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Research Article

Development of Phonological, Lexical, and Syntactic Abilities in Children With Cochlear Implants Across the Elementary Grades

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Purpose: This study assessed phonological, lexical, and morphosyntactic abilities at 6th grade for a group of children previously tested at 2nd grade to address 4 questions: (a) Do children with cochlear implants (CIs) demonstrate deficits at 6th grade? (b) Are those deficits greater, the same, or lesser in magnitude than those observed at 2nd grade? (c) How do the measured skills relate to each other? and (d) How do treatment variables affect outcome measures?
Participants: Sixty-two 6th graders (29 with normal hearing, 33 with CIs) participated, all of whom had their language assessed at 2nd grade.
Method: Data are reported for 12 measures obtained at 6th grade, assessing phonological, lexical, and morphosyntactic abilities. Between-groups analyses were conducted on 6th-grade measures and the magnitude of observed effects compared with those observed at 2nd grade. Correlational analyses were performed among the measures at 6th grade. Cross-lagged analyses were performed on specific 2nd- and 6th-grade measures of phonological awareness, vocabulary, and literacy to assess factors promoting phonological and lexical development. Treatment effects of age of 1st CI, preimplant thresholds, and bimodal experience were evaluated.
Results: Deficits remained fairly consistent in type and magnitude across elementary school. The largest deficits were found for phonological skills and the least for morphosyntactic skills, with lexical skills intermediate. Phonological and morphosyntactic skills were largely independent of each other; lexical skills were moderately related to phonological skills but not morphosyntactic skills. Literacy acquisition strongly promoted both phonological and lexical development. Of the treatment variables, only bimodal experience affected outcomes and did so positively.
Conclusions: Congenital hearing loss puts children at continued risk of language deficits, especially for phonologically based skills. Two interventions that appear to ameliorate that risk are providing a period of bimodal stimulation and strong literacy instruction.

Three levels of linguistic structure permit the complexity and subsequent utility that are emblematic of human language. First, words are organized to form sentences, and the relational structures among those words are conveyed either with bound morphemes or with word order. This level of structure is termed *morphosyntax*. Word-internal structure consists of smaller constituents, such as syllables, vowel nuclei, and consonants. This level of structure is termed *phonological*. Recursion at both of these levels of structure permits the unique breadth and depth of communicative exchanges inherent to human language. Taken together, these two levels of linguistic structure have traditionally been described as representing the "duality of patterning" in human language (Hockett, 1960). Although typically thought to be dependent upon phonological units, lexical structure may be considered the third level of linguistic structure because it appears to function independently at certain periods across the life span, in certain groups of language users, and in certain communication contexts for all language users (e.g., Port, 2007). In these instances, listeners appear to recover word units, without more fine-grained phonological representations. For those of us interested in language acquisition and its related

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disorders, it is essential to understand how each of these levels of language structure emerges in the typical child, how that emergence is related across structural levels, and how developmental and sensory disorders can impact proficiency with each kind of language structure. The overarching goal of the current study was to examine these issues in two groups of sixth-grade children: those with normal hearing (NH) or with cochlear implants (CIs).

Several developmental disorders can affect a child's ability to learn language, but these different disorders have differential effects on the acquisition of each of these separate levels of linguistic structure. It is critical that as a profession, we develop an understanding of how distinct disorders influence each level of linguistic structuring, so our interventions can be precisely tailored to the needs of children with different disorders. Often, intervention methods are applied broadly across children with different profiles of language abilities. At least where children with hearing loss are concerned, application of treatment methods in this "one-size-fits-all" approach has been shown to be less than optimally effective. For example, Nittrouer and Burton (2002) found that 8- to 10-year-old children who had participated in preschool intervention designed explicitly for children with hearing loss were performing significantly better on a range of language tasks than children with hearing loss who had been in general special education preschool programs, serving children with a variety of disabilities. Although this result suggests that interventions should be tailored to children based on their specific disorder, we continue to lack a complete understanding of what that means.

Disproportionately Large Phonological Deficits in Children With CIs

Where childhood hearing loss is concerned, there appears to be a disproportionately large effect on phonologically based language functions. This disparity of impairment across language structures can be difficult to identify, partly because many standardized tests used in clinical practice or research with this population more strongly assess lexical (vocabulary) and syntactic abilities than phonological awareness. Tools such as the Peabody Picture Vocabulary Test (L. Dunn & Dunn, 1997) and the Lexical Neighborhood Test (Kirk, Pisoni, & Osberger, 1995) are sensitive measures of a child's lexicon. Instruments such as the Preschool Language Scale (Zimmerman, Steiner, & Pond, 2002) and the Clinical Evaluation of Language Fundamentals (Semel, Wiig, & Secord, 2003) provide sensitive metrics of both lexical and syntactic abilities, and syntactic analyses of transcripts from children's narrative samples—such as those available through the Systematic Analysis of Language Transcripts or SALT (Miller & Iglesias, 2010)—allow descriptions of how well children use morphological and syntactic devices in their language productions. These are all important measures to have, both for diagnoses and designing individual treatment plans. However, without a strong measure of how sensitive a child is to word-internal phonological structure (especially phonemic structure), potential language and academic problems can either be overlooked or erroneously attributed to cognitive deficits, rather than to the processing problems that actually underlie them.

For the most part, children with CIs seem to be faring well when it comes to developing lexical and syntactic skills, with roughly two thirds of them falling within normal limits (i.e., better than 1 *SD* below the mean) by 10 years of age on standardized tests of abilities in these areas (Geers, Nicholas, Tobey, & Davidson, 2016). However, how are these children doing when it comes to acquiring sensitivity and skill in that other level of linguistic structure, namely, word-internal phonological structure? How efficiently are children with CIs able to recover phonological structure from the acoustic signal and use that structure appropriately? That question is equally as important to answer because age-appropriate sensitivity to phonological structure and facility with phonological processing are related to the acquisition of both verbal working memory and literacy (Brady, Shankweiler, & Mann, 1983; Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983; Katz, Shankweiler, & Liberman, 1981; Nittrouer & Miller, 1999; Snowling, 2000; Wagner & Torgesen, 1987). Consequently, poor awareness of phonological structure imposes serious challenges to academic success.

This question of how children with hearing loss are faring in the acquisition of phonological awareness relative to the acquisition of other language skills has been examined extensively in this laboratory by following a group of children with hearing loss and age-matched peers with NH. The original intention of this longitudinal project was to follow two groups of children with hearing loss through childhood: those with losses severe enough to warrant CIs and those with milder losses that could be adequately treated with hearing aids. Because criteria for cochlear implantation have been loosened over the years, however, many of the children with hearing aids received CIs at ages slightly older than is customary. Thus, this longitudinal project has a preponderance of participants with CIs, and outcomes for those children will be the focus of this report.

For much of this project, we have used instruments that assess children's sensitivity specifically to phonemic structure, rather than to other aspects of phonological structure, such as rhyme or syllables. The decision to focus on this level of phonological structure was made because rhyme and syllabic structure should be relatively accessible with only coarse acoustic representations, as are available through CIs. However, more refined signals should be needed to provide the kinds of acoustic details thought to underlie phonemic categorization, and in fact, that prediction has been borne out by findings from children in this longitudinal study, when they were tested at kindergarten (Nittrouer, Caldwell, Lowenstein, Tarr, & Holloman, 2012; Nittrouer, Sansom, Low, Rice, & Caldwell-Tarr, 2014). In separate tasks, these children were required to demonstrate awareness of either word-internal syllabic or phonemic structure. Children with CIs performed similarly to children with NH when it came to syllable awareness ($p = .077$)

but more poorly when it came to phonemic awareness ($p < .001$).

These results from kindergarten were the first to reveal the disproportionately large phonological deficit that appears to be a hallmark of language performance by children with CIs. In that work (Nittrouer et al., 2012, 2014), children were evaluated on their skills with all three levels of linguistic structure, using several measures:

(a) Syntax: This level of linguistic structure primarily has to do with the way words are combined to generate sentences, although skill in using morphological markers may also be involved. In this work, receptive syntax was assessed with the Auditory Comprehension subtest of the Preschool Language Scale–Fourth Edition (Zimmerman et al., 2002); productive syntax was assessed by collecting personal narratives, transcribing 100 utterances from those narratives, and submitting those transcripts to SALT (Miller & Iglesias, 2010).

