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Reading, Writing, and Phonological Processing Skills of Adolescents with 10 or More Years of Cochlear Implant Experience

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INTRODUCTION

Children with prelingual deafness typically demonstrate average delays of four to five years in reading development by the time they enter high school. Many of these children experience what teachers refer to as the “fourth grade problem,” meaning that they fail to make progress beyond identification of a limited number of words (Scarborough, 2001). Normative data indicate approximately half of deaf students read below the fourth grade level at the end of high school (Traxler, 2000). Most hearing children are competent language users when they begin to map reading onto existing phonological, syntactic, and semantic skills. The frequently reported low literacy levels among deaf students are, in part, due to the discrepancy between their incomplete spoken language system and the demands of reading a speech-based system (Perfetti & Sandak, 2000). However, the advent of the cochlear implant (CI) as a treatment for prelingual profound deafness is associated with a reduction in the achievement gap relative to age-mates with normal hearing (Connor & Zwolan, 2004). A recent comprehensive review of the literature on reading skills in students with CIs concluded that children with implants frequently read better than deaf peers who utilize hearing aids, even if they lag behind hearing age mates (Marschark, Rhoten, & Fabich, 2007). Some of the factors that affect reading in CI users also are important for reading development in hearing children (e.g., general intelligence, parent education, family income). However, it is possible other contributors to literacy are unique to children with hearing loss (Geers, 2002). Both kinds of predictors are examined in the current investigation. First, we describe several factors that are necessary for deaf children to learn to read and write, and how these factors are affected by cochlear implantation. We then describe the current study, which investigates reading and writing skills in a group of adolescents who received CIs as preschoolers.

Factors Necessary for Successful Literacy Development

Phonological Processing Skills—The early reader or speller must acquire knowledge of letter–sound or sound–letter correspondences based on an internal phonological system.

Not surprisingly, hearing children who have good phonological skills are good readers (see Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg for a review, 2001). Although deaf children's phonological development is delayed compared to hearing peers, some research has found that deaf children develop phonological awareness in a similar sequence as hearing children (e.g., Sterne & Goswami, 2000). Children who wear CIs may be at a greater advantage than profoundly deaf peers without CIs in terms of developing phonological awareness. Early access to sound assists young CI users to better encode the speech signal and accurately produce the sounds of language (Blamey, Sarant, Paatsch, Barry, Bow, Wales, et al., 2001; Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006). A review of the relevant literature suggests that children who use CIs develop phonological systems that are stronger than those of their deaf peers without CIs, but are weaker than those of their hearing peers (Spencer & Tomblin, 2008).

As might be expected, deaf children with CIs who demonstrate strong phonics skills are good readers. A study of 181 children with CIs who were 8-9 years old reveals a high correspondence ($r = 0.85$) between phonics skills and reading comprehension scores (Geers, 2003). Reading levels were associated with students' performance on a rhyme decision and a homophony lexical decision task, both of which assess use of a phonological strategy. A study by Johnson and Goswami (2010) also found that phonological awareness measures correlated with reading outcomes. Thus, just as is the case for hearing children, strong phonological processing skills are essential for successful reading development in deaf children and the CI appears to provide children an opportunity to acquire these crucial skills (Spencer & Oleson, 2008). It is important to note, however, that variation in phonological processing skills is quite large in children with CIs (James, Rajput, Brown, Sirimanna, Brinton, & Goswami, 2005). The successful acquisition of phonological processing skills may also depend on demographic factors, such as age at implantation, duration of CI use, and communication mode (Johnson & Goswami, 2010). It is possible that the longer the auditory deprivation or the poorer the signal from the CI, the less well-specified are a child's phonological representations of speech sounds (Pisoni, Kronenberger, Conway, Horn, Karpicke, & Henning, 2008).

Vocabulary—As phonological processing is essential for decoding letter-sound and sound-letter correspondences, vocabulary knowledge is essential for reading comprehension and expository writing. Vocabulary knowledge refers to word meanings that the child acquires through exposure and formal instruction to store in long-term memory. Children with prelingual deafness approach reading and writing with more limited vocabularies than their hearing age-mates do (Boothroyd, Geers, & Moog, 1991). Moreover, the greater the hearing loss, the larger the delay (Boothroyd et al., 1991). Vocabulary development proceeds more rapidly following cochlear implantation, especially when implant surgery occurs during preschool ages (Connor et al., 2006; Connor, Hieber, Arts, & Zwolan, 2000; Dawson, Blamey, Dettman, Barker, & Clark, 1995; Hayes, Geers, Treiman, & Moog, 2009). Unlike grammar, which is fairly complete in hearing children by 4-5 years of age (Ingram, 1989; Hirsh-Pasek & Golinkoff, 1996), meanings of words represent concepts that must be learned individually, contributing to the continuing refinement of vocabulary throughout development. The vocabulary advantage associated with cochlear implantation at an early age, combined with improved phonological decoding, facilitates reading and comprehension, resulting in more age-appropriate literacy skills (Connor & Zwolan, 2004; Johnson & Goswami, 2010).

Language/Discourse Skills—In the United States, current technological and societal demands necessitate a 10th- or 11th-grade reading ability for functional participation in society (Marschark et al., 2007). This relatively high level of literacy requires knowledge of cohesive devices (e.g., conjunctions, pronouns) as well as world knowledge and knowledge

of texts in general (Stanovich, 1980). Syntax, discourse, and metacognitive skills are especially important for achieving advanced reading and writing competence (Geers & Moog, 1989). Such skills contribute to the child's prior knowledge about the world and the ability to draw inferences and comprehend figurative language. A reduced ability to overhear conversation and narrative discourse may interfere with a deaf child's ability to comprehend connected language structure, main ideas, and associative relationships between events (Schopmeyer, 2009).

An effective reader and writer must understand how to use patterns of language and discourse factors that are particularly difficult for deaf students to acquire. For example, deaf students use fewer cohesive markers in their writing (DeVilliers, 1991) and elaborate the content of written composition less often than hearing age-mates (Yoshinaga-Itano, Snyder, & Mayberry, 1996). Difficulties with grammar are evident in the written expression of deaf students (Antia, Reed, & Kreimeyer, 2005; Moores & Sweet, 1990; Yoshinaga-Itano et al., 1996). Interestingly, if the written material consists of less formal material, such as stories or personal narratives, and the focus is on the structure and organization of discourse, deaf students' writing more closely resembles that of hearing peers (Marschark, Mouradian, & Halas, 1994). Thus, grammatical correctness is certainly important for effective written communication but assessment also should take into account dimensions such as content and organization when judging writing competence.

Spelling—Spelling is an often neglected component of general literacy skills. However, spelling is not to be overlooked, as recent studies suggest that poor spelling leads to poor perceptions of a person's overall writing abilities (Figueredo & Varnhagen, 2005; Kreiner, Schnakenberg, Green, Costello, & McClint, 2002). Contrary to traditional views, spelling involves more than memorizing letter sequences. In English, spelling draws on knowledge of many aspects of language, including the knowledge of relationships among words, root words, and words' historical origins. An accurate comprehension of the phonological structure of spoken words, together with an ability to represent this structure in writing, is a foundation of spelling skill. Studies of spelling in deaf children have shown that, not surprisingly, deaf children are poorer spellers on average than hearing children of the same age (Burden & Campbell, 1994; Harris & Moreno, 2004; Sutcliffe, Dowker, & Campbell, 1999). However, these studies were conducted primarily on deaf children without CIs. Deaf people using CIs have better access to spoken language phonology than previously possible through hearing aids or other means. Increased access to sound provided by CIs, combined with an emphasis on speech and phonological skills, may facilitate spelling in children using these devices.

