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Early predictors of phonological and morphosyntactic skills in second graders with cochlear implants

Susan Nittrouer[a], **Joanna H. Lowenstein**[a], and **Christopher Holloman**
The Ohio State University

Abstract

Purpose—Newborn hearing screening has made it possible to provide early treatment of hearing loss to more children than ever before, raising expectations these children will be able to attend regular schools. But continuing deficits in spoken language skills have led to challenges in meeting those expectations. This study was conducted to (1) examine two kinds of language skills (phonological and morphosyntactic) at school age (second grade) for children with cochlear implants (CIs); (2) see which measures from earlier in life best predicted performance at second grade; (3) explore how well these skills supported other cognitive and language functions; and (4) examine how treatment factors affected measured outcomes.

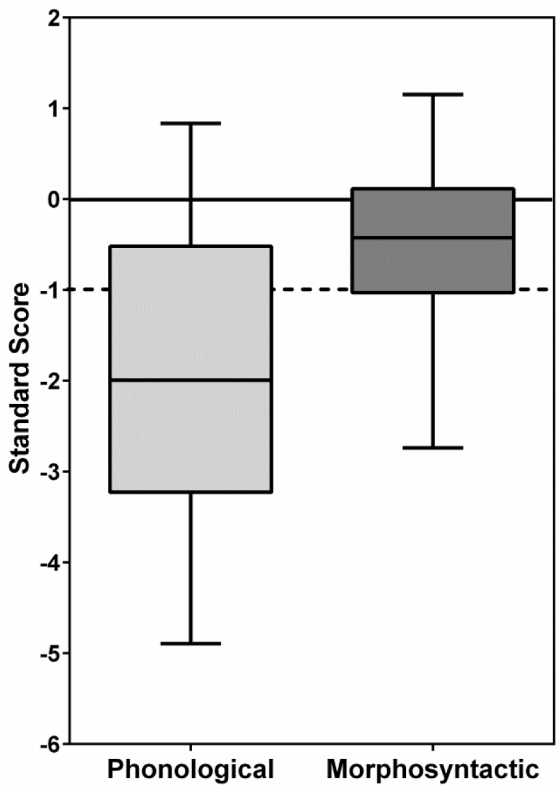
Methods—Data were analyzed from 100 second-grade, monolingual English-speaking children: 51 with CIs and 49 with normal hearing (NH). Ten measures of spoken language and related functions were collected: three each of phonological and morphosyntactic skills; and four of other cognitive and language functions. Six measures from preschool and seven from kindergarten served as predictor variables. The effects of treatment variables were examined.

Results—Children with CIs were more delayed acquiring phonological than morphosyntactic skills. Mean length of utterance at earlier ages was the most consistent predictor of both phonological and morphosyntactic skills at second grade. Early bimodal stimulation had a weak, but positive effect on phonological skills at second grade; sign language experience during preschool had a negative effect on morphosyntactic structures in spoken language.

Conclusions—Children with CIs are delayed in language acquisition, and especially so in phonological skills. Appropriate testing and treatments can help ameliorate these delays.

Graphical abstract

Address correspondence to: Susan Nittrouer, Department of Speech, Language, and Hearing Sciences, University of Florida, 1225 Center Drive, Room 2147, PO Box 100174, Gainesville, FL 32610, snittrouer@ufl.edu.
[a]Current affiliation is the University of Florida



Graphical abstract: Mean standard scores for children with cochlear implants at second grade on tests of phonological and morphosyntactic abilities. Means for peers with normal hearing are zero, with standard deviations of 1. It can be seen that children with cochlear implants perform much more poorly on tests of phonological abilities than on those of morphosyntactic abilities.

Keywords

Diagnostics; language; phonological awareness; children; cochlear implants; deaf

I. Introduction

Children born with severe-to-profound hearing loss are at risk for significant delays in learning language. Fortunately, the recent implementation of mandatory hearing screening for all newborns, rather than only those with risk factors for hearing loss, has meant these children are now often identified shortly after birth, so treatment can begin early. Evidence from several investigators has reliably shown that the early initiation of both medical interventions, especially cochlear implantation (CI), and behavioral interventions can substantially ameliorate delays in language learning imposed by congenital hearing loss (Geers & Nicholas, 2013; Houston et al. 2012; Moeller, 2000; Ramos-Macías, Borkoski-Barreiro, Falcón-González, & Plasencia, 2014; Robbins, Osberger, Miyamoto, & Kessler, 1995). Nonetheless, mean performance of these children remains below that of children with normal hearing (NH) (Geers & Hayes, 2011; Spencer & Tomblin, 2009; Tobey et al., 2013) and gaps exist in our understanding of why that is. Further investigation into the challenges faced by children with hearing loss is warranted, so we may continue to refine the diagnostic language measures we use with these children, as well as our intervention practices.

Language is typically conceptualized as a unitary construct, but it is actually a network of interrelated cognitive structures. In the past, there has been little investigation into the relative degree of challenge imposed by hearing loss on learning for each of these separate structures. A useful way to categorize these structures for present purposes is to consider language as consisting of two primary layers: morphosyntactic and phonological. Morphosyntax refers to the way that words are selected and combined to generate meaningful sentences. Knowing how to select and combine words appropriately is foundational to skills such as understanding meaning in the spoken language of communication partners, and being able to generate sentences that others can comprehend. Knowledge of word classes and how words fit together can also constrain potential word choices when listening to speech, which is an aid to communication in adverse listening conditions or when a hearing impairment exists. Of course, that advantage is only realized by listeners who have sufficient knowledge of morphosyntactic structure.

Phonological structure refers to the internal structure of words, and is usually viewed as having three layers itself: syllabic structure within words, onsets and rimes within syllables, and the consonants and vowels (phonemes) that form those word constituents. The ability to readily recognize phonological (especially phonemic) structure in spoken language is fundamental to a variety of language functions, including learning to read, working memory, and comprehending speech under adverse conditions, including hearing loss. As with morphosyntax, knowledge of how phonemes can be concatenated to form words allows listeners to recognize linguistic structure when incomplete sensory information is available (e.g., Ahissar, Lubin, Putter-Katz, & Banai, 2006; Caldwell & Nittrouer, 2013).