(b) Lexical knowledge: This skill refers to how many words children have in their long-term lexicons and how well they can retrieve those words. It was assessed using the Expressive One-Word Picture Vocabulary Test (EOWPVT; Brownell, 2000).

(c) Phonological awareness or sensitivity: This skill has to do with how well a language user can extract well-defined phonological representations from the speech signal. In this work, the focus was on the phonemic level of analysis. Although the term *awareness* is most commonly employed, the term *sensitivity* has also been used to avoid the suggestion that listeners are always consciously aware of having accessed this level of linguistic structure. In this study, phonological awareness was assessed using two matching tasks: one for initial consonants and one for final consonants.

Those results collected as children were completing kindergarten showed that children with CIs performed just 1.0 *SD* below children with NH (−1.0 *SD*), on average, when it came to productive syntax, −1.5 *SD* on the measure of expressive vocabulary, but −1.74 and −2.33 *SD*s on the two measures of awareness to phonemic structure: initial consonants and final consonants, respectively. Although receptive syntax would have been expected to show similar effect sizes as productive syntax, results for this measure actually trended more similarly to those for vocabulary, with an effect size of roughly −1.5 *SD*, as well.

Equivalent results were observed when children in the longitudinal study were tested at second grade. In that report (Nittrouer & Caldwell-Tarr, 2016), a principal components analysis was initially performed on a variety of measures from these children so that two factor components were derived. The measures presumed to be phonological in nature loaded on one factor, and the productive syntax measures loaded on the other factor. This pattern seemed to fit nicely with the notion of duality of patterning. However, vocabulary scores and scores for the measure of receptive syntax loaded on the phonological factor, which did not seem completely compatible with that model. Nonetheless, mean scores for children with CIs were 1.86 *SD* below the mean of children with NH for the phonological latent measure and −0.87 *SD* for the morphosyntactic latent measure. In a second analysis, three factors were derived: a phonological factor and a morphosyntactic factor, as in the first analysis, but this time, vocabulary and receptive syntax formed a third factor (Nittrouer, 2016). That new factor was termed a *lexical factor* because vocabulary loaded most strongly on it. Now, results showed that the mean latent score for productive syntax for the children with CIs was −0.6 *SD*, compared with the children with NH; the lexical and phonological latent scores were −1.5 and −1.9 *SD*s, respectively. Thus, again, these children with CIs performed most poorly when it came to phonological awareness.

This disproportionately large phonological deficit observed for children with CIs during the early elementary grades is especially concerning because of evidence that it is one skill that is not improving as a result of early intervention and better hearing technologies. That conclusion was reached in a study from another laboratory (Harris, Terlektsi, & Kyle, 2017) in which kindergarten children with moderate to profound hearing loss were administered the same vocabulary and phonological awareness tasks as those administered a decade earlier to different children with similar degrees of hearing loss, at the same chronological age. This design allowed the examination of effects introduced by earlier intervention overall and more recent hearing technologies. Results showed that although mean vocabulary age had advanced by 2 years in the later born group, phonological awareness had not changed as a function of the earlier intervention or the improved hearing technologies which these children received.

Lexical Restructuring

Of course, these findings of disproportionately large phonological deficits in children with hearing loss—especially those with CIs—have only been observed during the early elementary grades: second grade or less. It is possible that the language and literacy instruction received in the later elementary grades could lead to disproportionately large *improvements* in phonological awareness for children with hearing loss, bringing these skills more closely into line with their lexical and syntactic abilities. There are two principled and related reasons for offering this possibility. First, most developmental psycholinguists support a model of lexical and phonological development termed *lexical restructuring*. According to this model, the first items entered into a child's lexicon are not phonologically structured. Rather, these early items are represented by broader linguistic structure, such as the syllable or word. At the acoustic level, these items are presumably coded by coarse structure, specifically broad patterns of relatively slow spectral change. For children with NH and typical language development, the hypothesis is that it is not until the preschool years that these early lexical structures start to be reorganized into phonologically coded items, presumably from the pressure of a burgeoning lexicon (Charles-Luce &

Luce, 1990; Metsala & Walley, 1998; Storkel 2002; Walley, 1993). Evidence for this suggestion is found in studies demonstrating that children younger than roughly 7 years of age are poor at recognizing word-internal phonemic structure. In the first demonstration of this finding, Liberman, Shankweiler, Fischer, and Carter (1974) asked preschool, kindergarten, and second-grade children with NH and typical language either to count the number of syllables in multisyllabic words or to count the number of phonemes in monosyllabic words. Kindergarten children were found to be poor at counting the number of phonemes, even though they were able to count the number of syllables. Thus, in spite of demonstrating adequate metacognitive abilities to count linguistic constituents, they were poor at the task when those constituents were phonemic units.

In another study (Walley, Smith, & Jusczyk, 1986), kindergarten and second-grade children—also with NH and typical language—were taught that each of two puppets had a special "word" that it said; these were really disyllabic nonwords (e.g., [nuli]). The children were then presented with other disyllabic nonwords that differed by one, two, or three segments from each of the puppets' special words (e.g., [nulɚ]; [nuʃɚ]; [nɚtæ]). The child's task was to report which puppet would be likely to say that word, thus evaluating similarity between the puppet's own special word and the novel one presented. Kindergarten children were found to be poor at matching these disyllables, until they shared three segments; children in second grade were significantly better at the task and were able to recognize that two disyllables shared something in common when it was only the initial consonant.

These two studies demonstrate that sensitivity to word-internal phonological structure improves over the early elementary grades, but this evidence does not specifically tie that improvement to vocabulary growth. However, a study by Hogan, Bowles, Catts, and Storkel (2011) was able to do just that. These investigators reported results from a group of children who were given a phonological awareness task involving 17 words at both second and fourth grades. These results showed that the children's phonological awareness was better for words from phonologically dense neighborhoods and words with high frequencies of occurrence. Both these trends support the conclusion that developmental enhancement of sensitivity to word-internal structure is promoted by the pressures of having many phonologically similar words or frequent exposure to a word.

Thus, the preponderance of evidence indicates that children's early lexical structures are best described as holistic. Over the early elementary grades, the ability of typically developing children with NH to recognize individual phonemes improves. It is reasonable to suggest that this developmental process might be delayed by a year or more for children with hearing loss who do not receive CIs until 1 year of age or older. For that reason, this study sought evidence of lexical restructuring in the vocabulary development and the acquisition of phonological awareness for children with CIs following second grade.

Literacy Acquisition

Another reason to propose that phonological awareness may improve during the elementary grades is that literacy instruction is provided. Certainly, it is well recognized that phonological awareness and literacy are strongly related, even for children with hearing loss who receive CIs. For example, Geers and Hayes (2011) found that phonological awareness accounted for 38% of the variance in reading ability for a group of high school students with CIs. However, few studies have asked specifically if literacy acquisition actually promotes the development of sensitivity to phonological structure—for children with NH or for those with CIs. One study that did address that question reported improvements in phonological awareness for a group of 4.5-year-old children with hearing loss who were provided with literacy instruction on a regular basis through the school year; a control group of other children with hearing loss who were not provided with literacy instruction failed to demonstrate similar improvements (Lederberg, Miller, Easterbrooks, & Connor, 2014). These improvements still left children in the treatment group close to −1.0 *SD*, compared with normative samples. Nonetheless, it suggests that targeted literacy instruction can be an effective tool for combating phonological deficits in children with hearing loss. The design of the study reported here allowed investigation into the question of whether literacy acquisition is associated with advances in phonological sensitivity.