Child and family characteristics—Characteristics such as performance intelligence quotient (PIQ), family socioeconomic status (SES), parent education, age at onset of deafness, and gender were important factors associated with reading outcomes in 8-9 year old children with CIs (Geers, 2003). Female children with higher PIQs from higher SES families who had onset of deafness after birth (but before 36 months of age) scored best on a measure of reading comprehension. These child and family characteristics accounted for 25% of the variance in reading scores. CI characteristics were important as well, accounting for an additional 12% of variance in reading level after controlling for child and family characteristics. Better readers used the newest CI speech processing strategies available for longer time periods than poorer readers. They also used a larger dynamic range. One might expect that communication mode used in the child's educational setting following cochlear implantation would be important for reading; however, whether a child's educational program used sign and speech (simultaneous communication or SC) or only speech (oral communication or OC) did not account for significant variance in reading outcome after variance due to child, family and implant characteristics was removed. Child and family

characteristics also are important factors for writing success in deaf children (Antia et al., 2005), with SES, age, gender, and degree of hearing loss accounting for variance in written expression abilities.

Literacy Skills of Children with Cochlear Implants

Given that the above factors are crucial components of successful literacy development, and that cochlear implantation facilitates development in these areas, how do deaf children with CIs perform on reading and writing tasks compared with hearing peers? In tests of reading, 70% of children enrolled in a private oral education setting following cochlear implantation scored within the average range on standardized reading tests in elementary school (Moog, 2002). Geers (2003) reported 61% of CI children in North America scored within or above the average range for hearing age-mates and the mean standardized score for all children (89) was within the low-average range. Similar findings were reported for a group of 39 CI users in the United Kingdom (Johnson & Goswami, 2010). However, not all children with CIs achieve literacy levels expected for their age. An assessment of reading comprehension levels in 91 CI users (average age of 11 years) revealed they were not reading as well as their peers with normal hearing (Connor & Zwolan, 2004). A recent study of 12-16 year olds in the UK found that 48% of the students with hearing aids read within 1 year of hearing age-mates while only 19% of CI users achieved age-appropriate reading levels (Harris & Terleksi, 2010). The differences in reading achievement reported across studies may be associated with the age of the participants. Lags in reading development in children with hearing loss tend to widen with age (Kroese, Lotz, Puffer, & Osberger, 1986; Marschark & Harris, 1996). The current study compares reading levels of children with CIs in early elementary grades (age 8-9 years) with those same children in high school (age 15-18 years) to see whether they maintain their reading levels or whether the gap widens as they get older.

How do deaf children with CIs compare to hearing children on written language tasks? To our knowledge, only one study has quantitatively examined spelling skills in this specific population (Hayes, Kessler, & Treiman, in press) as compared to hearing peers. These children, ages 6 to 12 years, spelled as well as hearing children matched for reading, but poorer than hearing children of the same age. It is not known how well adolescents with CIs spell in comparison with hearing peers. However, a study of spelling errors in 12-16 year olds with hearing losses >85 dB, reported no difference between CI users and HA users in either number of correct spellings or percentage of phonetic errors (Harris & Terleksi, 2010).

The study of expository writing in deaf children with CIs has not received much attention in the literature. Previous research documents that 17-18 year old deaf students' written language resembles that of hearing students who are 9-10 years old (Paul, 2001). Does this gap in performance exist later in development or do the children with CIs catch up over time? Given the importance of literacy skills for academic and future career success (Kutner, Greenberg, Jin, Boyle, Hsu, & Dunleavy, 2007), further investigation into their development in deaf students is warranted.

Goals of the Current Investigation

The current study examines literacy skills of a group of early-implanted children when they were in high school (CI-HS). This population was examined first when they were in early elementary grades (CI-E) as part of a previous study on the effects of early cochlear implantation on speech, language, auditory, and reading skills (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Geers, Nicholas, & Sedey, 2003; Geers, 2003). The CI-E children's reading skills were not directly associated with auditory speech perception skills

achieved with the CI, but rather were associated with speech production skills and English language competence. Considerable variability was evident in the CI-E children's ability to use auditory skills to achieve language and academic parity. Although some CI-E children achieved above-average reading scores, other children exhibited barely-developed reading skills. The current study has three goals: 1) to document reading, spelling, expository writing, and phonological processing skills of CI-HS students, 2) to determine the extent to which age-appropriate readers kept pace with their hearing age-mates throughout elementary and high school grades in order to determine whether the below-average CI-E readers caught up over time, and 3) to assess the predictive contributions of phonological processing and child/family characteristics to literacy skills.

METHOD

Participants

Participants included 112 students who were administered a battery of speech, auditory, cognitive, language, and literacy assessments at CI-E and CI-HS test sessions. This report focuses on literacy skills at the CI-HS test session. Information about results from the speech, auditory, cognitive and language assessments are described in this volume (Davidson, Geers, Blamey, & Tobey, submitted; Geers, Brenner, & Tobey, submitted; Geers & Sedey, submitted; Moog, Gustus, Geers, & Brenner, submitted; Pisoni, Kronenberger, Roman, & Geers, submitted; Tobey, Geers, Sundarajan, & Lane, submitted). Characteristics of CI-HS students are also described in detail in this volume (Geers et al., submitted). The CI-HS students were 15;0 (15 years 0 months) to 18;5 years old, with a mean age of 16;7 at the time of assessment. Grade placement ranged from 9th to 12th grades, with the majority of the participants enrolled in 10th and 11th grades. All participants were implanted by age 5;4 years with a mean age at implantation of 3;5 years. The adolescents reported using either spoken language (N = 83) or sign and speech (N = 29) as their primary methods of communication.

Data were also collected from a control group of hearing teenagers (NHC-HS) (N = 46), who ranged in age from 15;3 to 18;4 years. Additional details about these participants can be found in this monograph (Geers et al., submitted). All participants and their families signed consent and assent forms approved by the Institutional Review Board of the University of Texas at Dallas.

Measures—Literacy skills assessed in the CI-HS students included reading vocabulary and comprehension, syntactic and text comprehension, spelling accuracy, expository writing, and phonological processing. Tests were administered in both individual and group sessions. The CI-HS participants were assessed on all of the measures described below. The NHC-HS participants were assessed only on written expression tasks and one phonological processing task, the Children's Test of Nonword Repetition (CNRep) (Gathercole & Baddeley, 1996). For the reading and other phonological processing tasks, hearing norms provided by the assessment developers were used for comparisons.

Reading

Peabody Individual Achievement Test (PIAT) – Revised (Dunn & Markwardt, 1989)—Both reading subtests—Reading Recognition and Reading Comprehension—were individually administered at both test sessions. Total correct scores were converted to standard scores in relation to a normative sample of typically-developing hearing age-mates (mean = 100; SD = 15).

Reading Recognition. Items consist of single words that the student reads aloud. Testing continues until a ceiling is obtained at the lowest 7 consecutive responses containing 5

errors. Either a signed or spoken production recognizable as the target word is scored as a correct response.

Reading Comprehension. The student is presented with a page containing one sentence to be read silently. The page is removed and the student is presented with four illustrations, one of which best represents the sentence provided. No speech is required for this task, as the student's response is to select one of the four pictures. The starting point is determined by the student's raw score on the reading recognition subtest and continues to a ceiling of 7 consecutive responses containing 5 errors.