Although both are likely essential to language function, the degree of transparency in the acoustic signal of these two levels of language structure differs, as illustrated in Figure 1. This figure displays a waveform at the top, which reveals that global structure is rather well preserved just in the pattern of rising and falling amplitude across time. This pattern exists because syllables always contain a vowel nucleus, and frequently have consonantal constrictions on one or both sides. Vowel production generally involves a more open vocal tract than consonant production, so the undulating amplitude pattern helps to delineate words and syllables. Furthermore, the relative amplitude of the syllables as well as their length provides information about prosody. Accordingly, infants usually display adult-like syllable structure in their own productions very early in life. They start to produce ‘canonical’ syllables with power envelopes differing by at least 10 dB from peak to valley, with peak-to-peak durations of 100 to 500 ms by 6 months of age, and language-specific prosodic structure (Oller, 1986). Thus, the acquisition of morphosyntactic structure, as well as of syllable structure, begins early.

Children’s awareness of phonemic structure, on the other hand, does not start to emerge until near the end of preschool, just as they are about to enter the elementary school grades (Vihman, 1991). The reason for this protracted developmental course is found in the lower portion of Figure 1, which displays a spectrogram. The continuous nature of this display illustrates that phonemes are not discretely represented in the acoustic speech signal. Instead, acoustic structure contributing to recognition of any single phoneme is spread broadly across the signal, and the spectral composition of any narrow slice of that signal is influenced by articulatory gestures affiliated with more than one phoneme. Listeners must apply language-specific strategies during speech perception in order to recover phonemic structure, and those strategies are acquired over the better part of the first decade of life. In tests requiring children to report (e.g., by counting) the number of smaller elements comprising a larger one, or to manipulate composite elements (e.g., by segregating them), it is reliably found that children as young as three years may demonstrate knowledge of syllable structure through counting or deletion tasks (Fox & Routh, 1975; Lonigan, Burgess, Anthony, & Barker, 1998; Maclean, Bryant, & Bradley, 1987), but knowledge of phonemic structure is emerging through roughly 8 years of age, which for most children places them in second grade (Bryant, Maclean, Bradley, & Crossland, 1990; Liberman, Shankweiler, Fischer, & Carter, 1974; Walley, Smith, & Jusczyk, 1986). This relatively late acquisition of sensitivity to phonemic structure means that children with hearing loss have left early intervention before evidence of its development or delay can be observed. Thus, the question may be asked of how well our early intervention programs are preparing these children for this aspect of language learning. Even though sensitivity to phonemic structure does not become observable until the late preschool or early elementary school years, presumably already acquired cognitive and linguistic phenomena promote this acquisition. If we understood how those earlier emerging phenomena lay the groundwork for phonemic sensitivity, we could focus on them during early intervention. The first and primary goal of the current study was to examine phonological (especially phonemic) and morphosyntactic sensitivity, as measured in early elementary school, to assess the relative independence of the two sorts of skills.

The second goal of the study was to examine early precursors to those skills. If the two types of skills are found to be largely independent of each other, they may have different precursors. On the other hand, it could be that the development of sensitivity to phonological structure is highly correlated with the development of sensitivity to morphosyntactic structure. Even though the two kinds of structure may be conceptualized as distinct, it may be that any individual child possesses a single propensity for learning about each, which would predict parallel acquisition.

The evidence thus far suggests that at least for children with NH these two levels of language structure – morphosyntactic and phonological – may be independently represented and acquired. This evidence comes from the finding that specific language impairment (a morphosyntactic deficit) and dyslexia (a phonological deficit) can exist in children separately (Catts, Adlof, Hogan, & Weismer, 2005). Such findings support the model of human language as a network of connected, but independent functions. When it comes to development, however, acquisition of both morphosyntactic and phonological structure likely starts with a single primitive structure. Children’s earliest utterances are unanalyzed forms that can include single words from the adult lexicon, or formulaic phrases (e.g., *all gone*). Then morphosyntactic and phonological structures bifurcate to create these separate layers as children discover both the internal structure of their early productions and the rules by which those early productions can be combined. This bifurcation can be observed perhaps most clearly at the point where the child has acquired a 50-word lexicon, typically around 18 months of age. After this point, the lexicon expands rapidly – presumably because the child has begun to discover that the internal components of words can be recombined to make new words – and words can be combined to generate sentences (Bloom, 1973; Gopnik & Meltzoff, 1986; Storkel & Morrisette, 2002). A question in this study was whether the same degree of independence between sensitivity to morphosyntactic and phonological structure would be observed for children with CIs as for children with NH. If children with CIs are delayed in their language development, the process of separation of these language functions may not be as advanced for them as it is for children with NH.

The motivation for suggesting that phonological structure may not be as well developed for children with CIs as for children with NH largely stems from the signal degradation these children experience. The processing implemented in CIs provides only a degraded spectral representation to the auditory system, and that is further degraded by the spread of excitation along the basilar membrane. Consequently, frequency structure is not as precise as what is shown in the spectrogram of Figure 1. Amplitude structure is better preserved by the signal processing of CIs, and the physiological interface. Consequently, access to the kinds of acoustic properties – or cues – long held to define phonemic categories is severely constrained, but access to syllable structure and prosody remains intact. Thus, it could be predicted that children who must develop phonological systems through CIs could have difficulty doing so; these children may be significantly hindered in their abilities to discover syllable-internal structure. Acquisition of sensitivity to morphosyntactic structure could be predicted to be less delayed because that structure is well preserved in the amplitude, or temporal, structure of speech processed through a CI.

A third goal of the current study was to examine how sensitivity to each of phonological and morphosyntactic structure supports other, potentially related language functions. In this study, four language functions were examined in addition to the measures of phonemic and morphosyntactic sensitivity:

(1) Children's abilities to understand the spoken language of communication partners were assessed. In the classroom, as well as in other environments, it is critical that children be able to understand the language they are hearing. The relative contributions of each kind of language structure to auditory comprehension of language have not been thoroughly assessed.

(2) Vocabulary development was assessed in this study. It is generally agreed that the early lexicon is organized by holistic or global acoustic structure, and is then reorganized during the late preschool/early elementary school years, as evinced by Storkel's (2002) statement that "…children may be able to rely on more holistic representations to uniquely differentiate each word from every other, and these representations may become more detailed as words are acquired" (p. 253). At issue is whether children with hearing loss are delayed in this reorganizational process, perhaps due to delayed acquisition of phonemic sensitivity.

(3) Word reading was examined in this study because reading becomes increasingly important during the elementary school years. Especially where alphabetic orthographies such as English are concerned, it is critical to have keen sensitivity to separate phonemic elements in order to be able to attach alphabetic labels to those units. Children with reading problems have significant deficits in phonemic sensitivity (Boada & Pennington, 2006; Bradley & Bryant, 1983; Mann, Shankweiler, & Smith, 1984; Wagner & Torgesen, 1987), although some investigators have also observed a link to morphosyntactic deficits (Bishop & Adams, 1990; Catts, 1993). Thus, similarly to vocabulary, the extent to which word reading is reliant on awareness of whole morphological forms or on sensitivity to phonemic structure remains poorly understood.