There is reason, however, to propose that the phonological deficits exhibited by young children with CIs may persist or even worsen as they proceed through the elementary grades. Even with improvements in CI technologies, these devices can provide only degraded spectral representations to users. Accordingly, children with CIs would be relatively unimpaired in the acquisition of early lexical items because even typically developing children rely on broad spectral patterns for this development. However, as greater acoustic detail is required in order to discover word-internal structure, children with CIs should become increasingly delayed, as other children go about the task of lexical restructuring. To the extent that lexical items can continue to be acquired based on broad structure, children with CIs should continue to acquire vocabulary items. However, that development should lag behind that of their peers with NH, who are able to acquire new lexical items using a phonological code.

Current Study

This study is part of a continuing effort to evaluate how well children born with hearing loss are managing when it comes to language learning. Toward the end of the 20th century, significant advances were made in our abilities both to identify hearing loss shortly after birth—and so, to intervene early—and to provide useable auditory input to these children. It is easy to become complacent in a belief that these advances have made the acquisition of typical language readily achievable for children with hearing loss, especially given that casual interactions seem to support that belief. However, it is clear that we have not reached that goal of being able to facilitate perfectly typical language acquisition for the majority of children with hearing loss. Therefore, it is essential that we evaluate—for each kind of language functioning—how close these children are getting to that benchmark. We must also identify ways to better support acquisition for these children, so they may reach their optimal language learning potential.

The first specific goal of this study was to examine how proficiency with all three levels of language structure had changed for these children across the elementary grades. At second grade, the children with CIs showed deficits for all three kinds of language structure, with the largest deficit observed for phonological structure and the least deficit found for morphosyntactic structure. A first question asked in the current study was simply whether the children with CIs continued to demonstrate significant deficits at sixth grade.

A second goal of this study was to examine whether the magnitude of the deficits had lessened, stayed the same, or increased over the intervening years from second to sixth grade. Because the size of the deficit in morphosyntactic abilities had been small at second grade and this level of language structure was thought to be relatively accessible even with degraded acoustic signals, it was predicted that children with CIs would have been able to close the gap for this kind of language structure. The lexical restructuring hypothesis suggests that lexical and phonological development may have accelerated after second grade, with burgeoning lexicons driving the discovery of phonological structure and sensitivity to that structure feeding back to fuel rapid vocabulary expansion. The intensive literacy instruction provided in the early elementary grades might also bolster the development of lexical and phonological abilities. However, an alternative to either of those scenarios would be that the degraded acoustic signals available through CIs would continue to curtail the development of both lexical and phonological abilities. These conflicting accounts were explored.

A third issue examined in this study concerned how the various language measures obtained from these children are related to each other. Understanding those relationships could help shape intervention during the elementary school years, by indicating whether specific language skills should receive more or less attention: Skills that facilitate growth in other language functions might be emphasized more, whereas those skills that are not facilitative, or are in fact largely independent, might not receive quite as much emphasis. For example, if it were found—as the lexical restructuring hypothesis suggests—that a growing vocabulary spurs advances in phonological awareness, then intervention strategies might place a stronger emphasis on activities designed to strengthen vocabulary, rather than on phonological awareness tasks, under the assumption that those vocabulary activities would contribute to development in both language skills.

Finally, the potential contributions of various treatment variables to children's language development were examined. In particular, the age at which a child receives a first CI has frequently been found to influence language outcomes (Ching et al., 2013; Gallego, Martín-Aragoneses, López-Higes, & Pisón, 2016; Geers, Davidson, Uchanski, & Nicholas, 2013; Geers et al., 2016; Geers & Nicholas, 2013; Leigh, Dettman, Dowell, & Briggs, 2013; Tobey et al., 2013), although evidence to the contrary has also been found (C. C. Dunn et al., 2014; Holt & Svirsky, 2008; Lund, 2016). For the specific children in this longitudinal study, it has been observed that having had a period of time using a hearing aid on the ear contralateral to a first CI (i.e., bimodal stimulation) at the time of receiving a first CI provided beneficial effects to language development, with higher mean scores consistently obtained for children with histories of bimodal experience (Moberly, Lowenstein, & Nittrouer, 2016; Nittrouer & Chapman, 2009). This finding differs from some others that show benefits for children from bimodal stimulation (e.g., Ching, van Wanrooy, Hill, & Incerti, 2006) because, here, the advantage is accrued from the history of that stimulation alone, rather than from having the configuration at the time of testing. Thus, the effects of both age of receiving a first CI and history of bimodal experience were explored in this study, along with preimplant auditory thresholds.

Method

Participants

Data are reported here for 62 children: 29 with NH and 33 with severe-to-profound hearing loss who wore CIs. All children had just completed sixth grade at the time of testing, and all were participants in an ongoing longitudinal study (Nittrouer, 2010). Outcomes of testing completed at sixth grade were compared with outcomes obtained at second grade for these 62 children. There had been a total of 124 children tested as they were completing second grade. Given variability in date of birth, that testing was planned to cover a 4-year period. However, a lapse in funding as these children were completing sixth grade prohibited testing with the later born children in the cohort. Nonetheless, all children tested at second grade who were eligible to be retested at sixth grade returned for that testing. For both groups of children (NH and CI), 59% of the second-grade cohort participated at sixth grade.

The children in this study were enrolled as infants, so they met criteria for participation at that time. No child was enrolled who had any condition (other than hearing loss) that on its own would be expected to negatively affect language learning. All children with CIs were identified before 2 years of age, and all were presumed to have had hearing loss since birth. All children had parents with NH and came from homes where only English was spoken to them. The children with CIs started receiving intervention shortly after being identified with hearing loss. That intervention was provided by someone with a master's degree or higher in a discipline requiring specialized training in how to work with children with hearing loss to promote spoken language. Intervention was provided at least once a week up to the age of 3 years. From 3 years of age until the start of school, these children with CIs were in preschool programs especially designed for children with hearing loss, on average for 16 hr per week. Since starting elementary school, all children were fully mainstreamed in regular classrooms.

Forty-eight percent of children in each group were male. Table 1 shows mean and median scores for age at the time of testing, socioeconomic status, and IQs for all children and values for audiologic factors for children with CIs. The metric used to assess socioeconomic status was one that has been used before, in which occupational status and highest educational level are ranked on scales from 1 to 8, from lowest to highest, for each parent in the home. These scores are multiplied together, for each parent, and the highest value obtained is used as the socioeconomic metric for the family (Nittrouer & Burton, 2005). The scores obtained show that the average child in this study had at least one parent who had a 4-year university degree. Groups did not differ on mean age or socioeconomic status.

The Leiter International Performance Scale–Revised (Roid & Miller, 2002) was given to assess nonverbal intelligence. Four subtests were used that form what is termed the *brief IQ*. These subtests assess figure–ground perception, form completion, sequencing abilities, and repeated patterns. Scores on Table 1 show that performance across groups was similar.

Children with NH were administered hearing screenings with pure tones at octave frequencies between 250 Hz and 8 kHz, at 20-dB hearing level to each ear separately. All children with NH passed. Audiologic variables for children with CIs show that most of these children were identified early and implanted early. Twenty-eight of the children received a first CI before 36 months of age; those children all had preimplant, better ear pure-tone average (PTA) thresholds poorer than 85-dB hearing level. The five children who received a first CI later than 36 months of age had preimplant, better ear PTA thresholds better than 85-dB hearing level. Preliminary analyses showed that mean outcomes for these late-implanted children on all dependent measures were no different than mean outcomes of children who received their CIs before 36 months of age. Thus, it was considered appropriate to combine data for all children with CIs.

Fourteen children had at least 1 year of bimodal experience at the time of receiving that first CI. Ten of these children eventually received a second CI; four of them continued to wear a hearing aid on the unimplanted ear. Although all five of the children who received a first CI after the age of 36 months continued to wear a hearing aid on the unimplanted ear for at least a year after receiving a first CI, only three of those children were still wearing a hearing aid at the time of testing. The other two children had received a second CI. Overall, there were 25 children with bilateral CIs in this study, with a mean latency between first and second CI of 26 months. Fifteen of these 25 children had no bimodal experience, and 10 of them did. Because only four children had just one CI at the time of testing, it was considered inappropriate to compare outcomes for children with one or two CIs.

