. The first was the Memory for Digits subtest of the CTOPP. Stimuli were presented using the audio files of the CD provided by the test designers played through a personal computer and external speakers. Responses were scored as per the test directions; the item was correct if the child repeated all digits correctly in order.

A second digit task, Digit Recall was administered. This task simultaneously presented both an auditory and a visual digit stimuli. The task was an adaptive procedure presented via a personal computer and E-Run software (E-Prime, 2005). The audio file for each single digit (one to nine) was pulled from the CTOPP CD and stored as separate files extracted by AdobeAudition, version 1.5 software (AdobeAudition, 2004). The audio file for each digit was randomly pulled and paired with a visual presentation of the same digit. The combined visual and auditory stimuli were simultaneously presented via a personal computer. Three digits were presented, one at a time on the computer screen, for example (6), then (5), then (1) paired with the audio file for each digit. The computer screen then went blank and the child was asked to enter the three digits using the number keypad in the correct order and press the enter key. The E-Prime program presented blocks of digits in an adaptive procedure, such that the child had to achieve a criterion of two of the four correct repetitions at each digit level (series of three, series of four, series of five) before the program advanced to the next series level. For example, once the participant was successful with two of four sets of three digits, the program would advance to presentations of four digits, and so on. If the participant was unable to achieve two accurate trials at a particular level, the program would adapt to the previous level and terminated when the participant could not achieve the criterion of two repetitions at a series level. The program recorded the total number of correct repetitions for this task.

The final phonological memory task was the Nonword Repetition subtest of the CTOPP. The protocol involved a cue, "Say …" followed by the test item, for example, "joop." The child was then supposed to repeat the nonword. Responses were either scored as correct or incorrect. The raw score was used to derive a standard score and grade equivalency.

PP tasks—rapid naming. Two subtests from the CTOPP were administered, including Rapid Letter Naming and Rapid Number Naming. Each child looked at a series of letters or numbers on a page and was asked to call out the names of the letters or numbers as fast as possible. The time it took the child to name the whole series of letters or the whole series of numbers was recorded. There were two series each of the letters and numbers. The child's raw score was the total time it took to name two series of letters and two series of numbers. The raw score was used to compute a standard score and an age equivalency.

Administration Issues

Two tasks from the CTOPP (Blending Words and Nonword Repetition) required the participants to listen to a prerecorded CD and then make an oral response. This presented a particular challenge to validity with respect to the CI children. A/O presentation for the children with CIs might not be a valid measure of PP because the children might require auditory and visual input of stimuli. In order to rule out that an incorrect response was due to a lack of the PP skill, rather than an inability to hear or receive the stimuli, the following modifications were implemented. At the beginning of the test session, the items for the Blending Words subtest were administered to the children with CIs as whole words using a live-voice, open-set, A/O verification procedure. Thus, an item (e.g., "can-dee") was presented as a whole word "candy." Each child was asked to identify the word to be sure he or she could indeed hear the word in an open-set condition. Twenty-eight of the 29 children with CIs achieved 100% correct on this pretest. The one child who could not complete open-set verification for the task was given spondee words that were identified correctly during speech perception testing as a substitute items in the Blending Words subtest. In order to avoid a possible priming effect, the verification task was completed approximately 1 hr before the Blending Words subtest, and the children were busy during the interim completing all other testing. Second, for all children, if an item was missed on the standard administration of the Blending Words or the Nonword Repetition subtest, the item was readministered at the end of the test session using and audio–visual, live-voice format. Thus, two scores were derived for these two subtests. One score based on A/O presentation and the other based on auditory–visual (A/V) presentation.

Nonverbal Reasoning Tasks

To address the question of whether any results were an artifact related to the child's intelligence level, the children completed two subtests (Nonverbal Memory and Block Design) from the Universal Nonverbal Intelligence Test (UNIT) (Bracken & McCallum, 1998) to yield a brief measure of nonverbal reasoning skills. Test scores were recorded in terms of standard score in order to investigate the contribution of intelligence on the variability of results.

Reading Skills

The Word Comprehension and Word Attack subtests from the WRMT (Woodcock, 1987) were used to measure reading skills. Both subtests were administered according to the procedure outlined in the test administration manual. We completed group-wise matching according to grade-level performance on the Word Comprehension subtest. The Word Comprehension subtest consisted of three tasks that required fairly well-developed vocabulary knowledge. First, the child read a word and supplied a word that meant the opposite of the word read. Second, the child read a word and supplied a synonym for the word. The final task required the child to read a series of words to complete an analogy (big is to small as sweet is to ___). All tasks continued until the child achieved a ceiling score (five incorrect responses). As such, the task was complex and did incorporate some of the decoding skills fond in the subsequent subtest. The Word Attack subtest assesses a child's ability to pronounce orthographic strings. This subtest required the child to read a pseudoword. If the child pronounced the word correctly, credit was given. Raw scores were then translated into standard scores. We used the norms provided from the test to convert the raw score to a standard score based on the child's grade in school.

Socioeconomic Status

Socioeconomic status (SES) has been demonstrated to be associated with reading outcome in children with CIs and those without (Connor & Zwolan, 2004; Hart & Risley, 1995; Hoffmeister, 1996; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). Unless a family is in extreme poverty, mother's educational level seems to be the best predictor of the parenting skills that are believed to contribute to language and literacy development (Bornstein, Hahn, Suwalsky, & Haynes, 2003; Hoffmeister, 1996). For this reason, we used the mother's educational level as measure of SES in order to account for the amount of variance in skill that was accounted for by SES (Hoffmeister, 1996). SES information for each participant was gathered by determining the highest level of education of the mother of each participant using the following scale: 1 = *completed grades kindergarten through grade 8*, 2 = *completed grades 9-12*, 3 = *graduated from high school*, 4 = *completed some post high school programming*, 5 = *completed a 4 year-college degree*, 6 = *completed a post-graduate college degree*.

Results

Summary Statistics for the PP Tasks

Phonological awareness. Figure 1 presents the mean grade equivalency scores for the PA tasks, including the Elision and Blending Words in the A/O and A/V conditions. Grade equivalency scores are independent of the age of the child and are based on the raw score. Grade equivalency scores represent the grade level at which the raw score is most likely to occur in a normative population. Because the ages of the two groups were disparate, we chose to represent the data using grade equivalency scores, a reflection of absolute ability rather than the standard score, a measure of relative ability among age-mates of the child.