(4) Verbal working memory was assessed in this study. This construct is foundational to much of learning and functioning in the academic setting because children must be able to store and recall teacher instructions as well as content material in order to be effective learners. Working memory in general is often modeled as being comprised of a central executive that handles processing, and several slave systems (Baddeley, 1986). Of relevance to verbal working memory, one slave system is a phonological loop that recovers phonological (specifically phonemic) structure from the heard speech signal, and uses that structure to store words in a short-term memory buffer. Thus, sensitivity to phonemic structure should be especially important to verbal working memory.

A fourth and final goal of the current study was to examine the extent to which factors associated with hearing loss and its treatment account for variability in the development of phonological and morphosyntactic skills. Factors considered were age of receiving a first CI, whether or not children had a period of bimodal stimulation when that first CI was received, and whether sign language was used when children were preschoolers.

In summary, the current study examines the acquisition of and relationship between two layers of language structure: morphosyntactic and phonological. Sensitivity to both of these kinds of language structure is presumably important to communication functioning in the real world, including the classroom. Four questions were addressed: (1) How strongly is sensitivity to each kind of structure related, and does the strength of that relationship differ for children with NH and those with CIs? (2) What are the early predictors of sensitivity to each kind of language structure? (3) How important is acquisition of sensitivity to each kind of structure to four potentially related communication functions? and (4) How do factors related to hearing loss and its treatment affect the acquisition of morphosyntactic and phonological sensitivity?

2. Methods

2.1. Participants

One hundred children served as research participants in this study: 49 with NH and 51 with severe-to-profound hearing loss who wore one or two CIs. All children were tested in the summer following the completion of second grade. All were participants in a longitudinal study in which they were tested every six months, on their six-month birthday from 12 to 48 months of age (Nittrouer, 2010), and then after they completed kindergarten, second grade, and fourth grade. More information regarding the original recruitment, the general background of participants, and their early interventions can be found in Appendix A.

Measures of language skills at 36 and 48 months of age, as well as at kindergarten (roughly 6 years of age) were used as predictor variables in this current study. However, some children tested in second grade missed testing at one of those younger ages, so data from all children are not available at those ages. None of the children in this study exhibited any problem – other than hearing loss in the case of children with CIs – that would be expected to delay language acquisition. All children heard only English in the home and had parents with NH. At the time of testing, all children with CIs were in mainstream educational settings. On average, they received 45 minutes of speech and language therapy per week, and had an academic tutor in their classroom for 75 minutes per week.

Table 1 shows means and standard deviations (SDs) of demographic data for all children, and of audiological data for children with CIs. Children in the two groups did not differ in terms of age at the time of testing, proportion of males/females, socioeconomic status, or nonverbal intelligence quotient. In this study, socio-economic status (SES) was indexed using a two-factor scale similar to that originally developed by Hollingshead (1957), but updated by Nittrouer and Burton (2005). On this scale both the highest educational level and the occupational status of the primary income earner in the home is considered. Scores for each of these factors range from 1 to 8, with 8 being high. Values for the two factors are multiplied together, resulting in a range of possible scores from 1 to 64. The scores for children in this study reflect the fact that most children had at least one parent who received a four-year college degree. The intelligence quotient (IQ) was the Brief IQ calculated from the Leiter International Performance Scale – Revised (Roid & Miller, 2002), a completely nonverbally administered instrument. This information was collected at the time of testing, following second grade.

Word recognition abilities were assessed with the CID W-22 word lists. Each child heard one of these 50-word lists, and the lists were randomized across children. Percent correct scores are shown in Table 1. Children with CIs performed more poorly than children with NH, $t(98) = 10.97$, $p < .001$. Speech intelligibility was assessed with the Children's Speech Intelligibility Measure, or CSIM (Wilcox & Morris, 1999). For this measure, each child repeated 50 words presented one at a time in audio-visual format. The children's productions were audio recorded. Later, two naïve listeners heard these words, and had to select which word out of a set of 12 closely related choices was produced. The scores shown in Table 1 are the mean percent correct scores across the two listeners. Children with CIs showed poorer speech intelligibility than children with NH, $t(98) = 5.20$, $p < .001$.

Nonetheless, in their daily lives all of these children could be understood, especially when the listener could see them talking.

Regarding audiological factors, 13 children wore just one CI, 33 wore bilateral CIs, and five children wore a hearing aid on the ear contralateral to the ear with a CI (i.e., had bimodal stimulation). Seventeen of the children had Cochlear Freedom devices, 13 had Cochlear System 5, 18 had Advanced Bionics Harmony, and two had MedEl devices. One child had a Cochlear Freedom implant in one ear and an Advanced Bionics Harmony device in the other ear. Of the children with just one CI, three had worn a hearing aid on the contralateral ear for at least one year after receiving that CI. Of the 33 children with two CIs, 17 had worn a hearing aid on the ear contralateral to the first CI for at least one year, before receiving the second CI. In total, 25 children had a year or more of experience wearing a hearing aid on the ear contralateral to their CI subsequent to receiving a first CI (i.e., had bimodal experience), and 26 children stopped wearing a hearing aid at all upon receiving a first CI, or shortly before receiving the first CI (i.e., had electric-only experience).

For all children with NH, hearing was screened at 20 dB hearing level for the octave frequencies between 250 Hz and 8,000 Hz at the time of data collection. Two measures of hearing sensitivity are shown in Table 1 for the children with CIs. These better-ear pure-tone averages (PTAs) are all for the three frequencies of 0.5 kHz, 1.0 kHz, and 2.0 kHz. The pre-implant PTAs are those obtained closest to, but prior to the time of implantation for the first CI. The aided PTAs were those obtained at the time of testing in second grade. Unaided PTAs were also obtained, but no child with a CI showed any residual hearing in an ear after implantation.

2.2. Equipment

2.2.1. Second grade and kindergarten testing—Data collection at these ages took place at the Ohio State University Medical Center. Stimuli for the measures of phonological awareness (three obtained at second grade and two at kindergarten) were presented in audio-visual format. Video signals were presented on the computer monitor using a 1500-kbps sampling rate and 24-bit digitization. Audio signals were presented via a computer with a Creative Labs Soundblaster soundcard using a 44.1-kHz sampling rate with 16-bit digitization, and a Roland MA-12C powered speaker placed 1 meter from the child at zero degrees azimuth.

Morphosyntactic measures were obtained from Systematic Analysis of Language Transcripts (SALT; Miller & Iglesias, 2010), done on 100 utterances obtained from 20-minute language samples. All language samples were audio-video recorded, using Sony HDR-XR550V video recorders. Children wore Sony FM transmitters that provided direct line input to the video cameras to ensure good sound quality for all recordings.