Twelve of the children with NH were taught baby signs as infants. Mean scores for those children on dependent measures examined in this study were no different than those of the 17 children with NH who were not taught baby signs. Ten of the children with CIs attended early intervention programs that supplemented spoken language with sign language, although none of those programs were sign only. Preliminary analyses showed that mean outcomes for these children on all dependent measures were no different from mean outcomes for the 23 children who attended auditory–oral early intervention programs. Thus, data were combined across groups, regardless of signing history. At the time of testing, no child relied on sign language for communication.

Table 1. Mean, median scores, and standard deviations for demographic and audiometric measures at sixth grade for children with normal hearing (NH) and children with cochlear implants (CIs).

	NH (29)			CI (33)		
Variable	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*
Age at time of testing (months)	147	147	4	150	149	5
Socioeconomic status (out of 64)	36	36	13	34	36	11
Leiter brief IQ standard score	105	102	15	102	100	15
Age at identification (months)				6.6	4.0	7.4
Age at first implant (months)				22	14	19
Age at second implant (months)				46	45	25
Preimplant better ear PTA (dB)				100	100	16
Aided two-ear PTA (dB)				26	25	9

Note. Socioeconomic status is a two-factor index based on the occupation and education of the primary income earner in the household. PTAs are given in decibel hearing level and are for the three speech frequencies of 500, 1000, and 2000 Hz. Twenty-five children had two CIs. PTA = pure-tone average.

Equipment and Materials

All testing was done in sound booths. For the three phonological awareness tasks, stimuli were presented in audiovisual format. Audio signals were presented through a computer with a Creative Labs Soundblaster soundcard using a 44.1-kHz sampling rate and 16-bit digitization, a Samson C-Que 8 mixer, and a Roland MA-12C-powered speaker. The speaker was placed 1 m in front of the child at 0° azimuth. Video signals were presented at 1500 kbps, with 24-bit digitization in the center of the monitor. Custom-written software controlled the presentation of the stimuli and recording of responses.

One measure of verbal working memory was administered. This task involved audio-only presentation of word sequences, through the same soundcard, mixer, and speaker as those used for the phonological awareness tasks.

Custom-written software controlled the presentation of the serial recall stimuli. Computer graphics (presented at 200 × 200 pixels) on a 21-in. touchscreen monitor were used to represent each word in picture form. Responses were collected by having the child touch the pictures in the order recalled.

Four standardized instruments were administered: the Word Reading subtest of the Wide Range Achievement Test 4 (Wilkinson & Robertson, 2006), the EOWPVT-4 (Martin & Brownell, 2011), and two subtests from the Comprehensive Assessment of Spoken Language (CASL; Carrow-Woolfolk, 1999). These were the Grammaticality Judgment and the Sentence Comprehension subtests. All practice and test items on these two instruments were audio- and video-recorded and used for presentation to ensure consistency of test materials across children. Audiovisual presentation was handled in the same way as for the phonological awareness tasks. For all four standardized instruments, the rules regarding when to discontinue testing were followed, but responses were audio- and video-recorded using a SONY HDR-XR550V video recorder. Children wore SONY FM transmitters, with the signal going to the video recorder, to ensure good sound quality. All scoring done at the time of testing was checked by an independent experimenter at a later time.

Four measures of productive syntactic capabilities were obtained from transcripts made of story narratives from the children. For these narratives, the children's book *The Day Jimmy's Boa Ate the Wash* (Noble, 1980) was presented as a video with accompanying audio. Again, the same recording parameters were used as those used for the phonological awareness tasks. One person served as the narrator, and two other people served as the two individuals in the story who were engaged in dialogue (mother and daughter). All narration and dialogue were presented in audio–video format so that children could see and hear the talkers. Pages from the book were interleaved with the clips of dialogue, providing sufficient time for children to study each picture.

Procedure

All procedures were approved by the Institutional Review Board at the University of Florida and The Ohio State University. All auditory stimuli were presented at 68-dB sound pressure level. Children came to the laboratory for 2 consecutive days. They were administered a number of tasks in individual test sessions lasting no more than 1 hr each and were given breaks between sessions of no less than 1 hr each. Outcomes for 12 measures are included in this report.

Phonological Awareness and Processing

Three measures of phonological awareness and processing were administered. All were developed in this laboratory and have been used previously (Moberly et al., 2016; Nittrouer & Lowenstein, 2013; Nittrouer, Lowenstein, Wucinich, & Moberly, 2016; Nittrouer, Shune, & Lowenstein, 2011). All three tasks consisted of 48 items, and testing in each was preceded by training. The words in each task were presented in audiovisual mode to ensure that all children could understand those words. All words were produced by a man with a midwest dialect who had no facial hair. Items in each task increased in difficulty across the task, and testing was discontinued after six consecutive wrong answers. Percent correct answers served as the dependent measures for all tasks.

The first task was the final consonant choice task, which consisted of only single-syllable words. In this task, the child first saw and heard a target word spoken by the talker. After the child correctly repeated the target, three words were presented, again in audio–video format. The child had to select the one that ended in the same sound as the target. The second task was pig Latin. Although some items in this task were two syllables, all were well within the vocabularies of sixth-grade children. In this task, a word was presented; again, the child was required to repeat it correctly. Then, the child provided the pig Latin version of that word, as best as possible. Unlike some schoolyard versions of this game, children were instructed to move only the first segment of any initial cluster to the end of the word, and this requirement was explained during the practice. The third phonological awareness task consisted of a backward words activity. Words again were one or two syllables in length. For this task, a target was presented. After the child correctly repeated it, the task was to reverse the order of segments, which resulted in a different real word.

Verbal Working Memory

This task has also been used extensively in this laboratory (e.g., Nittrouer & Miller, 1999). It consisted of the presentation of a closed set of six words in 10 different sequences. The words were *ball, coat, dog, ham, pack,* and *rake*. These stimuli were presented as audio-only files. These word files were obtained from a male talker with a midwest dialect. Pretest training introduced the words and associated pictures (shown on the computer monitor) to the children. All children demonstrated 100% reliability at matching the words heard to the pictures representing each word before testing started. During testing, the words were presented at a rate of one per second, in an order randomly determined by the software. After presentation of the six words, the associated pictures appeared at the top of the computer monitor. The child had to touch the pictures in the order recalled. After testing, the child was again asked to match each word to the associated picture. All children were again able to perform this goal with 100% reliability. The percentage of items (out of 60) recalled in the correct order was the measure obtained from this task.

Standardized Instruments

Four standardized instruments were administered to these children, and standardized scores were used in analyses. Training was presented, according to standard test procedures. During testing, all responses were scored by the experimenter, but testing was also audio- and video-recorded. Scores were subsequently checked by another experimenter. If it was thought that a score was in error, the laboratory manager would have been brought in to make a determination of the correct score. However, this situation never occurred during this testing.

The Word Reading subtest of the Wide Range Achievement Test consists of having the child read a list of words in isolation. In clinical settings, testing is discontinued after 10 consecutive errors. In this study, however, we allowed children to attempt to read all words.

The EOWPVT was given to assess children's vocabulary knowledge. This test consisted of showing the child a series of pictures one at a time on separate easels and having the child name the item or action in the picture. Testing was discontinued after six consecutive errors.

The Grammaticality Judgment subtest of the CASL was presented in audio–video format. The child saw and heard a talker present a sentence on the computer monitor and had to report if it was correct or not. If the child reported that it was not correct, the child had to say what would be a correct version of the sentence. One point was given for reporting if the sentence was correct or not. Another point was awarded if the child accurately reported the sentence as wrong and provided a correct version of the sentence. Testing was discontinued when the child failed to get full credit on five consecutive items.

The Sentence Comprehension subtest of the CASL was also presented in audio–video format. For this subtest, the child saw and heard two sentences and had to report whether they had the same meaning or not. Testing was discontinued after five consecutive errors.