The Rhyme Task was not part of the CTOPP and therefore did not have normative information available (right-hand side of panel). Therefore, the data are presented as mean raw scores where a maximum possible score was 24. Figure 1 reveals that the mean score for the children in the CI group was lower than that for the children in the HC group on all the PA tasks. For the Elision task, however, there was no significant difference in means—CI group: $M = 5.06$, $SE = 0.77$, and HC group: $M = 6.03$, $SE = 0.71$, $t(56) = -.92$, $p = .37$. For the Rhyme Task, there was a significant difference in means—CI group: $M = 21.07$, $SE = 0.79$, and HC group: $M = 23.28$, $SD = 4.03$, $t(40.2) = -2.51$, $p = .02$ (Satterthwaite correction for heterogeneity of variance used). Also note that the mean scores on rhyme for both groups reflected accuracy levels that were more than 87% on the test.

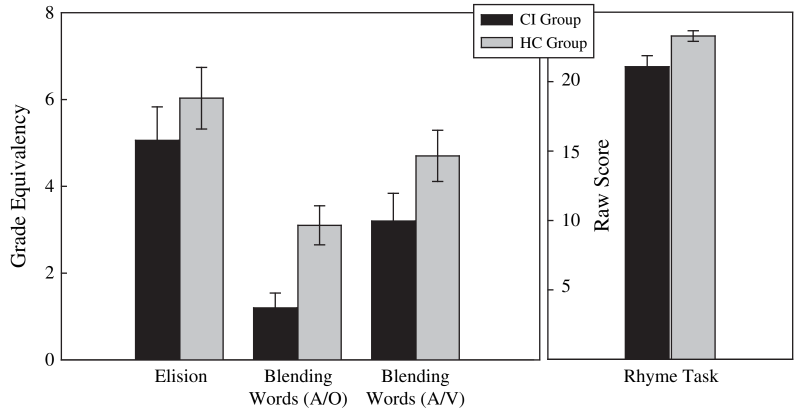

Figure 1 Test data showing CI and HC participants' mean performance on the tests of phonological awareness (error bars = 1 *SE*). CI = cochlear implants; HC = hearing control.

Effect of A/O and A/V conditions in blending words. To examine whether there was an effect of task condition (A/O vs. A/V), we performed a 2 × 2 split-plot analysis of variance (ANOVA) of the four mean scores from the Blending Words subtests under each presentation condition, A/V and A/O for each group. Results for all A/O and A/V testing are given in Figure 1, revealing a significant main effects for group, $F(1, 56) = 8.34$ $p = .006$, and presentation, $F(1, 56) = 21.44$, $p < .0001$, condition, but there was no interaction between group and presentation condition, $F(1, 56) = .07$, $p = .80$. In other words, the HC group performed better than the CI group in each presentation condition, but both groups did better in the A/V condition. Additionally, the correlation between scores between the task conditions was .75, with $p < .0001$ across both groups. For the CI group, the correlation between task conditions was .51, with $p < .01$, and for the HC group, the correlation was higher at .87, with $p < .0001$. A z-score difference between these two correlations was computed for the CI and the HC groups and reveals that the correlation between conditions are significantly different by group at −2.71, with $p < .01$ (Table 1).

Phonological memory. Figure 2 presents the mean grade equivalency scores for the phonological memory tasks, Memory for Digits and Nonword Repetition in the both the A/O and A/V conditions. For the Digit Span task, which was not part of the CTOPP, the data are presented in raw scores (right-hand side of panel). For the Memory for Digits task, there was a significant difference in means—CI group: $M = 1.94$, $SE = 0.63$, and HC group: $M = 4.77$, $SE = 0.92$, $t(56) = -2.51$, $p = .02$. For the Digit Span task, there was no significant difference in means—CI group: $M = 64.72.07$, $SE = 4.7$, and HC group: $M = 65.52$, $SE = 4.26$, $t(56) = -.12$, $p = .90$.

Effect of A/V and A/O conditions. Similar to Blending, it was necessary to examine the effect of the A/V and A/O conditions on Nonword Repetition and Digit Repetition. We performed 2 × 2 split-plot ANOVA on scores from the Nonword Repetition subtests under each presentation condition, A/O and A/V

Table 1 Correlation between PP tests and reading scores for the CI group

CI group	Word Attack	Word Comprehension
Elision	.63**	.70**
Blending		
A/V	.42*	.37*
A/O	.17	.07
Digit Span (A/V)	.37*	.61**
Memory for Digits (A/O)	.23	.16
Nonword Repetition		
A/V	.41*	.38*
A/O	.06	−.03
Rapid Letter Naming	.49**	.75**
Rapid Number Naming	.23	.004

Note. A/O = auditor only; A/V = auditory–visual; CI = cochlear implants; PP = phonological processing.
**p is significant at .01 level.
*p is significant at .05 level.

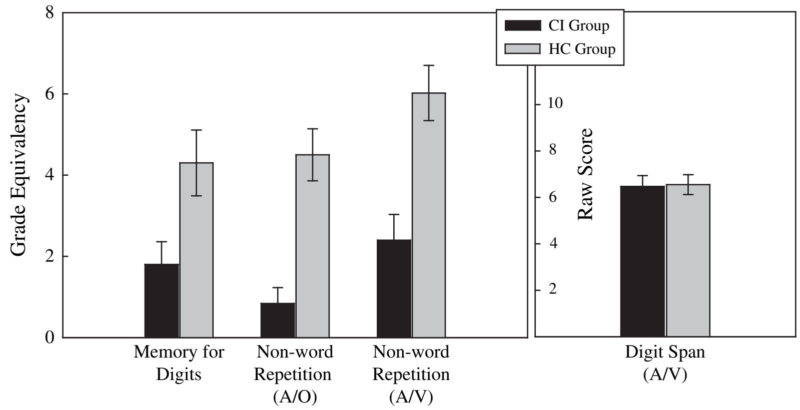

Figure 2 Test data showing CI and HC participants' mean performance on the tests of phonological memory (error bars = 1 *SE*). CI = cochlear implants; HC = hearing control.

for each group. Results revealed a significant main effects for group, $F(1, 56) = 23.06$ $p < .0001$, and presentation, $F(1, 55) = 10.45$, $p < .002$, condition, but there was no interaction between group and presentation condition, $F(1, 55) = 1.72$, $p = .20$. Again, the correlation between performance on task condition was high across groups at .77, with $p < .0001$. For the CI group, the correlation between task conditions was .47, with $p < .01$, and for the HC group, the correlation was higher at .82, $p < .0001$. Again, a *z*-score difference between these two correlations was computed for the CI and the HC groups and reveals that the correlation between conditions were significantly different by group at −2.33, $p < .01$ (Table 1).