Test of Reading Comprehension (TORC) (Brown, Hammill, & Wiederholt, 1995)

—The TORC assesses silent reading comprehension. Each student responds to all items. Number correct scores were converted to standard scores for each subtest in relation to a normative sample of hearing age-mates (mean = 10, SD = 3). The following subtests were administered in small groups of 5-6 students:

General Vocabulary. The student reads three stimulus words that are related in some way (*yellow, red, blue*) and selects two words from a group of four (*black, grass, green, yes*) that are related to the stimulus words. Both answers must be correct to receive credit for the item.

Syntactic Similarities. The student reads five sentences and selects the two that are most nearly alike in meaning (It was her wagon. It was not her wagon. It was his wagon. The wagon was not hers. It was not his wagon.)

Paragraph Reading. The student reads a paragraph and five questions. A multiple-choice format is used for all five questions. The student selects the "best" title, recalls story details, draws an inference, and draws a negative inference (*Which sentence could not go in the story?*)

Sentence Sequencing. Each item includes five randomly ordered sentences that, when ordered properly, create a meaningful paragraph. The student orders the sentences. Scoring is based on relational order rather than specific sequence. (*Soon it will be noon. Next it will be night. It is morning. Then, it will be morning again. Then, it will be this afternoon.*)

Written Expression

Picture Spelling Test—Traditional spelling tasks, in which the experimenter says a word and the student writes the word, are problematic for deaf children because it is difficult to know whether the word was accurately perceived. Thus, a picture spelling task was designed. One-hundred words were selected from familiar vocabulary to adolescents, picturable, and with varied orthographic length and complexity. Each item was presented as a photograph, a line drawing, or a cartoon image. Participants were asked to name each item (presented one-at-a-time) and spell the name on a worksheet. The participants were encouraged to guess at any item that they did not know; if needed, the experimenter named the item. See the appendix for a list of the spelling items.

Expository Writing with NTID Scoring (Schley & Albertini, 2005)—Each teenager wrote a descriptive essay. The following instructions were provided:

"Everybody knows of something that is worth talking about. Maybe you know about a famous building like the Empire State Building in New York City or something like the Golden Gate Bridge in San Francisco. Or you might know a lot about the Mormon Tabernacle in Salt Lake City or the sports stadium in your home town. Or you might be familiar with something from nature, like Niagara Falls, a

gigantic wheat field, a grove of orange trees, or a part of a wide muddy river like the Mississippi.

There is probably something you can describe. Choose something you know about. It may be something from around where you live or something you have seen while traveling, or something you have studied in school. Think about it for awhile and then write a description of what it looks like so that it could be recognized by someone who has read your description. Name what you are describing and try to use your best writing."

Students were tested in small groups and given unlimited time to compose their essay. They were encouraged to review their work and make changes after completion. Students wrote the essays by hand in pencil and later they were typed by someone else with punctuation, spelling and grammar maintained. Both the original written version and the typed version were sent to experienced raters who were faculty members in the English department at the National Technical Institute for the Deaf (NTID) for scoring. The scoring procedure was developed for assessing the writing ability of postsecondary deaf students (Schley & Albertini, 2005). Each essay was evaluated by three raters. Scores were found to be reliable between multiple raters (Albertini, Bochner, Dowaliby, & Henderson, 1996). Each rater assigned between 1 and 100 points, equally divided among the following four scoring categories:

Organization. Points are awarded for a clear statement of the topic and intent of the essay, presence of a unified and coherent theme, and application of appropriate transitions.

Content. Higher scoring essays address the assigned topic with persistent and noteworthy ideas. Inclusion of extraneous material is avoided and generalizations are supported by examples.

Language Use. Points are awarded for correct use of grammatical structures and punctuation, correct use of complex structures, intelligible spelling, clarity of style and expression and clarity of reference.

Vocabulary Use. Points are awarded for appropriate semantic use of vocabulary, consistent register, sophisticated choice of vocabulary and appropriate use of figurative and idiomatic expressions.

Scores were averaged for the three raters and a total score was obtained by summing across the four subscales. Reliability was assessed for triads of raters who evaluated 236 essays from students at the National Technical Institute for the Deaf (Schley & Albertini, 2005). Pearson correlations among pairs of raters were all above .81. Intra-class correlation coefficients among groups of 3 raters (Shrout & Fleiss, 1997) ranged from .70 to .90. In addition, difference scores were calculated among pairs of raters and the absolute values of these difference scores were examined. Mean difference scores ranged from 5.33 to 9.48 points on the score range of 1-100 (SDs 4.2 to 7.58). Raters did not differ by more than 10 points for the vast majority of essays evaluated.

Phonological Processing

A group of measures was included in the battery that required phonological knowledge, awareness and/or decoding. Skills sampled include letter-sound correspondence, phonetic spelling and manipulation of sounds in words and phonological memory and production. These tasks were chosen to represent a range of abilities associated with the child's phonological representations of language.

Woodcock Reading Mastery Test (WRMT)– Revised (Woodcock, 1987)

Word Attack. This 45-item subtest of the WRMT battery assesses the student's ability to pronounce nonsense words (e.g., *raff*, *chad*, *yeng*, *cigbet*, *bafmotben*) using phonic and structural analysis skills. Students are tested beginning at item 1 and proceed to a ceiling level of six consecutive incorrect responses. Correct articulation of each phoneme is required for a correct response.

Phonological Plausibility Score—A scoring procedure was developed to assess misspellings on the Picture Spelling Test. Unlike the spelling accuracy (percent correct) score, included as part of the written expression battery, the plausibility score quantified whether the children were making errors based on the sounds in the target words. The scoring technique is similar to a recent study of hearing children's spelling errors (Ellefson, Treiman, & Kessler, 2009; Hayes et al., in press). For each of the 100 spelling words, a list was generated reflecting all the letters used to spell each phoneme. The reference for whether a letter is a plausible one given a certain phoneme was an “aligned” corpus: a subset of a word frequency database (Zeno, Ivens, Millard, & Duvvari, 1995) aligned with pronunciations from the Carnegie Mellon Pronouncing Dictionary (Carnegie Mellon University, 1998). The children's misspellings were scored for whether they used plausible letters for the particular phonemes in the word, moving from left to right. Students received a 1 if all of the letters in the misspelling were phonologically plausible choices but received a 0 if any of the letters were implausible choices for a particular phoneme. The mean proportion of plausible misspellings was calculated for each participant.

Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen, & Rashotte, 1999)

Elision subtest. This individually-administered subtest taps the student's phonological awareness and access to the phonological structure of oral language. The examiner presents a word orally and asks the student to say the word with a syllable or phoneme deleted (e.g., “Say *airplane*. Now say airplane without saying *plane*.” “Say *farm*. Now say farm without saying */ff/*.”) Raw scores are converted to scaled score equivalents based on age-appropriate norms for hearing children.