Productive Morphosyntax

Measures of productive morphosyntax were obtained from the narrative samples. The recording of *The Day Jimmy's Boa Ate the Wash* was used to obtain these samples. This story is about a school field trip. When the child and experimenter entered the booth, the experimenter told the child that she had to leave to take a phone call. The child was told to watch the story and be prepared to tell the experimenter about it in detail when the experimenter returned. After the story was completed, the experimenter went back in the booth and collected 15 min of narrative sample based on (a) a retell of the story, (b) a narrative about a school field trip the child went on at some time in the past, and (c) a narrative about a family outing or vacation. These narratives were audio- and video-recorded in the same manner as the standardized tests. Later, they were transcribed by two student staff members independently. Their transcripts were compared, and any disagreements were resolved. Those transcripts were then submitted to analysis by SALT (Miller & Iglesias, 2016).

Four measures were used from the SALT output. All measures were computed on the first 100 complete utterances from the narrative sample. These four measures were mean length of utterance (MLU) in morphemes, number of conjunctions, number of bound morphemes, and number of pronouns. This group of measures provided a good representation of children's abilities with productive morphosyntax.

Results

Data for all 12 measures were screened for normal distributions and homogeneity of variances. All measures were found to be adequate in these regard for further analyses. An α level of .05 was used, although precise p values are reported for $p < .10$; for $p > .10$, outcomes are reported simply as *not significant*.

Sixth-Grade Outcomes

The first set of analyses examined scores across the 12 dependent measures at sixth grade. First, a principal components analysis was performed on these measures, with varimax rotation. Table 2 shows the outcome of that analysis. It shows that the three phonological awareness tasks loaded most highly on one component, termed the *phonological factor*. In addition, word reading, grammaticality judgments, and verbal working memory loaded most highly on that factor. A second component was formed by expressive vocabulary, bound morphemes, and sentence comprehension. That component was termed the *lexical factor* because expressive vocabulary loaded most strongly of the three. Finally, the number of pronouns, MLU, and number of conjunctions from the narrative transcripts formed a third component and was termed the *morphosyntactic factor*. Latent scores were derived for each child, based on the outcomes of that principal components analysis: one for each of the factors. Children with NH served as the standard, so mean scores for that group on all three latent factors were 0, and the *SD*s were 1.0. Mean scores for the children with CIs were −1.27 (SD = 1.52) for the phonological factor, −0.57 (SD = 1.04) for the lexical factor, and −0.24 (SD = 0.91) for the morphosyntactic factor. These latent scores can be compared with similar scores for these particular children obtained in second grade (Nittrouer, 2016). For this group of 33 children with CIs, mean latent scores from second grade were −1.69 (SD = 1.58) for the phonological factor, −0.98 (SD = 1.66) for the lexical factor, and −0.42 (SD = 0.82) for the morphosyntactic factor. Paired t tests revealed that only the phonological latent scores changed significantly, $t(32) = 2.14$, $p = .04$, although the change in lexical latent scores can be reported, $t(32) = 1.95$, $p = .06$.

Table 3 shows statistical outcomes for each of the 12 measures individually: means, standard deviations, t values, p values, and Cohen's *d*s. This table shows that, although children with CIs appeared to have been "catching up" to their peers with NH during these elementary grades when latent scores were considered, they remained behind in language development.

Cohen's *d*s are metrics of effect size and can be evaluated in the same way as scores for the latent measures: a Cohen's d of 1.0 indicates that the mean of a group—the children with CIs, in this case—is 1 SD below the mean of another group—children with NH, in this case. For reference, a Cohen's d of 0.5 indicates that the mean for children with CIs is at roughly the 30th percentile, relative to children

Table 2. Loadings of observed measures on three factors in principal components analysis.

Measure	Phonological	Lexical	Morphosyntactic
Phonological			
Pig Latin	**.884**	−.056	.222
Backward words	**.848**	−.015	.298
Word reading	**.822**	.383	.060
Final consonant choice	**.788**	.144	−.096
Grammaticality judgments	**.748**	.432	.102
Verbal working memory	**.688**	.323	−.362
Lexical			
Expressive vocabulary	.242	**.891**	.040
Bound morphemes	−.051	**.744**	.473
Sentence comprehension	.520	**.595**	.032
Morphosyntactic			
Pronouns	−.017	−.021	**.842**
Mean length of utterance	.129	.505	**.803**
Conjunctions	.431	.178	**.489**

Note. Bold font indicates highest factor loading for each measure.

with NH; a Cohen's *d* of 1.0 indicates that the mean for children with CIs is at roughly the 16th percentile. Table 3 illustrates that with the exception of backward words, the largest Cohen's *d*s tended to occur for the phonological measures.

Treatment Effects

Potential effects of three treatment variables on these 12 measures were examined for the children with CIs: (a) age of receiving a first CI; (b) preimplant, better ear PTA thresholds; and (c) having had a period of bimodal stimulation for a year or more after receiving the first CI. The first two of these—age of receiving a first CI and preimplant, better ear PTA thresholds—were evaluated using Pearson product–moment correlation coefficients but were not found to be related to performance on any of the 12 measures. However, the 14 children who had a period of bimodal stimulation showed significantly better scores on several measures, compared with the 19 children with no such period of bimodal stimulation. Table 4 shows statistical results for *t* tests, as a function of bimodal experience. This table reveals that two measures that loaded highly on the phonological factor (pig Latin and final consonant choice) showed significantly better scores for the children with some bimodal experience than the children with no bimodal experience. One measure that loaded highly on the lexical factor (expressive vocabulary) also showed a significant group difference. In addition, although no effects were observed for preimplant, better ear PTA thresholds, one-way analyses of covariance were performed on these three measures, with bimodal experience as the between-groups factor and those preimplant PTAs as the covariate. In all three cases, a significant effect of bimodal experience was observed, even when controlling for preimplant PTAs: pig Latin,

Table 3. Mean scores and standard deviations for dependent measures, along with outcomes of *t* tests and Cohen's *d*s.

	NH (29)		CI (33)				
Measure	*M*	*SD*	*M*	*SD*	*t*	*p*	Cohen's *d*
Phonological							
Pig Latin	80.8	24.8	58.4	39.9	2.61	.011	0.68
Backward words	67.5	22.2	55.0	26.3	2.01	.048	0.52
Final consonant choice	87.9	7.7	67.7	19.8	5.16	< .001	1.34
Word reading	117	18	104	18	2.90	.005	0.74
Grammatical judgments	104	14	91	15	3.52	.001	0.90
Verbal working memory	62.6	17.1	48.5	16.9	3.25	.002	0.83
Lexical							
Expressive vocabulary	114	15	105	17	2.16	.035	0.55
Bound morphemes	99	19	84	18	3.21	.002	0.82
Sentence comprehension	107	11	101	17	1.56	NS	0.40
Morphosyntactic							
Pronouns	170	25	159	23	1.77	.081	0.45
Mean length of utterance	9.9	1.0	9.2	1.0	2.42	.018	0.62
Conjunctions	119	19	105	29	2.38	.021	0.61

Note. Degrees of freedom = 60 for all tests. NH = normal hearing; CI = cochlear implant; NS = not significant.

Table 4. Mean scores and standard deviations for dependent measures, along with outcomes of *t* tests and Cohen's *d*s, from children with cochlear implants, dependent on whether they had some bimodal experience or not.

Measure	Bimodal (14)		No bimodal (19)				
	M	*SD*	*M*	*SD*	*t*	*p*	Cohen's *d*
Phonological							
Pig Latin	77.8	27.4	44.1	42.2	2.61	.014	0.95
Backward words	62.1	20.3	49.8	29.4	1.34	NS	0.49
Final consonant choice	79.2	10.9	59.2	20.8	3.27	.003	1.20
Word reading	108	17	101	18	1.09	NS	0.38
Grammatical judgments	97	13	87	15	1.94	.061	0.71
Verbal working memory	53.8	13.7	44.6	18.3	1.58	NS	0.57
Lexical							
Expressive vocabulary	113	17	99	15	2.47	.019	0.86
Bound morphemes	88	18	81	18	1.01	NS	0.35
Sentence comprehension	107	15	96	17	1.98	.057	0.70
Morphosyntactic							
Pronouns	165	20	154	25	1.29	NS	0.46
Mean length of utterance	9.3	1.0	9.2	1.1	0.38	NS	0.14
Conjunctions	114	22	98	32	1.64	NS	0.59

Note. Degrees of freedom = 31 for all tests. NS = not significant.