Finally, on the Memory for Digits task, it is interesting to note that the CI group had a lower mean performance on the task than the HC group. However, there was no group difference on the Digit Span task. Recall that the Digit Span task included both auditory and visual presentation of the stimuli, where the Memory for Digits task only included an auditory presentation of the stimuli. Once again in order to examine the effect of the A/V and A/O conditions on Memory for Digits and Digit Span tasks, we again performed 2 × 2 split-plot ANOVA on scores from the Memory for Digits subtests, which can be considered as an A/O condition, and the Digit Span task, which can be considered as an A/V condition. Results revealed no significant main effects for group, $F(1, 56) = 0.66$ $p < .42$, but there was an effect for presentation condition, $F(1, 56) = 363.63$, $p < .0001$. Additionally, there was no interaction between group and presentation condition, $F(1, 56) = 0.40$, $p = .5278$. Again, the correlation between performance on task condition was moderate across groups at .42, with $p < .01$. For the CI group, the correlation between task conditions was .37, with $p = .02$, and for the HC group, the correlation was at .45, with $p = .05$. This time, however, when a *z*-score difference between these two correlations was computed for the CI and the HC groups, it revealed that the correlation between conditions for were *not* significantly different by group at −.35, with $p = .36$ (Table 1). Thus, for the CI group, when digit repetition is done in an A/O condition, it is a more difficult task than it is for the HC group. Yet, the performance of the CI kids in the A/O condition is moderately correlated to their performance on the A/V task.

Rapid naming. Figure 3 presents the mean grade equivalency scores for the Rapid Naming tasks, including Rapid Number Naming and Rapid Letter Naming. Mean grade equivalency score on Rapid Number Naming for the CI group was 4.2 ($SE = 0.52$), whereas the mean grade equivalency score for the HC group was 4.34 ($SE = 0.57$). A *t* test demonstrated that these means were not significantly different, $t(56) = -21$, $p < .84$. For Rapid Letter Naming, mean grade equivalency score for the CI group was 5.6 ($SE = 0.61$), and the mean grade equivalency score for the HC group was 4.5 ($SE = 0.51$). A *t* test demonstrated that these means were not significantly different, $t(56) = 1.3$, $p = .20$.

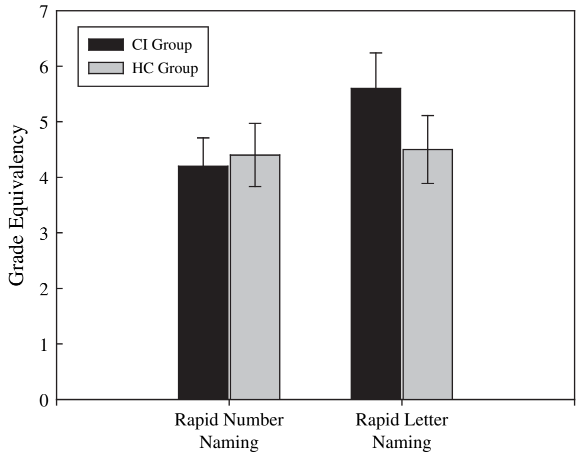

Figure 3 Test data showing CI and normal HC participants' mean performance on the tests of rapid naming (error bars = 1 *SE*). CI = cochlear implants; HC = hearing control.

Pearson correlation was performed on number and letter naming for each group. Results indicated that the correlation between number and letter naming for the HC children was high, $r = .87$, $p < .0001$; yet, for the CI children, the correlation was negative and not significant, $r = -.25$, $p > .05$.

Nonverbal reasoning tasks. Figure 4 reveals that the group mean standard score on the UNIT for the CI children was 103.7 ($SE = 2.42$), and the group mean standard score for the HC children was 110.1 ($SE = 1.97$). A *t* test demonstrated that these means were significantly different, $t(56) = -2.30$, $p = .03$. Although the means are significantly different, the mean standard score for each group was within the average range.

Reading achievement. Figures 5 and 6 present the results from the Word Attack and Word Comprehension subtest from the WRMT (Woodcock, 1987), using both the grade equivalency scores and the standard scores. Examination of the mean standard scores between the groups reveals significant differences for Word Attack in the CI group ($M = 101.31$, $SE = 4.91$) and the HC group ($M = 116.93$, $SE = 2.22$), $t(39) = -2.90$, $p = .006$. Similarly, the mean *standard score* for Word Comprehension in the CI group was

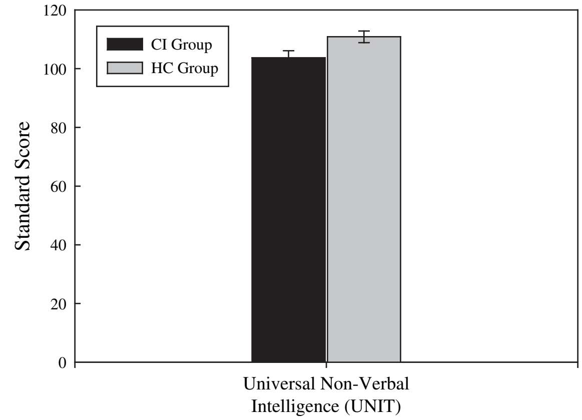

Figure 4 Test data showing CI and HC participants' mean performance on the nonverbal reasoning test, UNIT (error bars = 1 *SE*). CI = cochlear implants; HC = hearing control; UNIT = Universal Nonverbal Intelligence Test.