For the working memory task, children responded by tapping pictures on a touch-screen monitor (HP Compaq L2105TM). For the other three measures of potentially related language functions (auditory comprehension, vocabulary, and word reading), children's responses were audio-video recorded using the same equipment as that used to record the language samples.

2.2.2. Preschool testing—All data collection at 36 and 48 months of age took place in quiet rooms at facilities near the children's homes. Language samples at these ages were audio-video recorded using Sony model DCR-TRV19 cameras and the same FM transmitters as used in kindergarten and second-grade data collection.

2.3. Procedures

All procedures used in data collection at every age were approved by the Institutional Review Board of the Ohio State University. Procedures for data collection at the second-grade test age are described here. All testing took place in sound booths across three sessions, each lasting no more than one hour. Children had at least a one-hour break between sessions. Procedures for collection of the data obtained at younger ages are described in Appendix B.

2.3.1. Phonological measures—Three tasks measuring phonological sensitivity were administered. All three consisted of 48 items, which increased in difficulty through the task. Practice was provided for each task prior to testing. Testing stopped after six consecutive wrong answers. An audio-visual presentation format was used to minimize the risk of children failing to recognize the word stimuli. The Initial Consonant Choice (ICC) and Final Consonant Choice (FCC) tasks were identical in format. A target word was presented first, and children were required to repeat it correctly before the trial continued. If a child failed to do so for a specific trial, the target stimulus was presented again. None of these children had difficulty understanding the words presented, likely because of the audio-visual presentation. They all could readily repeat the target stimuli, with only rare need for repetition. Next three choice words were presented. The child had to select that choice word that either started or ended with the same consonant as the target word. Because these children had so little difficulty recognizing the targets, it seems fair to conclude that they could understand the choice words, as well. Both the ICC and FCC tasks were used because each one assesses a different level of phonological structure. For the most part, the ICC task evaluates subjects' abilities to differentiate syllable onsets (the initial consonant) from the syllable rimes. However, some items occurring later in the test list consisted of clusters, and children were required to isolate the first consonant from the cluster. The FCC task requires subjects to isolate the final consonant from the rest of the syllable rime. The third phonological task used in this study involved phoneme deletion, often termed elision. In this task, a target nonword is presented. After repeating it correctly, the child is instructed to say the item without one of its segments, which creates a real word (e.g., "Say *plig* without the 'l' sound"). The experimenter entered the child's responses, and the software kept track of correct responses. All testing was audio-video recorded. At a later time, a different member of the laboratory staff checked to ensure that all responses entered by the experimenter at the time of testing matched what the child had said. These children were all sufficiently intelligible that they were readily understood, especially because scorers could see them talking.

2.3.2. Morphosyntactic measures—A 20-minute narrative sample was collected. At the start of testing, the child entered the sound booth and the experimenter explained that she had been called away for a few minutes. The child was instructed to watch a video telling the story of *The Day Jimmy's Boa Ate the Wash* (Noble, 1980). This story had been audio-video recorded with a narrator reading the printed material, but with separate staff members saying the material that appeared in quotes in the book. Full images of the faces were shown to ensure optimal opportunity for speechreading. Illustrations from the book were shown when appropriate. After the story was finished, the experimenter re-entered the sound booth, and asked the child to tell her the story in as much detail as possible. That retelling was audio-video recorded. The story retelling never took the full 20 minutes, so the experimenter supplemented the time by asking questions about personal experiences the child had paralleling those of the children in the story. Later these narratives were transcribed independently by two members of the laboratory staff. Transcriptions of the two transcribers were compared, and those two individuals subsequently discussed any disagreements, arriving at consensus. Those transcriptions were submitted to the SALT software. Three measures of morphosyntax were obtained from a 100-utterance selection, starting 5-minutes into the narrative: (1) mean length of utterance in morphemes (MLU); (2) number of pronouns; and (3) number of conjunctions, excluding *and*. The reason for excluding *and* is that some young children use the conjunction *and* as a device simply for stringing utterances together, rendering it an ineffective marker of syntactic complexity.

2.3.3. Measures of potentially related language functions—Four measures were selected for this purpose. (1) Auditory comprehension of language was assessed using the paragraph comprehension subtest of the Comprehensive Assessment of Spoken Language (Carrow-Woolfolk, 1999). In this task, children listen to progressively more complex stories, and have to answer comprehension questions by pointing to one of four choices on an easel. The stories and questions had been audio-video recorded by a staff member, so presentation would be consistent for all children. Children's responses were audio-video recorded at the time of testing. Scoring was done later by a member of the laboratory staff, other than the one who collected the data. Still another member of the staff compared those scores to the original video recording made during data collection to ensure accuracy of scoring. Standardized scores were used as dependent measures. (2) Vocabulary was assessed with the Expressive One-Word Picture Vocabulary Test (Brownell, 2000). This task requires children to provide the words that label a series of pictured items shown one at a time on separate pages. As with testing for the auditory comprehension task, all testing was audio-video recorded for later scoring and checking. Standardized scores were used as dependent measures. (3) Word reading was assessed with the word reading subtest of the Wide Range Achievement Test (Wilkinson & Robertson, 2006). In this task, the child reads a list of words that become progressively harder. Again, all testing was audio-video recorded, and scored later by two members of the laboratory staff. Standardized scores were used as dependent measures. (4) For a measure of verbal working memory, children were asked to recall the order of six consonant-vowel-consonant non-rhyming nouns presented as auditory lists in ten trials at a rate of one per second. The child heard the words, and then tapped pictures representing the words on a computer monitor in the order recalled. The software kept track of the order in which words were presented, as well as the order recalled by each child. A single set of words served as stimuli, and recognition was checked for each child both prior to testing and after testing by presenting words one at a time, and asking children to touch the corresponding picture. If a child had difficulty recognizing even a single word auditorily, testing would not have been conducted (if it happened during the pre-test) or data would have been removed from analysis (if it happened on post-test). However, all children readily recognized these simple nouns.

3. Results

Before the specific goals of the study were addressed statistically, group differences were examined. Table 2 shows means and standard deviations (SDs) for both groups of children for the ten observed measures at second grade. Outcomes of *t* tests performed on these data are also shown, along with Cohen's *d*s. On all measures, children with CIs performed significantly more poorly on average than children with NH; however, effect sizes – as indexed by the Cohen's *d*s – differed across measures. Cohen's *d*s were greatest for two of the three measures of phonological sensitivity (i.e., ICC and FCC), as well as for the measure of verbal working memory. Cohen's *d*s were smallest for the three specific measures of morphosyntactic abilities (i.e., the second set of three measures in Table 2). Cohen's *d*s were intermediate for the three other measures. These outcomes provide some support for one hypothesis posed at the start of this study, which was that phonological sensitivity would be more strongly impacted by hearing loss and subsequent cochlear implantation than morphosyntactic structure.