Children's Test of Nonword Repetition- CNRep (Gathercole & Baddeley, 1996)

—In order to accurately repeat a nonsense word, the student must immediately construct a phonological representation, based on a single exposure to the novel auditory stimulus, and then “translate” or “reassemble” that newly-formed representation into an articulatory output in speech production. We used a shortened, adapted version of the CNRep list (Dillon, Burkholder, Cleary, & Pisoni, 2004). The stimuli were recorded by a female speaker of American English. The CNRep nonwords were presented auditorily via a desktop speaker (Cyber Acoustics MMS-1) at approximately 70 dB SPL. Each student heard the nonword stimuli played aloud one at a time, in random order. The students were told that they would hear a funny word and were instructed to repeat it back as well as they could. Their imitation responses were recorded via a head-mounted microphone (Audio-Technica ATM75) onto digital audio tape using a TEAC DA-P20 tape deck. The DAT tapes were later digitized and segmented into individual sound files. The children's nonword productions were transcribed by graduate students/clinicians in speech-language pathology using the International Phonetic Alphabet (International Phonetic Association, 1999). The transcribed productions were entered into the Computer Assisted Speech and Language Assessment (CASALA) software for analysis (Serry, Blamey, & Grogan, 1997; Serry & Blamey, 1999). Each production was transcribed by two different people and then a third listened to the words that the other two did not agree on for a final decision. Using CASALA, reports were generated to obtain a percentage of phonemes correct.

Child and Family Characteristics

Predictor variables summarizing child characteristics included gender, age at first hearing aid fitting (roughly corresponding to age at which educational intervention was initiated), duration of deafness (age at implant minus age at onset of deafness), age at the CI-HS test session, WISC- PIQ, and a CI-HS measure of sign enhancement. Sign enhancement was estimated by the difference in standard scores on Form A of the Peabody Picture Vocabulary Test (PPVT) (Dunn & Dunn, 1981) administered in simultaneous communication (SC) and Form B of the PPVT administered using oral communication (OC). Values greater than 0 indicate higher receptive vocabulary standard scores in the SC than in the OC test condition. Family characteristics included family size and socioeconomic status (SES) at the CI-HS test session. The SES value was a combination of the number of years of education completed by the most highly educated parent and a ranking of total family income.

Cochlear Implant Characteristics

Aided sound-field detection thresholds were obtained at the CI-HS evaluation using frequency modulated (FM) tones at octave frequencies from 250-4000 Hz. The CI-HS participants were seated approximately 1 to 1.5 m from the loudspeaker at 0° azimuth using their CI as typically worn. Speech processor technology from Cochlear Corporation (Cochlear Americas, 13059 E. Peakview, Centennial, CO 80111) was rank ordered from 1 to 4 with one representing the oldest technology (i.e., Spectra) and four the most recent (i.e., Freedom). A complete description of methods are contained in this volume (Davidson et al., submitted).

RESULTS

Table 1 summarizes the means and standard deviations of reading, written expression and phonological processing scores obtained from the CI-HS students and a normally hearing reference group. Scores of the reference group were derived either from the normative sample of typically-developing high school students (NS-TDS) published in the test manual or from the 46 hearing control high school students (NHC-HS) tested as part of this study. The percentage of CI-HS students scoring within normal limits (i.e., at or above one standard deviation of the mean for the specified reference group) is also provided. The following results section is presented according to the three goals of the study outlined in the introduction.

Literacy and related skills of CI-HS students Reading

Reading—Scores of CI-HS students on the PIAT-R were compared to the NS-TDS. The average standard score for the CI-HS students was 83, which falls just below the cutoff representing the lower end of the average range for hearing age-mates. Almost half of the CI-HS students (47%) scored within or above one standard deviation of the mean for hearing high school students in comparable grades. Somewhat lower scores were obtained on the recognition subtest than on the comprehension subtest. Performance on the recognition subtest requires more facility with phonological processing and speech production than the comprehension subtest, which places greater demands on vocabulary and language skills (although see Keenan, Betjemann, & Olson, 2008, which argues that the comprehension subtest of the PIAT mainly assesses decoding skills, particularly in young readers).

Scores of CI-HS students on the TORC were compared to the NS-TDS. The average total score on the TORC was higher ($SS = 90$) than for the PIAT-R and within 1 SD of hearing age-mates (Mean = 100; SD = 15). Over half of the sample (66%) scored within the expected range (≥ 85) based on hearing norms. The relatively high scores were due

primarily to strong performance on the Sentence Sequencing and Vocabulary subtests. Paragraph Comprehension was particularly difficult for this group.

Written Expression

Spelling: Percent correct scores on the PST were compared to the NHC-HS sample. On average, the CI-HS participants were significantly poorer spellers than the hearing control group, spelling 67% of items correctly compared to 80% (Mann-Whitney $U = 3480$, $z = 3.46$, $p = .001$). However, more than half of the CI-HS students (55%) spelled within one standard deviation of the NHC-HS group. The remaining 45% of CI-HS spellers scored two or more standard deviations below their hearing peers. This is in sharp contrast to the NHC-HS group, in which only 15% scored in that low range. Spelling accuracy did not differ significantly between the CI-HS students who used speech (68% accurate) or those students who used sign and speech (65% accurate).

Expository writing: Ratings on the NTID Essay were compared to the NHC-HS sample. Fewer than half of the CI-HS students scored within 1 SD of the hearing control group in each of the four rating categories. Mean ratings were highest for Language Use (14.8) and lowest for Organization (12.1) out of 25 possible points. When compared to the NHC-HS group, 44% of the CI-HS students scored within 1 SD of the mean on Content ratings, their highest-performing area.

Phonological processing

Word Attack: Scores of CI-HS students on The WRMT-WA subtest were compared to the NS-TDS. This measure of reading decoding skill was difficult for the CI-HS students, whose average quotient score (70) was 2 SD below the mean for the NS-TDS. Only 30% of the CI-HS sample scored within the average range. The WRMT-WA also was administered to these adolescents at the CI-E test session where performance was substantially higher than their CI-HS scores in relation to hearing norms (mean = 88.7; SD 15.5). At CI-E, 53% of the students scored within the average range. Thus, the development of decoding skills failed to keep pace with hearing peers between elementary and high school grades.

Spelling Errors: Another measure of phonological processing—the percent of phonologically plausible spelling errors—was compared to the NHC-HS sample. More than half of the spelling errors made by the CI-HS students were phonologically plausible (62%). However, the NHC-HS students made proportionally more plausible errors than the CI-HS group (89%), and this difference was significant (Mann-Whitney $U = 4230$, $z = 6.473$, $p < .001$). The NHC-HS students' primary strategy when encountering difficult words was to use a phonological approach to spelling, compared to the CI-HS students who did not use phonological knowledge in spelling to as great a degree. Interestingly, the CI-HS students who were primarily oral communicators made proportionately more plausible errors than those students who used sign and speech (66% vs. 51%) and this difference was significant (Mann-Whitney $U = 786$, $z = -2.71$, $p = .007$).

Elision: Elision scores of the CI-HS students were compared to the NS-TDS on the C-TOPP. The mean scaled score on the Elision task (6.9) was just below 1 SD of the mean for the NS-TDS. Almost half of CI-HS students (46%) scored within the expected range (7 to 13), indicating facility with manipulating the sounds of language.

Nonword repetition (CNRep): Percent phonemes correct scores of the CI-HS students were compared to those obtained from the NHC-HS sample. The CI-HS students had the most difficulty with this task and none accurately imitated phonemes within 1 SD of the

NHC-HS group. Average percent of correct phonemes for the CI-HS group was only about half (42%) of that observed for NHC-HS group (96%).