93.38 ($SE = 3.37$), and the mean standard score for the HC group was 107.93 ($SE = 1.65$). A *t* test revealed that the standard scores between the two groups were significantly different, $t(40.7) = -3.88$, $p = .0004$ (Satterthwaite correction for heterogeneity of variance used). The *grade equivalency* performance of the groups, however, is similar. Recall that the two groups were matched on grade equivalency performance on the Word Comprehension subtest. Although we did not specifically match the groups for performance level on the Word Attack subtest, *t*-test results revealed no significant difference in mean grade equivalency. The *t*-test results are $t(56) = -.08$, $p = .86$

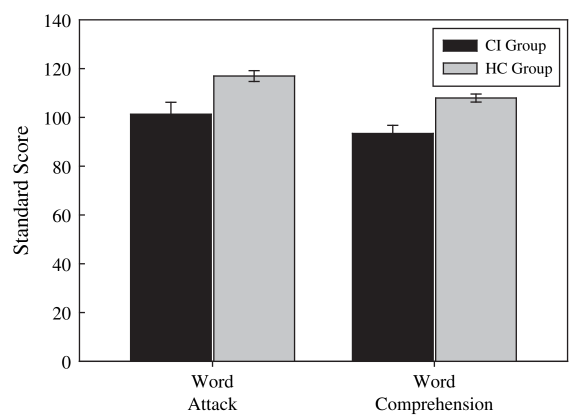

Figure 5 Test data showing CI and HC participants' mean performance on Word Attack and Word Comprehension in standard scores. CI = cochlear implants; HC = hearing control.

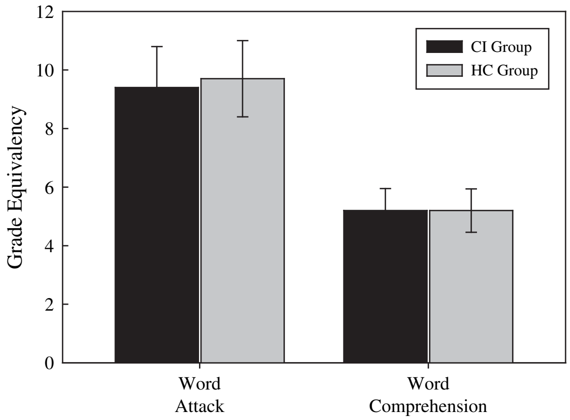

Figure 6 Test data showing CI and HC participants' mean performance on Word Attack and Word Comprehension in grade equivalency scores (error bars = 1 *SE*). CI = cochlear implants; HC = hearing control.

and $t(56) = .06$, $p = .95$, for Word Attack and Word Comprehension, respectively. The groups can be different with respect to one score (standard score), and similar on another score (grade equivalency) is illustrative of how the scores take into account the *age* of the child when tested, and the relative standing of the score achieved. In this case, the mean ages for the two groups were different. The mean age for the CI children was 11 years 9 months, whereas that for the HC children was 9 years 7 months (a difference of about 2 years 2 months); yet, the groups were performing at similar reading levels.

Distribution of scores. Figures 7 and 8 present box plots for all the PP tests as a way to illustrate the score distribution for both the CI and the HC groups. In Figure 7, the box plots reveal wide distributions for the tests of Elision and Blending in the A/V condition, Nonword Repetition in the A/V condition, Letter Naming, and Digit Span. In the Figure 8, the distributions are more restricted, especially for the CI group, for the tests of Blending in the A/O condition, Digit Repetition and Nonword Repetition in the A/O condition, Number naming, and the Rhyme task.

Relationship between PP tests, word attack, and word comprehension. Tables 2 and 3 present the Pearson correlations between the PP subtests and the reading scores for the CI and HC groups, respectively. For the CI group, the PA subtests of Elision and Blending (in the A/V condition) were significantly correlated with Word Attack scores, $r = .63$, $p < .01$ and $r = .42$, $p < .05$, respectively, and with Word Comprehension scores, $r = .70$, $p < .01$ and $r = .37$, $p < .05$, respectively. Similarly for the HC group, Elision and Blending (in the A/V condition) were significantly correlated with Word Attack scores, $r = .65$, $p < .01$ and $r = .40$, $p < .05$, respectively, and with Word Comprehension scores, $r = .78$, $p < .01$ and $r = .56$, $p < .01$, respectively. Blending in the A/O condition was not significantly correlated for either Word Attack or Word Comprehension in the CI group, and Blending in the A/O condition was significantly correlated only with Word Comprehension for the HC group, $r = .52$, $p < .01$. For the CI group, the phonological memory subtests of Digit Span and

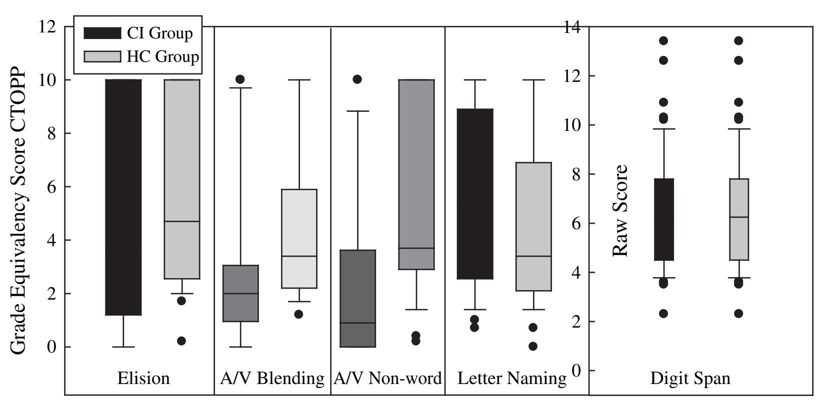

Figure 7 Box plots illustrating the univariate properties for CTOPP test results where the distributions are widely distributed. Boundary of box closest to 0 indicates the 25th percentile, and boundary of box farthest from 0 indicates the 75th percentile. Outliers are presented as filled circles. CTOPP = Comprehensive Test of Phonological Processing.