$F(1, 30) = 7.27$, $p = .011$; final consonant choice, $F(1, 30) = 9.28$, $p = .005$; and expressive vocabulary, $F(1, 30) = 7.19$, $p = .012$. None of the morphosyntactic measures revealed statistically significant effects of having had a period of bimodal stimulation.

Relationships Among Variables

Although it is generally true that measures that load on the same factor in principal components analysis share a great deal of common variance, it is not always the case. Thus, Pearson product–moment correlation coefficients were computed between every possible pair of measures that could be derived from these 12, for children with NH and those with CIs separately. Outcomes of these correlational analyses are shown in Table 5. Coefficients for children with NH are in the top rows of each cell, and coefficients for children with CIs are in the bottom rows. Coefficients with significance levels of less than .01 are bolded. This significance level was selected for these correlation coefficients—rather than the more common level of .05 used in the rest of the study—due to the large number of correlations computed. In this analysis, this criterion meant that significant coefficients were larger than .45, indicating that the two measures shared more than 20% of their variance. The correlation coefficients shown in Table 5 provide useful information regarding the relationships among language measures.

Phonological Measures

Looking first at the measures that loaded most highly on the phonological factor (top, left of the table), it can be seen that these measures are highly intercorrelated. (Correlations greater than .5 are termed *high*; those correlations of less than .5 that are nonetheless significant are termed *moderate*.) These measures also tended to be correlated with two of the three measures that loaded on the lexical factor (top, middle of the table): expressive vocabulary and sentence comprehension. In particular, for the children with CIs, every measure loading highly on the phonological factor correlated significantly ($p < .01$) with each of these two lexical measures. For children with NH, word reading and grammaticality judgments correlated highly with expressive vocabulary and sentence comprehension, and verbal working memory correlated highly with sentence comprehension. Generally speaking, these measures that loaded highly on the phonological factor failed to correlate strongly with any of the morphosyntactic factors (top, right of the table).

Lexical Measures

A striking result regarding the measures that loaded highly on the lexical factor is that scores for bound morphemes failed to correlate with any of the phonological measures. Looking at the other two lexical measures, it can be seen that bound morphemes correlated highly with expressive vocabulary for children with NH and correlated moderately with sentence comprehension. Bound morphemes correlated most strongly with MLU, for both groups of children, a finding that is reasonable given that MLU was a metric of the numbers of morphemes in each sentence. Expressive vocabulary and sentence comprehension correlated with each other, for both groups of children, but tended not to correlate very strongly with morphosyntactic measures.

Morphosyntactic Measures

The most conspicuous outcome regarding these measures is their almost total independence from phonological measures. Within the group of measures, MLU correlated with both the number of conjunctions and the number of pronouns for both groups of children, but conjunctions and pronouns did not correlate with each other.

In summary, these correlational analyses primarily illustrate the independence of the phonological and morphosyntactic levels of language structure, as well

Table 5. Within-group Pearson product–moment correlation coefficients.

	Phonological						Lexical			Morphosyntactic		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Conj**
1. Pig Latin	1	**.828** **.524**	**.633** **.681**	**.563** **.517**	**.534** **.675**	**.501** **.457**	.200 **.688**	.103 .173	.334 **.639**	.131 .359	.298 .204	.324 .214
2. Backward words		1	**.634** **.587**	**.579** **.536**	**.527** **.536**	.458 .383	.257 **.596**	.174 .306	.413 **.465**	.218 .386	.313 .335	.382 .348
3. Final consonant choice			1	**.618** **.520**	**.486** **.635**	**.504** **.462**	.336 **.509**	.139 .199	.403 **.605**	−.155 **.514**	.104 .294	.322 .411
4. Word reading				1	**.604** **.842**	**.575** **.589**	**.524** **.865**	.155 .181	**.612** **.685**	.018 .306	.287 .264	**.580** .266
5. Grammaticality judge					1	**.560** **.677**	**.533** **.839**	.225 .274	**.642** **.829**	−.025 .397	.333 .402	.441 .371
6. Verbal working memory						1	.354 **.560**	.026 .152	**.582** **.592**	−.155 .170	.006 .333	.034 .336
7. Expressive vocabulary							1	**.679** .292	**.485** **.710**	.015 .350	**.465** .355	.189 .309
8. Bound morphemes								1	.253 **.447**	.287 **.551**	**.754** **.737**	.246 .285
9. Sentence comprehension									1	.078 **.539**	.346 **.459**	.558 .152
10. Pronouns										1	**.624** **.669**	.193 .432
11. Mean length utterance											1	**.503** **.481**

Note. Bolded coefficients represent $p < .01$. Top row = children with normal hearing; bottom row = children with cochlear implants. Conj = conjunctions.

as the independence of development within these levels of structure.

Comparison to Second-Grade Outcomes

Scores on five representative measures were compared at second and sixth grade in order to determine if performance for the children with CIs improved, stayed constant, or deteriorated relative to that of children with NH. Raw, rather than standardized, scores were used for word reading and expressive vocabulary so that performance could be compared across test ages.Although these measures were selected largely because they were the ones available at both test ages, they represent skills related to phonological, lexical, and morphosyntactic factors. For the last of these factors, however, just one measure was selected to represent morphosyntactic skills overall: MLU was selected because it shared the most variance with every other morphosyntactic factor.

Table 6 presents means, standard deviations, and results of *t* tests for these five measures at second and sixth grade. It is apparent that significant differences in performance between children with NH and those with CIs were present for all measures, except MLU, at both grade levels. In addition, other than MLU, effect sizes were at least somewhat similar at both grades. These broad observations suggest that language development may proceed at largely the same rate for children with CIs as for children with NH, leaving children with CIs behind by a consistent margin. To test that impression, a series of repeated-measures analyses of variance were performed, with scores at second and sixth grade serving as the repeated measures and the listener group serving as the between-groups factor. An analysis of variance was performed for each of the five measures separately, and the Grade × Group interaction was the term of interest because it would indicate whether the mean difference between groups was similar at both grades, thus indicating if the rate of growth was similar across groups. That interaction was not significant for any of the measures, supporting the conclusion that language performance proceeded at roughly the same rate for the children with CIs as for the children with NH; performance was consistently poorer across these grades for the children with CIs.

Examining Development in Lexical and Phonological Skills for Children With CIs

The final analysis that was performed was done to investigate lexical and phonological development across these elementary grades, specifically to explore whether development

Table 6. Mean scores and standard deviations of five dependent measures, at second and sixth grade, along with outcomes of *t* tests and Cohen's *d*s.