Another noticeable trend in Table 2 is that some outcomes were more variable for children with CIs than for those with NH. In particular, measures of phonological sensitivity showed standard deviations roughly twice as large for children with CIs as for children with NH; variability was fairly similar across groups for other measures. Although this trend is obvious, the enhanced variability seen for these children with CIs is more restricted than that reported by others, such as Tobey et al. (2013). It may be that the efforts taken to control demographic factors in this study helped to constrain variability.

3.1. Deriving latent scores of phonological and morphosyntactic skills

Next, factor analysis was performed on these ten observed measures, separately for children with NH and for those with CIs. This analysis was largely confirmatory for the six factors selected to index phonological or morphosyntactic sensitivity; for the other four factors, it could be considered exploratory in nature. The analysis was done using a maximum likelihood method of extraction and varimax rotation. Table 3 shows factor loadings for each of the ten observed measures for children with NH, and Table 4 shows these factor loadings for children with CIs. The highest factor loadings are highlighted. Three factors emerged for children with NH, but only two factors emerged for children with CIs, suggesting that separate language functions are diverging into independent constructs more clearly for children with NH. For both groups, it is apparent that the three specific measures of phonological sensitivity loaded highly on one and only one factor and the three specific measures of morphosyntactic abilities loaded highly on a different factor, and only on that factor. Consequently, the factor on which the three phonological measures loaded highly was labeled as the phonological factor, and the factor on which the three morphosyntactic measures loaded highly was labeled as the morphosyntactic factor. Three of the other four measures (i.e., auditory comprehension, expressive vocabulary, and word reading) loaded highly on a third factor for children with NH, but loaded highly on the phonological factor for the children with CIs. Verbal working memory loaded moderately on the phonological factor for both groups of children. Although not the primary means of addressing the goal, outcomes of these factor analyses address the third goal of the study: apparently, phonological sensitivity underlies the other measures of language functioning examined here, at least for children with CIs, the experimental group of interest.

As a result of these factor loadings, two scores of latent language abilities were derived: one based on the phonological factor and one based on the morphosyntactic factor. Latent scores combine several observed measures in order to index in a more veridical manner an underlying construct. In this case, the phonological latent score was derived from ICC, FCC, and PD; the morphosyntactic latent score was derived from MLU, the number of conjunctions, and the number of pronouns. To compute these latent scores, children with NH served as the benchmark group from which factor loadings were derived. As a result, mean latent phonological and morphosyntactic scores for these children were zero, and SDs were 1.

Figure 2 displays standard Tukey box and whisker plots for the latent phonological and morphosyntactic scores of children with CIs. These plots reveal that the performance of children with CIs was not much below that of children with NH on the morphosyntactic latent score: the mean score (and SD) was −.49 (.89). However, these children with CIs were quite far below on the phonological latent score: the mean score (and SD) was −1.91 (1.53). This outcome was predicted going into this study.

3.2. Independence of morphosyntactic and phonological sensitivity

The first-stated goal of the current study was to examine the extent to which sensitivity to phonological and morphosyntactic structure appears to be developing independently, for children with NH and for those with CIs. To achieve that goal, separate Pearson product-moment correlation coefficients were computed between latent phonological and morphosyntactic scores for children with NH and those with CIs. For children with NH, this correlation coefficient was .137, which was not significant; for children with CIs, it was .290, which was significant ($p = .039$). Thus, for children with NH the acquisition of sensitivity to these two kinds of language structure was completely independent by second grade, but that acquisition was mildly related for children with CIs.

3.3. Early predictors of phonological and morphosyntactic sensitivity

The second goal of this investigation involved finding measures obtained at younger ages that might serve as predictors of phonological and morphosyntactic abilities in these children with CIs in second grade. To address that goal, observed measures obtained when these children were younger (i.e., in kindergarten and at 48 and 36 months of age) were correlated with each of these latent measures derived at second grade. These correlations were obtained for children with NH and those with CIs separately. The analyses provide an examination of the sorts of measures that might be collected during preschool in order to predict language knowledge and performance at older ages. Table 5 shows these outcomes for children with NH, and Table 6 shows outcomes for children with CIs. Mean scores on the observed measures obtained at kindergarten, 48 months, and 36 months are shown in Appendices C, D, and E, respectively, along with outcomes for *t* tests and Cohen's *d*s.

The first finding that is apparent in Tables 5 and 6 is that for the children with NH there were only two observed measures from younger ages that were predictive of language performance at second grade. The first was for the phonological latent score, where performance on the FCC task at kindergarten was found to be highly correlated. That outcome is not terribly surprising, given that it is one component of the phonological latent score derived at second grade. It is also the only task reported for kindergarten that explicitly examined sensitivity to phonemic structure; syllable counting examined sensitivity to syllabic structure. Thus, FCC was the only task administered at an earlier age that measures the construct represented by the phonological latent measure at second grade. Regarding the morphosyntactic latent score, only the number of conjunctions produced in the language sample collected at 36 months of age was significantly correlated with this score at second grade. In the absence of significant relationships for measures made at older ages, however, this outcome must be viewed with caution: it might be that it was spurious.

For children with CIs, many more early-collected measures were significantly correlated with both the phonological and morphosyntactic latent scores at second grade. In fact, for the morphosyntactic latent score, all but two of the measures collected at these earlier ages correlated significantly. This outcome supports the trend described in the Introduction: Skills across the various domains of language appear to be acquired in a more independent fashion by children with NH. For children with hearing loss who receive CIs, these various language skills appear to be highly inter-related, all facets of a single, underlying language construct.

Outcomes for the phonological latent scores further support this suggestion. Again, many more early-collected measures significantly predicted phonological scores at second grade for these children with CIs than was found for the children with NH. At the same time, it is interesting that one observed score that was not significantly correlated with phonological scores at second grade was the FCC score at kindergarten. This lack of relationship could reflect the very poor performance of children with CIs on this task at that earlier age: mean performance of 13.4 percent correct in kindergarten. Looking at scores across kindergarten and second grade, it is found that these children with CIs did not start acquiring sensitivity to word-final phonemic structure in earnest until sometime after kindergarten. This lack of correlation in performance across ages provides a useful clinical insight: Although a task of explicit phonemic sensitivity may seem an appropriate predictor of future skill, it was not found to be the case. Instead, a measure of syllable sensitivity collected at kindergarten did explain a significant amount of variability in the latent phonological score at second grade.