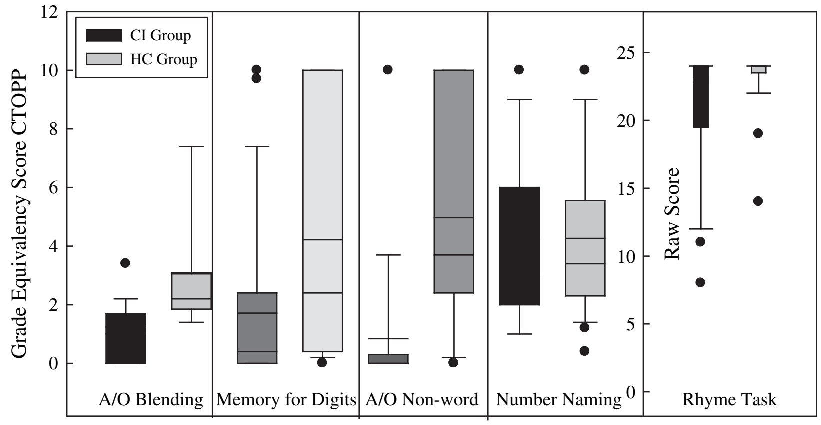

Figure 8 Box plots illustrating the univariate properties for CTOPP test results where the distributions were more restricted. Boundary of box closest to 0 indicates the 25th percentile, and boundary of box farthest from 0 indicates the 75th percentile. Outliers are presented as filled circles. CTOPP = Comprehensive Test of Phonological Processing.

Nonword Repetition (both presented in the A/V condition) were moderately correlated with Word Attack, $r = .37$, $p < .05$ and $r = .41$, $p < .05$, respectively, and Word Comprehension, $r = .61$, $p < .01$ and $r = .38$, $p < .05$, respectively. For the HC group, Digit Span and Nonword Repetition (both presented in the A/V condition) were also correlated with Word Attack, $r = .53$, $p < .01$ and $r = .55$, $p < .01$, respectively, and even more so with Word Comprehension, $r = .74$, $p < .01$ and $r = .54$, $p < .01$, respectively. The A/O version of the Memory for Digits task was not significantly correlated for either Word Attack or Word Comprehension, for the CI children. The A/O version of Memory for Digits was not correlated for Word Attack, but it was for Word Comprehension in the HC group, $r = .54$, $p < .01$. Finally, for the CI group, Rapid Naming for letters was significantly correlated with both Word Attack and Word Comprehension, $r = .49$, $p < .05$ and $r = .75$, $p < .01$ and also for the HC group, $r = .55$, $p < .01$ and $r = .75$, $p < .01$. Rapid Naming for numbers was significantly correlated with Word Attack and Word Comprehension only for the HC group, $r = .53$, $p < .01$ and $r = .72$, $p < .01$.

Discussion

The first main goal of the study was to investigate whether it was possible to establish a series of tasks to validly measure the PP skills of CI users. Second, we wanted to document the range of the PP skills in children with more than 3 years of CI experience. Finally, we wanted to investigate the relationship between the measured PP skills and reading skills. We briefly review each measure of PP in order to address these goals.

Validity of Tasks

It was previously not clear whether one could validly measure PP skills in deaf children. Validity is defined as the degree to which a task actually measures what it is attempting to measure (Heffner, 2007). An additional consideration with regard to validity is the question of how appropriate are the inferences and

Table 2 Correlation between PP tests and reading scores for the HC group

HC group	Word Attack	Word Comprehension
Elision	.65**	.78**
Blending		
A/V	.40*	.56**
A/O	.30	.52**
Digit Span (A/V)	.53**	.74**
Memory for Digits (A/O)	.35	.54**
Nonword Repetition		
A/V	.55**	.55**
A/O	.44**	.52**
Rapid Letter Naming	.55**	.75**
Rapid Number Naming	.53**	.72**

Note. A/O = auditor only; A/V = auditory–visual; HC = hearing control; PP = phonological processing.
** p is significant at .01 level.
* p is significant at .05 level.

Table 3 Correlation between A/V and A/O conditions in CI and HC groups

	Combined correlation	CI	NH	Z-score difference
Blending	**.75**	**.51**	**.87**	**−2.78**
Nonword Repetition	**.77**	**.47**	**.82**	**−2.33**
Digit Span/digit Repetition	**.42**	**.37**	**.45**	.35

Note. All values in bold face are significant at $p < .01$ level. A/O = auditor only; A/V = auditory–visual; CI = cochlear implants; HC = hearing control.

decisions we make based upon the results of the child's performance on the tasks. In this case, we were attempting to validly measure PP skills in profoundly deaf children who wear CIs. Assessment of rhyming was possible through a picture identification task, and assessment of sound-based tasks was possible through using standard test materials provided by a commercial test distributor. We found that all the children were able to complete all the tasks administered. That is, they were able to perform the training items, and then, they were able to complete additional test items before they missed enough items to obtain a ceiling performance. This is a prerequisite for achieving a valid assessment. Yet, does the ability to complete tasks designed to measure PP skills in hearing children indicate that the tasks are valid in this population?

We hypothesized that if poorer hearing in the CI children influenced their PP performance, then their performance on parallel tasks that vary in auditory demands will be affected more than what we would find in hearing children with comparable reading abilities. On the Elision subtest (a PA task), we found no significant difference in performance between CI and HC children. Additionally, performance on Elision was correlated with performance on the two reading tasks. On the Blending (also a PA task) and Nonword Repetition task (a task incorporating phonological memory), we found a main effect for group condition (HC children performed better) and for presentation condition (both HC and CI children did better when they were in A/V condition). There was, however, no interaction between group and presentation condition. Again, we found that there was a significant correlation between performance on Blending and the reading tests, plus Nonword Repetition and the reading tests, but only in the A/V condition for the CI group. For the HC group, the correlations remained significant for all conditions, except the A/V condition of Blending and Word Attack. On the Digit Repetition task, although there was no significant main effect for group, there was a main effect for presentation condition and no interaction between group and presentation condition. These findings indicate that to the extent that all these tasks are valid in the HC group, they are also valid in the CI group. Furthermore, we see that performance for the PP tasks are correlated with both Word Attack and Word Comprehension, but that this finding only held for the CI group if they received an A/V condition.