	NH (29)		CI (33)				
	M	*SD*	*M*	*SD*	*t*	*p*	Cohen's *d*
Final consonant choice, 2nd	71.1	17.9	40.5	26.2	5.25	< .001	1.37
Final consonant choice, 6th	87.9	7.7	67.7	19.8	5.16	< .001	1.34
Word reading, 2nd	41.8	6.4	37.4	6.3	2.68	.010	0.69
Word reading, 6th	52.9	6.0	46.9	8.4	3.17	.002	0.74
Verbal working memory, 2nd	55.0	18.2	44.0	13.7	2.69	.009	0.68
Verbal working memory, 6th	62.6	17.1	48.5	16.9	3.25	.002	0.83
Expressive vocabulary, 2nd	94.4	12.7	82.3	16.9	3.15	.003	0.81
Expressive vocabulary, 6th	133.6	14.0	125.4	16.0	2.13	.038	0.55
Mean length of utterance, 2nd	5.8	1.4	5.8	1.2	0.065	NS	0.02
Mean length of utterance, 6th	9.9	1.0	9.2	1.0	2.42	.018	0.62

Note. Degrees of freedom = 60 for all tests. NH = normal hearing; CI = cochlear implant; NS = not significant.

at one level of linguistic structure spurred development at the other level. This analysis would test the lexical restructuring hypothesis by determining if an expanding vocabulary contributed to the honing of sensitivity to phonological structure or if enhanced sensitivity to phonological structure contributed to an expanding vocabulary. To accomplish this goal, cross-lagged analysis was used. This analysis is based on the assumption that a skill will generally develop over time, on its own, even if at a modest rate. Thus, to examine potential effects of each of these two skills on each other, partial correlation analyses were performed, controlling for any development in either one that was occurring on its own. This cross-lagged analysis was performed for children with NH and those with CIs separately. Outcomes for children with NH are shown in Figure 1, and outcomes for children with CIs are shown in Figure 2. The top panel of each figure shows outcomes of these partial correlation—or cross-lagged—analyses performed on final consonant choice (the phonological measure obtained at both grade levels) and expressive vocabulary (the lexical measure obtained at both grade levels). The horizontal lines and associated coefficients show the zero-order correlation coefficients for performance at each of the two grades, for each separate measure. Partial correlation coefficients are shown between measures, from second to sixth grade (diagonal lines) and at just sixth grade (vertical lines), controlling for development on that skill from second to sixth grade. Solid lines represent coefficients with significance levels of less than .01. This top panel indicates that, although both phonological and lexical skills developed over this time span—each on its own—the development of neither one was influenced by the other, according to these measures. This lack of contributory effect was observed for both children with NH and those with CIs. Thus, no evidence was found to support the lexical restructuring hypothesis.

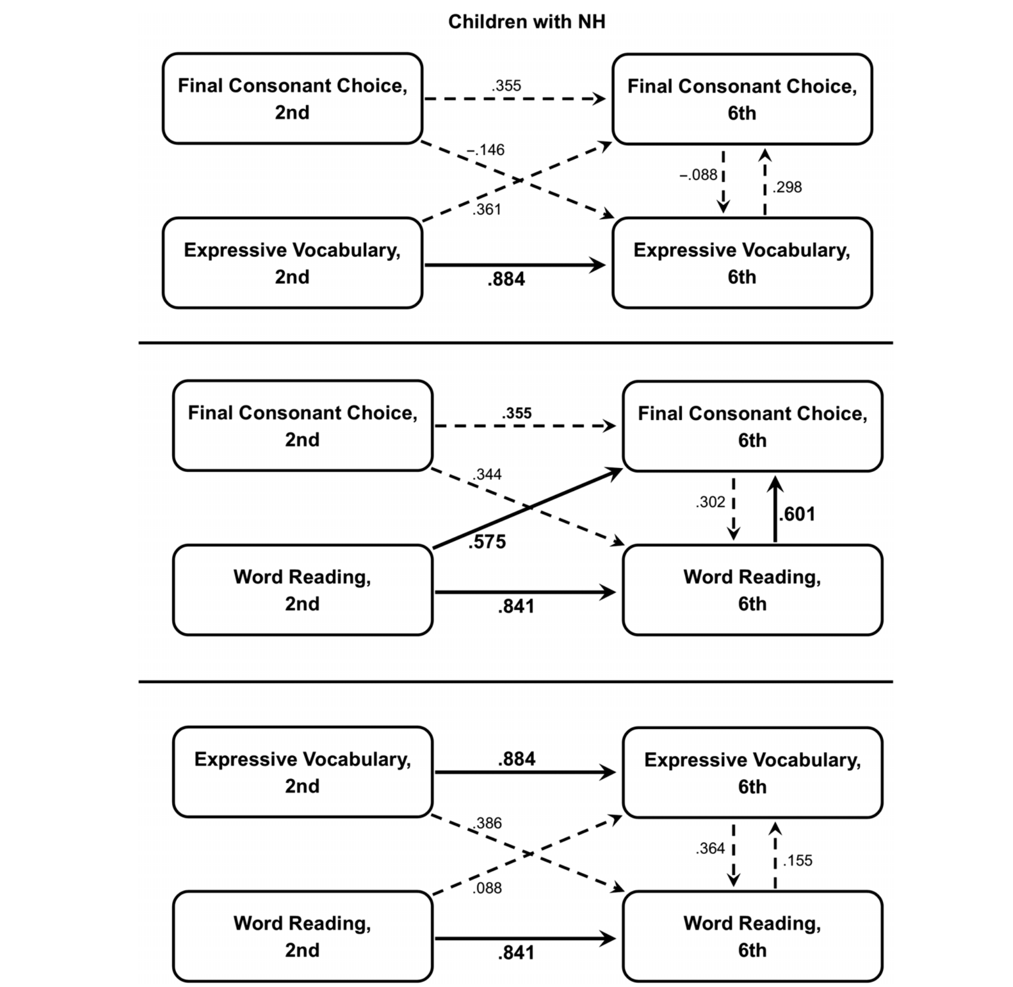
Next, the hypothesis was tested that literacy acquisition may have influenced the development of either phonological or lexical skills. Of course, the possibilities were also examined that effects could have been in the other direction, with either phonological or lexical development supporting the acquisition of literacy. To examine these possibilities, cross-lagged analyses were performed for final consonant choice and word reading and for expressive vocabulary and word reading. Outcomes of these two analyses are shown in the middle and bottom panels of Figures 1 and 2. For children with NH, literacy acquisition was found to contribute to the development of phonological sensitivity but not lexical knowledge. For children with CIs, literacy acquisition contributed to both phonological and lexical development. For neither group was it observed that either phonological sensitivity or lexical knowledge supported literacy acquisition.

Discussion

In this study, language measures collected at sixth grade from a group of children with CIs were analyzed and compared with the same measures collected from a group of children with NH. These measures spanned three levels of language structure: phonological, lexical, and morphosyntactic. Proficiency with each of these levels of language structure is essential for children to be successful in school. An aspect of this study that was unique and important was that these same children had been tested 4 years earlier, as they were finishing second grade. Consequently, it was possible to examine growth in these language skills across the elementary school years.

Four major goals were addressed with these analyses. The first goal was simply to see if these children with CIs were still demonstrating deficits in their knowledge and skill across the three kinds of language structures. The second goal was to see if the magnitude of observed deficits had lessened, remained the same, or increased since second grade. The third goal was to explore relationships across measures to help design interventions for children with CIs during the elementary school years. Finally, the fourth goal was to examine the effects of treatment variables on these language measures. In summary, this study allowed us to explore how language skill in a group of children with CIs had developed across the critical elementary school years and what affected that development so that

Figure 1. Outcomes of cross-lagged analyses from second to sixth grade for data from children with NH. Horizontal arrows and accompanying correlation coefficients are the zero-order coefficients representing the relationships between scores at second and sixth grade for the same measures. Diagonal and vertical arrows and accompanying correlation coefficients are the partial coefficients, with growth on the same measures controlled. NH = normal hearing.