Each of the observed measures that evoked a significant correlation coefficient could be used as a potential predictor in a clinical setting. However, these measures likely share variance among themselves, so not all of them would need to be administered in order to derive the predictive power that might be sought. To investigate that possibility, stepwise linear regression was performed on data from children with CIs using the phonological and morphosyntactic latent measures as dependent variables in separate analyses. As predictor measures, the decision was made to focus on MLU, auditory comprehension, and expressive vocabulary, for two reasons: First, these three measures were significantly correlated with both the phonological and morphosyntactic latent measures at every age for children with CIs, except for 36 months when auditory comprehension and expressive vocabulary did not correlate with the second-grade phonological latent score. Second, each of these measures is fairly straightforward to obtain in clinical settings. The measures of auditory comprehension and expressive vocabulary rely on standardized tests, and MLU can be easily computed from a language sample. And unlike the number of conjunctions and the number of pronouns used, MLU is not strongly dependent on the number of utterances included in the sample.

Table 7 shows the outcomes of the six stepwise regression analyses conducted. In each row is shown the predictor measure that was found to explain the largest amount of variance in the dependent latent measure. In each case, the predictor variable shown was the only one contributing to the derived model: the other two were excluded in each case. Here it is seen that the amount of variance explained by the predictor variables declines with decreasing age.

3.4. Relationship of morphosyntactic and phonological sensitivity to other language functions

The third goal of this investigation was to examine the extent to which the latent constructs of phonological and morphosyntactic sensitivity could explain variability in measures that assess other, potentially related language functions. To achieve that goal, separate Pearson product-moment correlation coefficients were computed for children with NH and those with CIs using latent phonological and morphosyntactic scores, paired with each of auditory comprehension, expressive vocabulary, word reading, and working memory. Table 8 shows results, and reveals that there were only two significant correlations for children with NH, both of which involved the latent phonological score. For children with CIs, all of the correlations were significant; in two cases (expressive vocabulary and verbal working memory), however, the strength of the relationship was stronger when the latent phonological score was involved. These results add further support for the conclusion that the various components of the global construct of language are more interconnected for children with CIs than for those with NH. Language has not yet differentiated into distinct skills for these children.

3.5. Relationship of treatment factors to phonological and morphosyntactic sensitivity

Finally, the possible effects of treatment variables on phonological and morphosyntactic sensitivity were examined. Only children with CIs were included in these analyses. First, the effect on phonological and morphosyntactic sensitivity of age of receiving a first CI was examined by computing separate Pearson product-moment correlation coefficients between age of first CI and the latent phonological and morphosyntactic scores. No relationship was found for either one. Next, the effect of having one or two CIs was examined using two *t* tests: one with latent phonological scores and one with latent morphosyntactic scores. Again, outcomes were not significant: there were no differences in scores for children with one or two CIs.

The third factor related to treatment that was examined was having a period of bimodal stimulation near the time of receiving a first CI. For this analysis, data from the children who were still getting bimodal stimulation were not included because that group consisted of only five children. Thus, 46 children were included in the analysis of bimodal effects. There were only three children with just one CI at second grade who had experience with bimodal stimulation, but their mean latent phonological and morphosyntactic scores were found to be identical to those of children with one CI who never had bimodal experience. Consequently, all children with just one CI continued to be treated as a single group, providing a total of 13 children. The children with two CIs were divided according to whether they had bimodal experience at the time they received their first CI, creating two groups of essentially equal size (17 with some bimodal experience and 16 with electric-only experience). Mean scores for these three groups of children for demographic and audiological factors are shown in Table 9. One-way analyses of variance (ANOVAs) performed on these values showed that only the ages of first and second CI differed: children in the two CIs, some bimodal group received both of their CIs later than children in the other two groups received their first (or only) and second CIs. Table 10 shows mean latent scores for phonological and morphosyntactic sensitivity for these groups. One-way ANOVAs done on these data failed to reveal a significant group effect for either score, although the phonological score was close, $F(2,43) = 2.72$, $p = .078$. When a t test was done on the latent phonological scores of children with two CIs based on whether they had early bimodal experience or not, the outcome was also close to significant, $t(31) = 1.88$, $p = .069$. Although it is difficult to interpret statistical outcomes that are close to significant, it does appear there was a mild positive effect of having had a period of bimodal stimulation on the development of phonological sensitivity – at least if children subsequently received a second CI.

The last treatment variable examined was whether or not children were in early intervention programs that included sign language. All 51 children with CIs were included in this analysis, 17 of whom used sign language in addition to spoken language during early intervention. A series of t tests showed that these groups did not differ on any demographic or audiological factors. Mean latent phonological and morphosyntactic scores are shown in Table 11. The t tests conducted on each of these latent scores separately revealed a significant effect of sign language for the latent morphosyntactic scores, $t(49) = 2.54$, $p = .014$. Thus, children who were not in programs using sign language had better sensitivity to morphosyntactic structure for spoken language.

4. Discussion

The purpose of this study was to explore the relationships among language constructs, and potential early predictors of those constructs. Three measures each of phonological and morphosyntactic sensitivity obtained from second grade children were examined, as well as four measures of other, potentially related language functions: auditory comprehension of language, expressive vocabulary, word reading, and verbal working memory. Because all data came from children who had participated in testing during their time in preschool and possibly kindergarten, analyses involving earlier abilities were able to be performed.

The overarching model of language and its acquisition that was considered in this study was one in which language structure is initially a unitary construct for the young child, with single-word utterances (or short, unparsed phrases) serving all communicative functions. Eventually this single construct bifurcates into two layers of structure: one morphosyntactic and one phonological in nature. Specific questions that were addressed in this study were these: (1) How strongly is acquisition of sensitivity to each kind of structure related, and does the strength of that relationship differ for children with NH and those with CIs? (2) What are the early predictors of acquisition of sensitivity to each kind of language structure? (3) How important is acquisition of sensitivity to each kind of structure to other communication functions? and (4) How do factors related to hearing loss and its treatment affect the acquisition of morphosyntactic and phonological sensitivity?

A correlational analysis addressed the first goal. It revealed that acquisition of phonological and morphosyntactic structure was unrelated for children with NH; these two constructs were more related for children with CIs, but not strongly so. Thus, the two layers of language structure had begun to separate for these children, but just not to the same extent as for the children with NH.

Regarding the second goal, it was found that few measures collected in preschool or kindergarten were very strong predictors of phonological or morphosyntactic sensitivity in second grade for children with NH. However, for children with CIs, quite a few early measures were found to be predictive of performance in second grade. An important trend to emerge was that early measures of morphosyntactic skills – especially MLU – were robust predictors of both morphosyntactic and phonological sensitivities in second grade for these children with CIs. On the other hand, measures of phonological sensitivity obtained in kindergarten for these children were not good predictors of either morphological or phonological sensitivity in second grade.