We also hypothesized that the correlations between performances on these parallel tests varying only in mode of presentation (A/O vs. A/V) would differ between the CI and the HC children if hearing affected performance. What we found was that performance on each task presented in the A/O modality was significantly correlated with performance on the task presented in the A/V modality for both groups. We did find that there was a difference in the strength of correlation between groups, however. There was a higher correlation between task performance for the hearing children in the PA tasks of Blending and the PP task of Nonword Repetition. For a Digit Repetition task, however, the strength of correlation between task conditions was similar for the CI and HC groups. This finding provides us further evidence that the tasks are as valid in the CI group as they are in the HC group.

PP: Task Selection, Development, and Theoretical Implications

Certain tasks were better suited for evaluating the PP skills in the children with CIs. In this section, we briefly review all the PA tasks in order to discuss the validity of the tasks and the theoretical implications of the results.

Phonological awareness. One of the easiest PA tasks for hearing children is the rhyming task (Adams, 1990). Hearing children usually begin to show rhyme awareness in the preschool years and have mastered the concept by first grade (Bradley & Bryant, 1991). In the current study, the majority of the CI children could perform the Rhyme task with more than 85% accuracy. Unlike hearing children, however, there were some CI participants in this study who did not achieve ceiling performance even by age 10. The present group of CI children did perform better than the group of younger CI children in the study by James et al. (2005). In that study, 20 CI children achieved a mean accuracy level of 56% and then 77% at mean age levels of 8 years 5 months and 9 years 5 months, respectively. Those children also had, on average, fewer years of CI experience (4 and 5 years, respectively). Taken together, the findings of this study and the study of James et al. indicate that awareness of syllables and rhyme emerges gradually over time for most but not all of the CI children.

For the Blending Words task, the CI children performed nearly uniformly at the early-elementary level (up to third-grade equivalencies) regardless of their chronological ages and of presentation condition (A/O or A/V). In contrast, the HC children tended to achieve ceiling performance by age 10. This finding indicates that the HC children master the blending skill by age 10, but that the CI children are still developing this skill throughout their elementary years and even into their teen years. In the continuum of difficulty of PA skills, blending is considered to be an intermediate skill (Adams, 1990; Stahl & Murray, 1994).

The CI children fared much better on the Elision task, one of the harder PA skills (Adams, 1990; Stahl & Murray, 1994). Both the HC and the CI children tended to display a well-distributed performance pattern across age ranges. Even so, there was not a pattern of uniform mastery on Elision by a specific age for the CI children. Where the HC children demonstrated evidence of mastery on the task by age 10, there were approximately six children in the CI group who performed below the fourth-grade level after age 10.

The implications of these findings reveal that although there is certainly evidence that children with CIs do develop PA skills, their performance is characterized by a longer, more protracted learning phase before mastery is achieved than their HC counterparts. Interestingly, the CI children performed fairly well as a group on the harder task of Elision. One explanation for this result could be attributed to the nature of the task, which requires the child to first say the word (e.g., "bold"). Then, the child is to repeat the word without saying a part of the word (e.g., "b") as in "Say 'bold' without the 'b'." The first task of saying the word may serve two purposes. In the case of the children with a CI, the examiner can verify that the child hears the correct word. Also, the child produces the movements for the whole word. This act of articulating the whole word could facilitate awareness of the "mental model" of the parts of the word (Leybaert & Alegria, 1995). The Elision task, when completed in this manner, is thus felt to be a particularly useful task to assess PA, in children with hearing loss or with CIs because it assures that the child has the correct word in mind.

In summary, the CI children performed best on rhyming, with a near ceiling effect. In contrast, they had a near floor effect for the Blending task, but the performance on the Elision task was well distributed. The performance differences within the CI group across the tasks could indicate that rhyming is a precursor skill to reading and that Elision tasks are well suited for assessing PA skills in children with CIs who are at this age and developmental level.

Phonological memory. On the phonological memory subtests, we frequently noted differences between the CI and the HC groups with regard to performance on most tasks. There were significant differences in group performance on the Nonword Repetition task for both the A/O and the A/V modalities. On the Nonword Repetition task, the CI children had a nearly uniform performance at the early-elementary level (kindergarten to second-grade equivalencies) regardless of their age in the A/O presentation condition, with slightly better performance (up to fourth grade) in the A/V condition. In contrast, the HC children tended to achieve ceiling performance by age 10 regardless of presentation condition (i.e., A/O or A/V). On the Digit Repetition task, there were significant differences in performance between groups with higher mean scores for the HC group. The results are in concert with the findings of others in that children with CIs tend to display shorter working memory for verbal and spatial patterns than their hearing counterparts (Burkholder & Pisoni, 2003; Cleary, Pisoni, & Geers, 2001).

For the Digit Span task, the two groups performed similarly and the distribution of scores was uniform for both groups. The Digit Span task used visual presentations of digits on a computer monitor, paired with auditory presentations. Additionally, the response modality was the computer keyboard. The distributed results and the similarities seen between groups on the Digit Span task, tested using the described methodology in this study, are in contrast with the abovementioned studies that found significant short-term memory differences between children with CIs and those with hearing. This finding suggests that the visual/auditory/ keypad testing method for digit Span for CI children is more indicative of their true short-term memory skills, and these results reveal that there may not be memory differences between the CI and the HC groups. This response method appears to be less susceptible to the effects of the distorted auditory signal. In addition, the use of the keypad for responding eschews the effects of slowed or distorted speech production. These results also support the finding by Burkholder, Pisoni, and Svirsky (2005) that for adults with *hearing*, digit span was reduced if they were given a degraded auditory signal (an eight-channel, frequency-shifted acoustic simulation of a CI). The authors attributed the performance decline to misidentification or to an incorrect encoding of digits due to the degraded signal rather than to ineffective subvocalization rehearsal or serial scanning of phonological representations in the short-term memory task. Given this logic, the same precautions should be made in testing the memory skills in prelingually deaf children who use CIs, who would be even more likely to have performance declines related to listening and speaking. Unlike hearing adults who have well-developed audition, children with CIs have never had hearing, nor do they have the articulation skills of adults. Thus, testing memory using vision, sound, and keyboarding could be a more accurate method of assessment for the CI children; yet, this now adds a confound of including visual, short-term memory. At any rate, the method of testing in this study is a compromise to best avoid the confound of perceptual skills and underscores that we need to use caution in testing memory in this population.