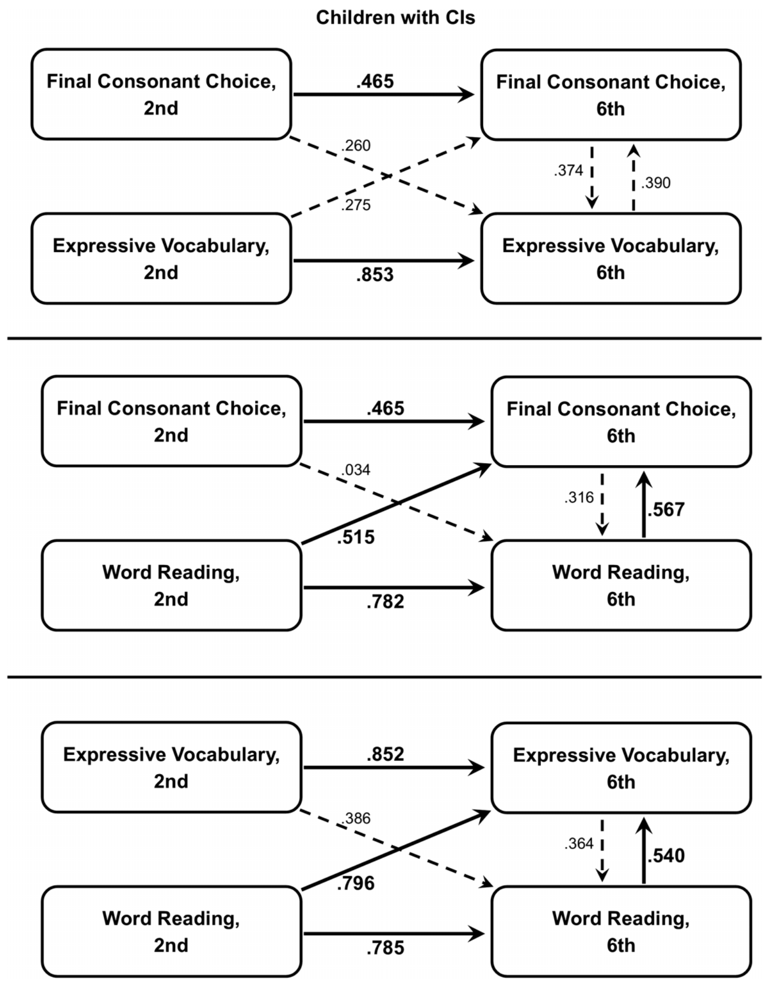
insights could be gained regarding effective intervention strategies.

Outcomes of this study revealed that children with CIs continued to perform more poorly than children with NH at sixth grade across the language measures examined. The most accurate description of their performance over time would be that they were acquiring language at the same rate as children with NH, so they demonstrated deficits of constant magnitude.

Correlational analyses across the set of 12 measures showed strong relationships among the six measures that loaded highly on a phonological factor in the principal components analysis, suggesting a strong, well-defined phonological core to language processing. Unfortunately, these are the very skills on which children with CIs demonstrate the largest deficits. These correlational analyses also revealed that phonological and morphosyntactic skills, as well as development of these skills, were independent. That finding might be viewed as good news because it means that children with CIs can develop morphosyntactic knowledge and abilities without being constrained by their poor phonological sensitivities.

Three hypotheses were offered in the Introduction section regarding how phonological abilities might fare across the elementary grades. First, it was suggested that lexical restructuring may occur for children with CIs across these grades. These grades represent a time span that is later than this process is observed for children with NH, but the timing was predicted because those children who are born deaf have a period of auditory deprivation prior to getting CIs. Thus, they may come to lexical restructuring late. According to this hypothesis, rapid growth in phonological sensitivity was predicted. A second hypothesis was that literacy acquisition during the early elementary grades might facilitate the development of both lexical and phonological abilities.

Figure 2. Outcomes of cross-lagged analyses from second to sixth grade for data from children with CIs. Horizontal arrows and accompanying correlation coefficients are the zero-order coefficients representing the relationships between scores at second and sixth grade for the same measures. Diagonal and vertical arrows and accompanying correlation coefficients are the partial coefficients, with growth on the same measures controlled. CI = cochlear implant.



An alternative to those accounts was that phonological skills might become even more deficient for children with CIs across these years, as children with NH continued to hone their sensitivity. Children with CIs might be expected to face continuing problems because of the very degraded signals available through CIs. If this degradation put significant constraints on that development, it would be predicted that children with CIs would fall even further behind children with NH in phonological sensitivity and processing abilities.

Cross-lagged correlational analyses helped to address these questions surrounding the development of phonological skills, as well as the relationships between lexical, phonological, and literacy acquisition. First, these analyses demonstrated that there was no contribution to the development of either vocabulary or phonological awareness by the other language function. Thus, using these measures, no support was obtained for the hypothesis that lexical restructuring might occur for these children with CIs, only at a later age than is typically seen. Nonetheless, children with CIs were honing their sensitivity to phonological structure over these elementary grades. Furthermore, significant contributions of literacy acquisition to the development of both vocabulary knowledge and phonological awareness were observed for the children with CIs, suggesting that literacy acquisition facilitates the development of both skills. This observation is commensurate with findings of other investigators, such as Lederberg, Miller, Easterbrooks, and Connor (2014). In sum, children with CIs continued to hone their sensitivity to word-internal phonological (i.e., phonemic) structure across the elementary grades but at a rate roughly the same as that of the children with NH. Thus, the children with CIs remained behind in their development of phonological sensitivity and processing abilities.

A clinically significant finding from this study involved treatment variables. Age of receiving a first CI and hearing thresholds prior to receiving a first CI were not correlated with any of the 12 language measures evaluated. Of course, most of the children in this study had received their CIs early; the children who had not received their CIs early had relatively good auditory thresholds before implantation. Those factors could largely explain why the effect of age of receiving a first CI was not related to outcome measures. Nonetheless, it is valuable to find that variability in when a child receives a CI on the order of months does not affect language outcomes.

The one treatment variable that was found to influence language outcomes was whether a child had a period of bimodal experience or not. Although many of the effects did not reach statistical significance, there were apparent advantages to having had such a period of bimodal experience. When the group of children with CIs was divided into those who had bimodal experience and those who did not, these sample sizes were reduced, and power was lost. If the differences observed for these groups were present with larger groups, more effects would have been significant. This finding raises the question of why having had a period of bimodal stimulation roughly a decade earlier would have facilitated better outcomes, given that the signals available to the children with histories of bimodal stimulation at the time of testing were surely no different from those available to children without that stimulation. Previously (Moberly et al., 2016; Nittrouer & Chapman, 2009), we have suggested that having even very low frequency signal components available may help children learn how to organize the degraded signals they receive through their CIs. This effect continues to positively influence speech recognition, even after the second CI is received. Thus, it would not be the case that the signals available to children with bimodal experience would have been different from the signals available to children without such experience; those children with bimodal experience were just better at deriving a linguistically meaningful percept from the signals they did receive.

Limitations of Current Study

The most severe limitation of the current study was sample sizes. Although samples of children with NH and children with CIs, in aggregate, were sufficiently large to uncover statistically significant effects that exist in the populations being sampled, that did not seem to be the case when the group of children with CIs was divided into those who had some period of bimodal stimulation and those who did not.

A second limitation of the study was that interventions were not administered prospectively. Two interventions were found to significantly and positively affect language outcomes—literacy instruction and bimodal stimulation—but neither intervention was administered in a controlled fashion. A prospective experimental design would permit more valid tests of these effects, as well as help reveal exactly what amounts and kinds of treatments are most effective.

Clinical Outcomes

In spite of the limitations described above, several important clinical outcomes were observed. First, it was observed that the age of receiving a first CI was not critically important to these outcomes. Although it would not be advised to wait until the preschool years to provide a CI to a child with auditory thresholds in the profound range, a difference of a couple of months did not seem to matter.

However, the outcomes of this study did suggest that sequential, bilateral implantation might be most desirable. There appears to be some advantage to allowing a child to have a year or two of bimodal stimulation.

Finally, literacy instruction played a large role in the development of lexical and phonological skills. Morphosyntactic skills developed independently of these and developed relatively well. However, the other two levels of language structure appeared to benefit from instruction with a visible language input.

Summary

This report provided outcome data from a study of language performance by sixth graders with NH or with CIs in order to address four goals: (a) examine whether children with CIs demonstrate deficits in knowledge and processing abilities with three levels of language structure at sixth grade; (b) determine if those deficits are greater, the same, or lesser in magnitude than those observed at second grade; (c) evaluate how the various measures relate to each other; and (d) examine if and how treatment variables affect language outcomes. Results revealed that language deficits continued for children with CIs at sixth grade and were roughly the same in magnitude as those observed at second grade. The various measures of phonological abilities were tightly related to each other and related to the lexical measures, especially for the children with CIs; however, these phonological and lexical skills were independent of morphosyntactic abilities. A period of bimodal stimulation and strong literacy acquisition were found to be the best predictors of positive outcomes for these children with CIs.

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