To address the third goal, both the morphosyntactic and phonological latent scores were used in correlational analyses with each of the four measures of other language functions. For children with NH, it was observed that the phonological latent score explained significant amounts of variability for word reading and working memory, reinforcing the notion that access to this level of structure is a requisite for these two functions. For children with CIs, both latent scores were found to be strongly related to all four language functions, although slightly stronger effects were observed for the phonological as opposed to the morphosyntactic latent scores.

When it came to examining the roles of treatment factors in the acquisition of phonological and morphosyntactic sensitivity – the fourth goal of this study – some clinically significant trends were observed. First, the age at which children received a first CI was not found to affect sensitivity for either kind of language structure. This finding is contradictory to outcomes from some other studies demonstrating that earlier implantation is associated with better scores on language measures made later in childhood. However, the finding matches results of a retrospective analysis reported by Dunn et al. (2014), who failed to find an influence of age of implantation on speech perception or language performance in school-age children. Those authors emphasized that higher order language skills seem particularly immune to continued influence of age of implantation. The two latent scores that served as dependent measures in this study fit the bill of being higher order skills, so these outcomes support the conclusion of that earlier study.

The second trend that was observed regarding treatment factors was that a period of time with bimodal stimulation may have promoted acquisition of sensitivity to phonological structure for these children with CIs – at least for those who had two CIs. Having a period of bimodal stimulation early in life that was transformed into bilateral CI stimulation provided the greatest benefits to phonological acquisition. Thus, although the acoustic stimulation available to these children was extremely limited and likely restricted only to the low-frequency regions of the speech spectrum, it appears that having some access to that kind of structure early in life can help children with severe-to-profound hearing loss discover phonological structure.

Finally, early exposure to sign language was associated with poorer scores on the measure of latent morphosyntactic knowledge. This last finding was also complementary to outcomes of the Dunn et al. (2014) report. The morphosyntactic structure of sign language is different from that of spoken English. It appears from this finding that rather than promoting language acquisition – or at least the acquisition of English morphosyntax – having early exposure to sign-language morphosyntactic structures can inhibit the learning of English morphosyntactic structures.

4.1. Clinical significance

The outcomes of this study should inform efforts to improve clinical and educational interventions for children with hearing loss, especially those with CIs. Considering early intervention first, this study revealed that syntactic skills were the best predictors from the preschool years of later language development. In particular, MLU was found to be a strong prognosticator of both later morphosyntactic and phonological sensitivity. Because this measure is an index of utterance length, the results suggest that intervention with young children should include helping children to generate complete sentences. This idea runs counter to some approaches, which focus more strongly on teaching individual vocabulary items or learning how to produce individual phonemic elements. At the heart of such approaches is a model of language acquisition proposing that children learn small elements in a cumulative manner, and then learn how to combine those elements. Instead, here is evidence that children actually first discover the frames into which those elements will fit, and gradually acquire elements to place in those frames. This suggestion is complementary to a similar one for speech production, offered by MacNeilage and Davis (1991).

Regarding early diagnostic tests, these outcomes suggest that it is worth the time it takes for a clinician to collect a language sample, and analyze it in order to derive MLU. Almost counterintuitively, it was found that for children with CIs the one measure of early sensitivity to phonemic structure (FCC) was at best a weak predictor of later phonological sensitivity. Likely that outcome reflected the fact that as a group, these children were still quite insensitive to syllable-internal phonemic structure before second grade.

Looking next at intervention for children once they enter elementary school, the current study suggests it would be useful to include phonological awareness as targets in educational plans. The children with CIs in this study demonstrated much poorer sensitivity to this kind of language structure than that of children with NH; nonetheless, sensitivity to this structure was observed to be foundational to several language functions. Thus, phonological awareness should be treated in a remedial manner. Where morphosyntax is concerned, these children with CIs were closer in their performance to that of children with NH, so morphosyntactic abilities could provide an important means by which these children could compensate for poorer phonological knowledge and skill. Thus, even if a child with CIs may be close to typical in performance on standardized language measures, there would be value in sharpening those morphosyntactic abilities as much as possible.

4.2. Limitations of current study

One possible concern with the current study was that data from the preschool years were not available for all children tested at second grade. The smallest number of children was tested in kindergarten, where data were available for only 43 children out of the 100 tested at second grade. However, this was the age for which correlations with second-grade outcomes were strongest, so concern that the sample was not adequate is ameliorated.

Another limitation of this study was that no data regarding phonological sensitivity were obtained prior to kindergarten. Thus, it was not possible to do correlational analyses of early phonological sensitivity with measures obtained at second grade. However, only one significant correlation was observed between a phonological measure – syllable counting – obtained in kindergarten and sensitivity to one layer of language structure at second grade – phonological structure – for children with CIs. This outcome suggests that sensitivity to phonological structure at a level broader than the phoneme (i.e., syllables or onsets and rimes) during the early years may be important to later phonological development.

4.3. Future research

From a theoretical perspective, the most intriguing hypothesis to emerge from the current data is that language development appears to involve the differentiation of language facilities, especially the bifurcation of sensitivity to phonological (i.e., word internal) and morphosyntactic (i.e., word and sentence level) structure. This hypothesis deserves further exploration. In addition, evidence was found to support the hypothesis that perhaps children with language-learning deficits – at least those with CIs – may not be developing proficiency in morphosyntactic and phonological skills as independently as children with NH and typical language acquisition. The failure to demonstrate a bifurcation in acquisition of these two levels of language may be a more general marker of deficit or delay.

From a clinical perspective, these data suggest that a prospective study on potential advantages of having a period of bimodal stimulation would be warranted, as well as an expanded study of the effects of early sign-language intervention on the development of English morphosyntax. The data reported here suggest that early bimodal stimulation may especially benefit the acquisition of phonological sensitivity, and the use of sign language may negatively influence the acquisition of English morphosyntax.

4.4. Summary

The primary purpose of this report was to examine early predictors of children's sensitivity to phonological and morphosyntactic structure in elementary school. Two groups of children participated: children with NH and children who required CIs. Outcomes showed the acquisition of sensitivity to these two kinds of language structure emerges fairly independently. Children with CIs were most delayed in their acquisition of phonological sensitivity. The most consistent early predictor of both phonological and morphosyntactic sensitivity in second grade was found to be a measure of syntax, MLU. Evidence was found to suggest that early experience with bimodal stimulation may have a positive effect on phonological sensitivity, while early experience with sign language may delay morphosyntactic development. Broadly speaking, the current study demonstrated benefits of studying children longitudinally, with a wide set of dependent measures.