Rapid naming. Naming speed has been found to be predictive of early reading skill because it is thought to be a measure of the efficiency of retrieving phonological codes associated with phonemes, parts of words, or entire words (Shankweiler & Crain, 1986; Share, 1995; Torgesen & Burgess, 1998). For Number Naming, the CI group demonstrated a lot of variability in their performances, with a very unequal distribution of scores. The CI group never did evidence mastery of the skill (i.e., never displayed ceiling performance), even after age 12. In contrast, both groups demonstrated variable and similarly distributed performances on Letter Naming.

According to the authors of the CTOPP, performance with number and letter naming is highly correlated in children with hearing (Wagner et al., 1999). In this study, we replicated this finding with the HC group but not for the CI group. The correlation between number and letter naming for the HC children was high, $r = .87$, $p < .0001$; yet, for the CI children, the correlation between number and letter naming was negative and not significant, $r = -.25$, $p > .05$. The discrepancy between the Letter Naming and Number Naming results in the CI group tends to support the idea that they were better at retrieving the sounds or name codes associated with the letters than for numbers. This indicates that for the CI children, the act of vocalizing the names of numbers takes more time than the act of vocalizing the names of letters. Again, it is difficult to tell for certain whether letter-naming proficiency is a *precursor* to reading or *result* of reading; yet in this study, for some reason letter naming was associated with reading in a way that is more closely related than is the act of naming numbers. The CI children in this study were familiar with sign language. As a result, it is likely that their school experience as preschoolers included listening to the names of letters as they were simultaneously signed and spoken during finger-spelling and letter-learning activities. This could mean that letter names are highly salient for the children, and the names of numbers are less salient. The task of letter naming is therefore evidence of very well-learned phonological representations, where the task of number naming is not.

Thus, given the above-mentioned findings, a possible PP test battery for children who have several years of CI experience and who are beginning to read could include a rhyme task, an elision task, an A/V digit span task as described above, and a letter-naming task.

The results of this study indicate that although children with CIs can complete tasks in an A/O condition, the A/V testing condition was significantly correlated with Word Attack and Word Comprehension. As such, the A/V condition may be a more accurate measure of the actual PP skills and is not as susceptible to artifact from the degraded sound signal, yet either way, the tasks yield a valid measurement of skill. A challenge with the current version of the blending-type and nonword repetition–type tasks is that young children, particularly those with CIs, find the tasks quite difficult and are therefore susceptible to floor effects.

Relationship Between PP test and the Reading Skills of Word Attack and Word Comprehension

This study illuminates the importance of assessing the PP skills in children with CIs. PP skills correlated with the reading skills of decoding words and understanding words in children with CIs. Similarly, PP skills are correlated with reading skills in hearing children. The presence of this correlation in this study provides evidence that the tasks used within the study were indeed tapping skills that relate to reading achievement. With assessment of PP skills, we can potentially identify those CI users who are significantly below their peers with respect to their PP abilities and consequently which children need extra intervention to increase their PP skills. The results of this study indicate that clinicians can use PP assessment information to identify a particular child's areas of strength and weakness regarding phonological skill development. This information can hopefully be used in a proactive manner to support the development of strong reading skills.

Future Directions and Considerations

We would expect there to be a positive relationship between PP, word reading, and reading comprehension in children with CIs, based on the literature that finds this relationship in children with hearing. This study indicates that it is possible to find tasks that can assess the PP skills of children who are deaf and who use CIs. Furthermore, we did find a correlation between PP skills and reading skills. A subsequent study in progress will conduct a more fine-grained analysis of the relationship between the phonological skills and the reading skills in the children with CIs. That study will provide an idea of how much of the variability in reading skills of CI users can be predicted by their phonological skills.

The Reciprocal Nature of PA

Some argue that PA comes about as a result of learning to read, or what is known as the notion of reciprocal causation. We see evidence of reciprocal causation when we examine the PA skills of illiterate adults. Morais, Bertelson, Cary, and Alegria (1986) compared PA skills in adults who have never received reading training and with adults who received reading training in adulthood. The former group had significantly inferior phonemic segmentation skills than the latter group, suggesting that PA skills do not develop naturally but are learned. Furthermore, if PA skills improve after literacy training, this may indicate that one develops the ability to reflect on spoken words *after* learning to read.

In the context of children with CIs, it could be that this reciprocal relationship is more evident than in the context of children who hear. For example, there could be instances where a deaf child who uses a CI does not hear all the sounds of a word but comes to realize that there are sounds that are included within the word only after seeing the word in print. Alternatively or additionally, some children may come to the reading task with a more developed sense of what words sound like.

In this particular set of participants, the average age at implantation was just over 3 years 6 months; the average length of CI experience was 8 years. In spite of the relatively "late" age of implantation by today's standards, these children could produce nearly 88% of the phonemes correctly on a sentence repetition task. One could predict that with early identification of profound hearing loss, and earlier implantation, the listening and speaking skills of the CI children will continue to be well developed in the future. The results of this study set the stage to begin formulating prospective, controlled studies designed to explore the contribution of age and duration of implant use on the subsequent skills such as PP, which are thought to contribute to literacy as suggested by Marschark, Rhoten, and Fabich (2007).

Similar Reading Levels and Similar PP Levels?

Both groups of children in this study were decoding words at the early ninth-grade level and comprehending words at the early fifth-grade level. There was a strong correlation between PP skills and reading skills for both groups. At first blush, it appears that the HC group had much higher grade-level performance on several of the PP tests (e.g., Blending, Nonword Repetition); yet, performance for Rhyme and Elision and Digit Span was similar for both groups. This outcome suggests that there are subtle ways that children with CIs may go about the process of reading differently from their hearing children. Further studies could explore the influence of the "resilient reader" effect posited by Jackson and Dollinger (2002) who speculated that resilient readers might have more skills with using contextual cues for comprehension.