Development of reading skills in CI students

Because the PIAT-R also was administered at the CI-E test session (Geers, 2003), we examined change in reading skills over time. The average standard score at CI-E was 89, within the low-average range for hearing peers; 61% of the CI-E students scored within or above the average range. We expected that the mean standard score might decrease over time because deaf students experience a gap in reading achievement that increases as they get older (Kroese et al., 1986). The average standard score of the CI-HS students was indeed slightly lower at 83. As a group, CI students did not quite keep pace with normal development of reading skills. However, most of the sample maintained their standing relative to hearing norms over time: 40% of the students ($N = 45$) scored within 1 SD of the normative average at both sessions while 32% ($N = 36$) scored more than 1 SD below hearing age mates at both test sessions. The remaining 28% of students' standing relative to the hearing norms changed over time. The majority of these ($N = 23$) scored within the average range in elementary grades, but fell below-average in high school. The remaining 8 students showed delayed reading in elementary grades but caught up by high school.

Reading improvement between elementary grades and high school is perhaps better reflected in grade equivalent scores, which are plotted by age at test in Figure 1. At CI-E, most students scored between second and fourth grades. CI-HS scores ranged from second grade to post high school. In Figure 1, these outcomes are grouped according to three categories of performers identified among children with hearing impairment (Nevins & Chute, 2009).

Challenged Performers—These students are characterized by slow and laborious academic progress. This category is exemplified in the current study by the 17% of CI-HS students who scored below the 4th grade reading level, indicating barely-developed reading comprehension.

Capable Performers—Although these students do not catch up to their typically developing peers linguistically or academically, capable performers demonstrate academic progress. This category is exemplified by 46% of the CI-HS students who scored between 4th and 8th grade levels, reflecting moderate and consistent reading growth, but with some delay.

Commensurate Performers—These students perform within the range of typically developing peers. In our sample, 36% of the CI-HS group scored at 9th grade or higher and appeared to have successfully overcome the reading deficits expected from profound deafness.

Forming Composite Variables using Principal Components Analysis

Test scores that are highly related to one another may be combined, using principal components analysis (PCA) to form composite factor scores that are more robust and representative of the underlying construct than any single component measure (Strube, 2003; submitted). Correlation matrices summarizing relations among literacy and among phonological processing measures are presented in Table 2 to demonstrate how these measures could be combined to form composite factors. Both sets of measures were significantly correlated, and PCA determined that the reading/written expression measures could be combined into a Literacy factor score and the phonological processing measures into a Phonological Processing factor score. The principal component loadings for literacy and phonological processing measures are listed in Table 3. For the literacy measures, an

eigenvalue of 3.195 indicated that 80% of the original score variance was accounted for by the combined factor score. For the phonological processing measures, an eigenvalue of 2.596 was obtained, indicating that a linear combination of individual measures into a single score accounted for 65% of the original score variance.

Factors contributing to literacy skills in CI students

Multiple linear regression analysis was used to predict the amount of variance in the literacy factor score accounted for by the phonological processing factor score after removing variance associated with child, family and implant characteristics. Results are shown in Table 4. The analysis was conducted in four steps so that groups of variables were considered and then controlled in subsequent stages in the analysis. First, the child characteristics of gender, duration of deafness, and age at first hearing aid fitting were entered in the regression and accounted for 8.6% of the variance in literacy outcome. Duration of deafness was the only significant predictor from this group of variables, and the influence was negative. This means that a shorter duration between the onset of profound deafness (birth in most cases) and CI surgery was associated with a higher level of literacy. This result suggests that there are long-term literacy benefits of early cochlear implantation.

Next, a number of child, family, and implant characteristics were entered in Step 2 of the analysis: Age at test, PIQ, sign enhancement (OC-SC difference score on the PPVT), family size, family SES, aided CI threshold and device technology rating. Together, these variables accounted for 19.8% of additional variance in high school literacy outcomes of CI participants. Significant predictors in this group of variables included gender (girls did better than boys), PIQ and the *sign enhancement metric* that describes how much benefit a student receives by the addition of sign language to spoken language during the PPVT receptive vocabulary assessments. Students with higher PIQ scores and those whose receptive vocabulary was not enhanced by addition of sign language obtained the highest literacy levels in high school.

The third step in the analysis examined the degree of importance of phonological processing skills to literacy outcomes in CI-HS students. Phonological processing accounted for 38.3% of added variance in literacy level. Thus, not only were phonological processing skills highly related to one another (i.e., the ability to imitate nonwords from an auditory model, to pronounce nonwords presented in print, to manipulate the phonological structure of oral language by deleting sounds and syllables, and to create phonologically plausible misspellings of words) but they also played a major role in successful reading and written expression. Furthermore, the contribution of phonological processing skills to literacy was independent of the influence of performance intelligence.

In a final step, we examined the amount of residual variance in literacy that was accounted for by reading scores obtained at the CI-E test session. This step accounted for an additional 10% of variance in high school literacy level. This result indicates that those with the highest literacy levels at CI-HS were those with the best reading skills at CI-E. The predictor variables examined accounted for 76.7% of the variance in CI-HS literacy. The continued significance of PIQ in step 4 indicates that those with higher PIQs made even greater reading gains than would be anticipated from their CI-E reading levels alone.

DISCUSSION

The goals of the current study were threefold: document the literacy skills of early-implanted deaf adolescents, determine whether students who demonstrated age-appropriate reading skills in elementary school were able to keep up with their hearing peers in high school, and determine the degree to which phonological processing skills and demographic

characteristics play a role in literacy achievement among deaf high school students with cochlear implants. To our knowledge, no other study in the literature has addressed reading and writing skills in this particular population using such a broad array of measures. Using a wide battery of literacy and phonological processing measures, we documented the achievements of CI-HS students who had received CIs as preschoolers and used their implants for many years. Many CI-HS students had strong literacy skills commensurate with hearing peers. Between 47% and 66% of the CI-HS students scored within or above the average range for hearing age-mates on two tests of reading (the PIAT-R and TORC, respectfully). Thirty-six percent of the students read at 9th grade level or above on the PIAT-R, compared to only 17% reading below the 4th grade barrier that characterized deaf students' performance before the advent of the CI. Written expression, however, posed greater difficulty for CI-HS students. CI-HS students were poorer spellers on average than hearing peers. They also were rated as having poorer expository writing skills on average than hearing peers. Despite increased access to spoken language via the CI, CI-HS students struggled with phonological processing tasks as compared to hearing peers. On measures of word attack, plausibility of spelling errors, elision, and nonword repetition, the CI-HS students performed below the levels achieved by their hearing peers. Learning to read is a task typically mastered in the early years of elementary school; children then must "read to learn" in mid- to later-elementary grades. It is this transition that seems to pose great difficulty to children who are deaf. However their relatively better performance on literacy measures than on phonological processing tasks suggests that other strategies (e.g. visual processing) may provide an alternate route to successful reading acquisition. In other words, phonological processing is only one contributor to literacy competence.

Because this population of children had been assessed for reading abilities at ages 8-9 years (Geers, 2003), we were able to document reading development in children with cochlear implants from elementary through high school. We found many CI-HS students who were good readers at ages 8-9 years were good readers in high school. In fact, 36% of the CI-HS students scored at 9th grade levels or higher. The majority of the CI-HS students showed reading growth over time, even if some CI-HS students were delayed compared to hearing peers.