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Appendix A: Demographic information for CI users

ID	Sex	Age at CI	Age at testing	Months' experience	SES	Etiology	CI type	Processing strategy
CI 1	M	2.58	17.83	183.00	5	Meningitis	Nucleus 22 Sprint	MPEAK
CI 2	F	2.32	8.16	70.13	3	Unknown	Nucleus 22 Sprint	ACE
CI 3	F	1.63	9.64	96.10	6	Ushers	Nucleus 3G	ACE
CI 4	M	2.27	9.25	83.77	4	Heredity, NS	Nucleus 22 Sprint	ACE
CI 5	M	2.74	14.06	135.90	6	CNX 26	Nucleus 22 Spectra	SPEAK
CI 6	M	2.88	16.04	158.03	3	CNX 26	Nucleus 22 Esprit	SPEAK
CI 7	M	3.39	16.73	160.07	4	CNX 26	Nucleus 22 Esprit	SPEAK
CI 8	M	1.74	7.89	73.73	3	Unknown	Nucleus 22 Sprint	ACE
CI 9	F	1.59	8.71	85.43	6	Unknown	Nucleus 3G	ACE
CI 10	M	3.57	15.94	148.53	4	CNX 26	Nucleus 22 Spectra	SPEAK
CI 11	F	6.24	13.30	84.70	4	Heredity, NS	Nucleus 22 Sprint	ACE
CI 12	M	3.34	9.74	76.83	4	Heredity, NS	Nucleus 3G	ACE
CI 13	F	10.54	15.43	58.63	4	Unknown	Nucleus 3G	ACE
CI 14	F	3.36	9.44	72.93	4	Unknown	Nucleus 22 Sprint	ACE
CI 15	M	4.27	8.23	47.50	4	Unknown	Nucleus 3G	ACE
CI 16	F	3.53	15.92	148.70	5	Unknown	Nucleus 22 Esprit	SPEAK
CI 17	M	1.64	8.53	82.70	3	Ototoxic	Nucleus 3G	ACE
CI 18	M	1.48	8.43	83.40	4	Meningitis	Nucleus 22 sprint	ACE
CI 20	M	5.68	12.81	85.63	4	Unknown	Nucleus 3G	ACE
CI 21	F	2.27	8.25	71.73	5	CMV infection	Nucleus 3G	ACE
CI 22	M	2.98	11.99	108.07	3	Coch Mal	Nucleus 22 Sprint	ACE
CI 23	F	1.61	8.06	77.43	5	Unknown	Nucleus 3G	ACE
CI 24	M	2.60	10.59	95.93	5	Heredity, NS	Nucleus 22 Sprint	ACE
CI 25	M	1.69	7.19	66.07	5	Unknown	Nucleus 22 Sprint	ACE
CI 26	F	10.99	15.13	49.77	4	Unknown	Nucleus 3G	ACE
CI 27	M	3.82	16.89	156.87	5	Meningitis	Nucleus 22 Esprit	SPEAK
CI 28	M	3.53	11.85	99.87	3	Coch Mal	Nucleus 3G	ACE
CI 29	F	2.34	11.40	108.73	3	Heredity, NS	Nucleus 3G	ACE
Average		3.55	11.88	99.97	4.24			
SD		2.39	3.50	36.80	0.95			

Note. CI = cochlear implants; CNX 26 = GJBT mutation (Connexin 26); CMV = cytomegalovirus; Coch Mal = cochlear malformation; F = female; Heredity, NS = nonspecific hereditary component; M = male; SES = socioeconomic status.

Appendix B: Demographic information for HC group

Name	Sex	Age/test	SES
NH 1	M	6.51	6
NH 2	F	10.14	5
NH 3	M	9.63	5
NH 4	M	10.82	6
NH 5	M	7.31	5
NH 6	M	6.73	5
NH 7	F	11.35	5
NH 8	F	7.62	5
NH 9	F	10.96	6
NH 10	M	6.44	6
NH 11	M	8.65	4
NH 12	M	7.46	4
NH 13	F	12.18	3
NH 14	F	17.96	3
NH 15	M	6.65	3
NH 16	M	10.14	3
NH 17	M	9.29	4
NH 18	F	13.29	3
NH 19	F	7.51	3
NH 20	M	6.20	4
NH 21	M	7.71	4
NH 22	M	8.48	4
NH 23	M	10.61	3
NH 24	M	13.94	6
NH 25	F	11.58	5
NH 26	M	10.53	5
NH 27	F	8.31	4
NH 28	F	11.49	5
NH 29	F	7.44	4
Average		9.55	4.41
SD		2.70	1.05

Note. F = female; HH = hard of hearing; M = male; SES = socioeconomic status.

Appendix C: Description of phonological processing tasks

Phonological processing	Subtest or task names and brief description		
Phonological awareness tasks	Elision[a]: watching and listening to examiner (e.g., say "pink," say "pink" without the "p").	Blending[a]: (A/V)[b] watching and listening to examiner; (A/O) listening to audio file played through a personal computer and external speakers, asking "What words do these sounds make?" Test item "can dee." The child puts the word together and says "candy."	Rhyme task: 24 trials presented on a personal computer via E-Run software. Each trial with four photos (a cue—top photo) a target, and two distracters (e.g., the cue *hair* had the target *pear*, with a distracter of *bow*). Examiner named all photos.

Appendix C: Continued

Phonological processing	Subtest or task names and brief description		
Phonological memory tasks	Nonword Repetition[a]: (A/V)[b] watching and listening to examiner; (A/O) listening to audio file played through a personal computer and external speakers, asking "Say …," followed by the test item "joop."	Memory for Digits[a]: listening to audio file played through a personal computer and external speakers. Child repeated number sequence.	Digit Span: digits presented one at a time on computer screen (6), then (5), then (1) paired with the spoken words for each digit. Screen becomes blank and participant entered digits in the correct order on keypad. The E-Prime program presented blocks of digits in an adaptive procedure.
Rapid naming tasks	Rapid Letter Naming[a]: child calls the names each letter from block of letters on page. Task is repeated twice and total time is recorded.	Rapid Number Naming[a]: Child calls the names each letter from block of numbers on page. Task is repeated twice and total time is recorded.	

Note. A/O = auditor only; A/V = auditory–visual.
[a]Indicates that the test is from the Comprehensive Test of Phonological Processing battery.
[b]Indicates modification to (AV).

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