The third goal of the study was to investigate how well certain factors predicted literacy success. We were primarily interested in the contributions of phonological processing measures and child/family characteristics to overall skills in reading, spelling, and written expression. Using step-wise regression, important contributors to literacy success included duration of deafness (shorter was better, indicating early implantation), PIQ, sign enhancement (students with strong OC skills did better) and phonological processing skills. After controlling for these variables, early reading skills at CI-E accounted for an additional 10% of remaining variance in literacy skills in high school.

It is not entirely surprising that phonological processing skills accounted for 38% of variance in literacy abilities for students with CIs, or that early reading success was important for later reading success. What is striking are the numbers of students (72% of sample) who retained their reading standing compared to hearing peers over a relatively long academic period of time. That is, 72% of the sample made age-appropriate growth over time. For these students, the gap that often exists between deaf and hearing peers in reading did not widen with time. The current CI-HS sample may not represent the entire population of children receiving CIs in the United States and Canada in the early 1990s and the 112 CI-HS students recruited from the original sample of 181 CI-E students may be advantaged in some respects (Geers, Brenner, & Tobey, submitted).

Academic success relies heavily on reading and writing skills; skills reported as seriously deficient in deaf students. With early cochlear implantation, deaf children have the opportunity to strengthen phonological awareness skills influencing reading and spelling development. The current study documented a broad array of reading, writing, and phonological processing skills in a relatively large group of adolescents with CIs. Although these students received their implants at relatively young ages (preschool), current practices in combination with universal newborn hearing screening dictate that many children receive implants at 12 months (and younger), or receive a second CI either concurrently or shortly after the first one. Thus, future studies must document the effects of cochlear implantation on academic skills, particularly in populations of children who receive their implants at 12 months or younger, and those children who use bilateral cochlear implants from very young ages.

Appendix

Stimuli for Picture Spelling Task

Cucumber, embarrassed, thumb, leopard, cafeteria, iron, scissors, refrigerator, ambulance, squirrel, mirror, camouflage, biscuit, giraffe, potato, diamond, astronaut, beard, chimney, cigarette, mosquito, chocolate, dinosaur, license, magician, oven, whale, cookie, hockey, cauliflower, thermometer, eighth, broccoli, ballerina, shoulder, bracelet, sandwich, convertible, soup, alligator, piano, caterpillar, statue, restaurant, camera, mountain, mustache, faucet, building, trampoline, spaghetti, vanilla, pyramid, soccer, razor, castle, purple, scuba, orchestra, lizard, tornado, neighbor, ceiling, tractor, umbrella, garage, island, twelfth, watermelon, tongue, licorice, calendar, curtain, turtle, mustard, breakfast, vacuum, calculator, antenna, lightning, muscle, submarine, forty, balloon, scarf, motorcycle, kangaroo, sword, referee, orange, satellite, telescope, guitar, stadium, ghost, secretary, asparagus, reindeer, witch, fountain

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References

- Albertini J, Bochner J, Dowaliby F, Henderson J. Valid assessment of writing and access to academic discourse. *Journal of Deaf Studies and Deaf Education* 1996;2:71–77. [PubMed: 15579837]
- Antia SD, Reed S, Kreimeyer KH. Written language of deaf and hard-of-hearing students in public schools. *Journal of Deaf Studies and Deaf Education* 2005;10:244–255. [PubMed: 15901658]
- Blamey PJ, Sarant JZ, Paatsch LE, Barry JG, Bow CP, Wales RJ, et al. Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. *Journal of Speech, Language, and Hearing Research* 2001;44:264–285.
- Boothroyd A, Geers A, Moog J. Practical implications of cochlear implants in children. *Ear and Hearing* 1991;12:81–89.
- Brown, VL.; Hammill, DD.; Wiederholt, JL. *Test of Reading Comprehension*. 3. Austin, TX: Pro-Ed; 1995.
- Burden V, Campbell R. The development of word-coding skills in the born deaf. *British Journal of Developmental Psychology* 1994;12:331–349.

- Carnegie Mellon University. Carnegie Mellon pronouncing dictionary [data file]. 1998. Retrieved 2007, from <ftp://ftp.cs.cmu.edu/project/speech/dict/cmudict.0.6>
- Connor CM, Craig HK, Raudenbush SW, Heavner K, Zwolan T. The age at which young deaf children receive cochlear implants and their vocabulary and speech production growth: Is there an added value for early implantation? *Ear and Hearing* 2006;27:628–644. [PubMed: 17086075]
- Connor CM, Zwolan T. Examining multiple sources of influence on the reading comprehension skills of children who use cochlear implants. *Journal of Speech and Hearing Research* 2004;43:1185–1204.
- Connor CM, Hieber S, Arts HA, Zwolan TA. Speech, vocabulary, and the education of children using cochlear implants: oral or total communication? *Journal of Speech, Language and Hearing Research* 2000;43:1185–1204.
- Davidson L, Geers A, Blamey P, Tobey E. Factors contributing to speech perception scores in long-term pediatric CI users. *Ear and Hearing*. submitted.
- Dawson PW, Blamey PJ, Dettman SJ, Barker EJ, Clark GM. A clinical report on receptive vocabulary skills in cochlear implant users. *Ear and Hearing* 1995;16:287–294. [PubMed: 7672477]
- DeVilliers, PA. English literacy development in deaf children: directions for research and intervention. In: Miller, J., editor. *Research on Child Language Disorders: A Decade of Progress*. Austin, TX: Pro-Ed; 1991.
- Dillon C, Burkholder R, Cleary M, Pisoni D. Nonword Repetition by Children with Cochlear Implants: Accuracy Ratings from Normal-Hearing Listeners. *Journal of Speech, Language, and Hearing Research* 2004;47:1103–1116.
- Dunn, L.; Dunn, L. *Peabody Picture Vocabulary Test-Revised*. Circle Pines, MN: American Guidance; 1981.
- Dunn, L.; Markwardt, FC. *Peabody Individual Achievement Test-Revised*. Circle Pines, MN: American Guidance; 1989.
- Ellefson MR, Treiman R, Kessler B. Learning to label letters by sounds or names: A comparison of England and the United States. *Journal of Experimental Child Psychology* 2009;102:323–341. [PubMed: 18675428]
- Figueredo L, Varnhagen CK. Didn't you run the spell checker? Effects of type of spelling error and use of a spell checker on perceptions of the author. *Reading Psychology* 2005;26:441–458.
- Gathercole, SE.; Baddeley, A. *The Children's Test of Non-Word Repetition*. London: Psychological Corporation Europe; 1996.
- Geers A. Factors affecting the development of speech, language and literacy in children with early cochlear implantation. *Language, Speech and Hearing Services in Schools* 2002;33:172–183.
- Geers A. Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing* 2003;24:59S–68S. [PubMed: 12612481]
- Geers A, Brenner C, Tobey E. Long-term outcomes of cochlear implantation in early childhood: Sample characteristics and data collection methods. *Ear and Hearing*. submitted.
- Geers A, Moog JS. Factors predictive of the development of literacy in hearing-impaired adolescents. *Volta Review* 1989;91:69–86.
- Geers AE, Nicholas JG, Sedey AL. Language skills of children with early cochlear implantation. *Ear and Hearing* 2003;24:46–58.
- Geers A, Sedey A. Language and verbal reasoning skills in sdolescents with 10 or more years of cochlear implant experience. *Ear and Hearing*. submitted.
- Harris M, Moreno C. Deaf children's use of phonological coding: Evidence from reading, spelling and working memory. *Journal of Deaf Studies and Deaf Education* 2004;4:111–123.
- Harris M, Terlektsi E. Reading and spelling abilities of deaf adolescents with cochlear implants and hearing aids. *Journal of Deaf Studies and Deaf Education*. 2010 10.1093/deafed/enq031
- Hayes H, Geers AE, Treiman R, Moog JS. Receptive vocabulary development in deaf children with cochlear implants: Achievement in an intensive auditory-oral educational setting. *Ear and Hearing* 2009;30:128–135. [PubMed: 19125035]
- Hirsh-Pasek, K.; Golinkoff, RM. *The origins of grammar: Evidence from comprehension*. Cambridge, MA: MIT Press; 1996.

- Ingram, D. First language acquisition: Method, description, explanation. Cambridge: Cambridge University Press; 1989.
- International Phonetic Association. Handbook of the International Phonetic Association: A guide to the use of the International Phonetic Alphabet. Cambridge, England: Cambridge University Press; 1999.
- James D, Rajput K, Brown T, Sirimanna T, Brinton J, Goswami U. Phonological awareness in deaf children who use cochlear implants. *Journal of Speech, Language and Hearing Research* 2005;48:1511–1528.
- Johnson C, Goswami U. Phonological awareness, vocabulary, and reading in deaf children with cochlear implants. *Journal of Speech, Language, and Hearing Research* 2010;53:237–261.
- Keenan JM, Betjemann RS, Olson RK. Reading comprehension tests vary in the skills they assess: Differential dependence on decoding and oral comprehension. *Scientific Studies of Reading* 2008;12(3):281–300.
- Kreiner DS, Schnakenberg SD, Green AG, Costello MJ, McClint AF. Effects of spelling errors on the perception of writers. *Journal of General Psychology* 2002;129:5–17. [PubMed: 12038495]
- Kroese J, Lotz W, Puffer C, Osberger MJ. Language and learning skills of hearing-impaired students: Academic skills. *ASHA Monograph* 1986:66–76.
- Kutner, N.; Greenberg, E.; Jin, Y.; Boyle, B.; Hsu, J.; Dunleavy, E. Literacy in everyday life: Results from the 2003 National Assessment of Adult Literacy (NCES 2007-480). Washington, DC: U.S. Department of Education National Center for Educational Statistics; 2007.
- Marschark, M.; Harris, M. Success and failure in learning to read: The special case (?) for deaf children. In: Cornoldi, C.; Oakhill, J., editors. *Reading comprehension difficulties: Processes and intervention*. Mahwah, NJ: Erlbaum; 1996. p. 279-300.
- Marschark M, Mouradian V, Halas M. Discourse rules in the language productions of deaf and hearing children. *Journal of Experimental Child Psychology* 1994;57:89–107. [PubMed: 8126397]
- Marschark M, Rhoten C, Fabich M. Effects of cochlear implants on children's reading and academic achievement. *Journal of Deaf Studies and Deaf Education* 2007;12:269–282. [PubMed: 17526867]
- Moog J. Changing expectations for children with cochlear implants. *Annals of Otology, Rhinology & Laryngology* 2002;111:138–142.
- Moog J, Gustus C, Geers A, Brenner C. Psychosocial adjustment in adolescents who use cochlear implants since preschool. *Ear and Hearing*. submitted.
- Moore, DF.; Sweet, C. Factors predictive of school achievement. In: Moore, DF.; Meadow-Orlans, KP., editors. *Educational and Developmental Aspects of Deafness*. Washington DC: Gallaudet University Press; 1990. p. 154-201.
- Nevins, M.; Chute, P. Educational considerations: From listening to literacy. In: Eisenberg, L., editor. *Clinical Management of Children with Cochlear Implants*. San Diego: Plural Publishing; 2009. p. 459-512.
- Paul, PV. *Language and Deafness*. San Diego: Singular; 2001.
- Perfetti CA, Sandak R. Reading optimally builds on spoken language: implications for deaf readers. *Journal of Deaf Studies and Deaf Education* 2000;5:32–50. [PubMed: 15454516]
- Pisoni, D.; Kronenberger, W.; Conway, CM.; Horn, DL.; Karpicke, J.; Henning, S. Efficacy and effectiveness of cochlear implants in deaf children. In: Marschark, M.; Hauser, P., editors. *Deaf Cognition: Foundations and Outcomes*. New York: Oxford University Press; 2008. p. 52-101.
- Pisoni DB, Kronenberger W, Roman A, Geers A. Measures in digit span and verbal rehearsal speed in deaf children following more than 10 years of cochlear implant use. *Ear and Hearing*. submitted.
- Rayner K, Foorman BR, Perfetti CA, Pesetsky D, Seidenberg MS. How psychological science informs the teaching of reading. *Psychological Science in the Public Interest* 2001;2:31–74.
- Scarborough, H. Connecting early language and literacy to later reading (dis)abilities: Evidence, theory and practice. In: Neuman, S.; Dickenson, D., editors. *Handbook of Early Literacy Research*. Vol. 1. New York: The Guilford Press; 2001. p. 97-110.
- Schley S, Albertini J. Assessing the writing of deaf college students: Reevaluating a direct assessment of writing. *Journal of Deaf Studies and Deaf Education* 2005;10:96–104. [PubMed: 15585751]

- Schopmeyer, B. Reading and Deafness. In: Niparko, J., editor. Cochlear Implants: Principles and Practices. 2. Baltimore: Lippincott, Williams, & Wilkins; 2009. p. 263-266.
- Serry T, Blamey P, Grogan M. Phoneme acquisition in the first 4 years of implant use. *Otology & Neurotology* 1997;18:S122–S124.
- Serry TA, Blamey PJ. A 4-year investigation into phonetic inventory development in young cochlear implant users. *Journal of Speech, Language, and Hearing Research* 1999;42:141–154.
- Shrout PE, Fleiss JI. Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin* 1997;86:420–428. [PubMed: 18839484]
- Spencer L, Oleson JJ. Early Listening and speaking skills predict later reading proficiency in pediatric cochlear implant users. *Ear and Hearing* 2008;29:270–280. [PubMed: 18595191]
- Spencer L, Tomblin B. Evaluating phonological processing skills in children with prelingual deafness who use cochlear implants. *Journal of Deaf Studies and Deaf Education* 2008;14:1–20. [PubMed: 18424771]
- Stanovich KE. Toward an interactive-compensatory model of individual differences in the development of reading fluency. *Reading Research Quarterly* 1980;1:32–71.
- Sterne A, Goswami U. Phonological awareness of syllables, rhymes and phonemes in deaf children. *Journal of Child Psychology and Psychiatry* 2000;41:609–625. [PubMed: 10946753]
- Sutcliffe A, Dowker A, Campbell R. Deaf children's spelling: Does it show sensitivity to phonology. *Journal of Deaf Studies and Deaf Education* 1999;4:111–123. [PubMed: 15579881]
- Tobey E, Geers A, Sundarajan M, Lane J. Factors Influencing Elementary and High-School Aged Cochlear Implant Users. *Ear and Hearing*. submitted.
- Tobey EA, Geers AE, Brenner C, Altuna D, Gabbert G. Factors associated with development of speech production skills in children implanted by age five. *Ear and Hearing* 2003;24:36S–45S. [PubMed: 12612479]
- Traxler CB. Measuring up to performance standards in reading and mathematics: Achievement of selected deaf and hard-of-hearing students in the national norming of the 9th Edition Stanford Achievement Test. *Journal of Deaf Studies and Deaf Education* 2000;5:337–348. [PubMed: 15454499]
- Treiman R, Hirsh-Pasek K. Silent reading: insights from second-generation deaf readers. *Cognitive Psychology* 1983;15:39–65. [PubMed: 6831857]
- Wagner, R.; Torgesen, J.; Rashotte, C. *Comprehensive Test of Phonological Processing*. Austin, TX: Pro-Ed; 1999.
- Wechsler, D. *Wechsler Intelligence Scale for Children*. 3. San Antonio, TX: Psychological Corporation Harcourt Brace; 1991.
- Woodcock, RW. *Woodcock Reading Mastery Test*. Allen, TX: Teaching Resources; 1987. Revised ed
- Yoshinaga-Itano C, Snyder L, Mayberry R. Examining written-language assessment and intervention links to literacy: Can lexical/semantic skills differentiate deaf or hard-of-hearing readers and nonreaders? *Volta Review* 1996;98:39–61.
- Zeno, SM.; Ivenez, SH.; Millard, RT.; Duvvari, R. *The educator's word frequency guide*. Brewster, NY: Touchstone Applied Science Associates; 1995.

Figure 1.

Grade equivalent scores on the Peabody Individual Achievement Test are plotted by age for 112 students at the CI-E (triangles) and CI-HS (diamonds) test sessions. Performance at each test session is indicated for three sample students from each of three achievement groups: Commensurate performers (solid line) exhibited reading progress within the range of typically developing peers. Capable performers (dot-and-dash line) demonstrated reading progress, but did not catch up to typically-developing peers. Challenged performers (dashed line) scored below the 4th grade reading level, at both test sessions, indicating barely-developed reading comprehension.

Mean Literacy Outcomes for Deaf Adolescents with Cochlear Implants as compared with Hearing Peers

Table 1

Groups						
	CI			Normal Hearing		
	Measures	Mean	SD	Percent WNL	Mean	SD
READING						
Peabody Individual Achievement Test (PIAT): Standard Score						
	TOTAL	83	17	47	100 ^a	15
	Reading Recognition	82	16.8		100 ^a	15
	Reading Comprehension	88.9	20.1		100 ^a	15
Test of Reading Comprehension (TORC): Standard Score						
	TOTAL	90	15	66	100 ^a	15
	Sentence Sequencing	9.2	3		10 ^a	3
	Syntactic Similarities	8.3	3		10 ^a	3
	Paragraph Comprehension	7.6	2.6		10 ^a	3
	General Vocabulary	9	2.5		10 ^a	3
WRITTEN EXPRESSION						
Picture Spelling Test (PST): Percent Correct Score						
	Spelling Accuracy	67	22	55	80 ^b	10
NTID Written Essay (Rating Points)						
	TOTAL (out of 100)	53.5	16.8	38	69.2 ^b	9.6
	Organization (out of 25)	12.1	4.2	36	16.1 ^b	3.0
	Content (out of 25)	13.3	4.5	44	17.1 ^b	2.9
	Language Use (out of 25)	14.8	4.7	39	18.3 ^b	2.1
	Vocabulary (out of 25)	14	4.8	38	17.7 ^b	2.3
PHONOLOGICAL PROCESSING						
Woodcock Reading Mastery Test: Quotient Score						

	Groups			
	CI		Normal Hearing	
Measures	Mean	SD	Percent WNL	Mean SD
Word Attack (WRMT-WA)	70	27.8	30	100 ^a 15
Comprehensive Test of Phonological Processing (C-TOPP): Standard Score				
Elision	6.9	3.1	46	10 ^a 3
Picture Spelling Test (PST): Percent of Spelling Errors				
Phonological Plausibility	62	25.9	30	89 ^b 8
Children's Test of Non-Word Repetition (CHNWR): Percent Correct				
% Phonemes Correct	41.7	18.3	0	95.8 ^b 3.0

Note. WNL = percent of CI sample scoring within one standard deviation of the mean or better.

^aNormative sample of typically-developing hearing age-mates.

^bHearing control group of high school students (N = 46).

Table 2

Intercorrelation matrices for literacy and phonological processing measures

	Literacy Measures		
	PIAT	TORC	NTID-WL
Picture Spelling Test (PST)	.702	.669	.680
Peabody Individual Achievement Test (PIAT)	1	.794	.780
Test of Reading Comprehension (TORC)		1	.771
Written Language (NTID-WL)			1
Note. All coefficients significant at $p < .001$.			

	Phonological Processing Measures		
	ChNWR	PST-PL	WRMT-WA
Children's Test of Phonological Processing: Elision (C-TOPP-E)	.316	.505	.663
Children's Nonword Repetition (ChNWR)	1	.504	.490
Picture Spelling Test: Plausibility Score (PST-PL)		1	.677
Woodcock Reading Mastery Test: Word Attack (WRMT-WA)			1
Note. All coefficients significant at $p < .01$.			

Table 3**Principal Components Loadings for Literacy and Phonological Awareness Factors**

Literacy Factor	Loadings
Peabody Individual Achievement Test (PIAT)	.919
Written Language (NTID-WL)	.906
Test of Reading Comprehension (TORC)	.904
Picture Spelling Test (PST): Percent Correct	.846
Note. Total variance explained = 80%	

Phonological Processing Factor	Loadings
Woodcock Reading Mastery Test: Word Attack (WRMT-WA)	.894
Picture Spelling Test: Plausibility Score (PST-PL)	.844
Children's Test of Phonological Processing: Elision (C-TOPP-E)	.776
Children's Nonword Repetition (ChNWR)	.695
Note. Total variance explained = 65%	

Table 4

Hierarchical Multiple Regression Predicting CI-HS Literacy

Predictor	Step 1			Step 2			Step 3			Step 4		
	β	t	p	β	t	p	β	t	p	β	t	p
Gender	0.157	1.701	0.089	0.207	2.317	0.020	0.076	1.214	0.225	0.074	1.400	0.162
Age 1 st HA	-0.142	1.511	0.131	-0.024	2.256	0.798	0.031	0.486	0.627	0.034	0.643	0.520
Duration of Deafness	-0.244	2.590	0.010	-0.179	1.889	0.058	-0.040	0.615	0.538	-0.023	0.406	0.685
Age				0.080	0.876	0.381	0.092	1.468	0.142	0.079	1.489	0.137
PIQ				0.250	2.744	0.006	0.150	2.389	0.017	0.152	2.850	0.004
Sign Enhancement				-0.329	3.488	<0.001	-0.052	0.746	0.455	-0.043	0.740	0.460
Family Size				-0.40	0.426	0.670	-0.018	0.289	0.772	-0.033	0.619	0.536
Family SES				0.081	0.830	0.407	0.206	0.389	0.697	0.011	0.187	0.851
Aided Threshold		0.110	1.131	0.258	0.115	1.726	0.084	0.113	2.000	0.045		
Device		0.015	0.157	0.875	0.027	0.416	0.677	0.033	0.603	0.546		
Phonological Processing					0.733	10.753	<0.001	0.391	4.944	<0.001		
CI-E Reading Level								0.475	6.376	<0.001		
ΔR^2	0.086	0.198			0.383			0.100				
R ²	0.086	0.284			0.667			0.767				

Note. HA = hearing aids, PIQ = performance IQ as measured by WISC-III, SES = socioeconomic status, CI-E = early cochlear implant group measured at ages 8-9 years.