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Appendix A: Recruitment of participants

All children for whom data are reported in this study were recruited as infants, and that process followed well-defined principles. First, twenty geographic locations were identified within the continental United States that had both a high-quality auditory-oral and sign-supported early intervention program. In this case, high-quality intervention was defined as being provided by teachers and clinicians who had Master's degrees or higher in relevant disciplines, and served only children with hearing loss. Thus, the children in both auditory-oral and sign-supported programs came from the same geographic regions. They were recruited through the distribution of flyers at their intervention programs. Children with normal hearing were recruited through the distribution of flyers at pediatrician offices and daycare centers in the same geographic regions. Only one of these families moved over the course of the study a great distance from their home at the time they originally enrolled in the study, so children in the study continued to share common geographies. That meant that the educational methods they encountered once they entered school were evenly distributed across groups.

All children were born between August, 2002 and June, 2004. Seventy-two percent of these children were White, 9 percent were Hispanic, 8 percent were African American, 8 percent were Asian, and 3 percent were American Indian. None of the children was diagnosed with a syndrome or comorbid condition that would on its own be expected to affect language development, and none had known risk factors for such a condition.

In order to be included, all children with hearing loss had to be receiving services at least once a week up to the age of three years, and then at least 16 hours per week during the preschool years. All participants had parents with normal hearing who were monolingual English speakers. Two of the children with hearing loss had relatives in their extended families with hearing loss. Regardless of whether a child was in an auditory-oral or sign-supported program, the parents had to assert that they wished for their child to be able to attend a regular school program by first grade, without the help of sign-language interpreters.

Seventeen of the 51 children included in this report attended preschool programs that were sign-supported. Of these 17 children, two had one parent each who had known sign language before the child was born. These were the parents of the two children with relatives who had hearing loss. Twelve of the 17 children attended programs that reported using American Sign Language, and five children attended programs that reported using Manually Coded English. All parents of children in sign-supported programs reported that they had elected to enroll their children in those programs in the belief that early sign language would promote the acquisition of spoken language.

Appendix B: Measures obtained at kindergarten and at 48 and 36 months

Language Measure	Age tested	Description
Auditory Comprehension	All three test ages	The auditory comprehension subtest of the Preschool Language Scales-4 (Zimmerman, Steiner, & Pond, 2002) was used to measure children's understanding of spoken language. The task requires children to demonstrate their understanding of language by performing specific commands given by an examiner. Standardized scores were used in analysis.
Expressive Vocabulary	All three test ages	The Expressive One-Word Picture Vocabulary Test (Brownell, 2000) was used to assess expressive vocabulary. For this task, children are asked to provide the words that label a series of pictured items shown one at a time on separate pages. Standardized scores were used in analysis.
Morphosyntactic measures (MLU, conjunctions, pronouns)	All three test ages	A 20-minute language sample was obtained at each test age, transcribed, and submitted to SALT analysis. At kindergarten the sample was based on five related themes, presented to the child in a series of prompts. At the younger ages the sample was obtained from a parent-child play session involving a standard set of toys. Each sample was transcribed by two (kindergarten) or three (48 and 36 months) independent viewers. When disagreement was found in how an utterance was transcribed, it was resolved by discussion among transcribers. Mean length of utterance in morphemes (MLU), conjunctions (excluding *and*), and pronouns were assessed.
Syllable Counting	Kindergarten	Syllable counting assesses sensitivity to syllable structure within words. Children saw and heard a man on a computer monitor say a word and were asked to count the number of syllables in the word by tapping them on the table. The percentage of correct answers (out of 48) was used in analysis.
Final Consonant Task	Kindergarten	In the Final Consonant Choice task, children saw and heard a male speaker produce a target word which the child needed to repeat correctly. Three more words were then presented in a similar fashion. The child's task was to select the word out of the three that had the same ending sound as the target word. The percentage of correct answers (out of 48) was used in analysis.
Real-word Utterances	48 and 36 months	The numbers of utterances containing at least one real word were counted for the entire 20-minute language sample obtained from children, and served as a dependent measure of language advancement.

Appendix C: Mean scores and SDs for observed measures obtained at kindergarten, along with outcomes of t tests and Cohen's ds

	Normal Hearing *19*		**Cochlear Implants *24***		***t***	***p***	**Cohen's *d***
	M	***(SD)***	**M**	***(SD)***			
Syllable Counting (% correct)	70.0	*(37.0)*	48.0	*(31.0)*	1.81	<.001	0.64
Final Consonant Choice (% correct)	63.5	*(25.5)*	13.4	*(15.3)*	7.87	<.001	2.38
Mean Length of Utterance	5.5	*(0.6)*	4.2	*(1.3)*	3.94	<.001	1.28
Conjunctions	19.7	*(6.1)*	11.3	*(7.0)*	4.15	<.001	1.28
Pronouns	114.2	*(20.2)*	83.9	*(30.6)*	3.72	.001	1.17
Auditory Comprehension Standard Score	103.0	*(10.5)*	80.0	*(19.8)*	4.65	<.001	1.45
Expressive Vocabulary Standard Score	110.0	*(10.9)*	91.0	*(17.8)*	4.02	<.001	1.29

Appendix D: Mean scores and SDs for observed measures obtained at 48 months, along with outcomes of t tests and Cohen's ds

	Normal Hearing *35*		**Cochlear Implants** *45*		***t***	***p***	**Cohen's *d***
	M	***(SD)***	**M**	***(SD)***			
Real Word Utterances	126.3	*(32.2)*	107.5	*(37.7)*	2.32	.023	0.54
Mean Length of Utterance	3.9	*(0.8)*	3.0	*(1.0)*	3.77	<.001	0.99
Conjunctions	10.7	*(8.0)*	4.4	*(6.4)*	3.68	<.001	0.87
Pronouns	41.3	*(11.4)*	25.5	*(14.1)*	4.95	<.001	1.23
Auditory Comprehension Standard Score	106.9	*(12.3)*	86.9	*(19.4)*	5.30	<.001	1.23
Expressive Vocabulary Standard Score	100.4	*(11.0)*	84.8	*(13.1)*	5.68	<.001	1.29

Appendix E: Mean scores and SDs for observed measures obtained at 36 months, along with outcomes of t tests and Cohen's ds

	Normal Hearing 36		Cochlear Implants 37		*t*	*p*	Cohen's *d*
	M	*(SD)*	M	*(SD)*			
Real Word Utterances	123.1	*(30.0)*	86.9	*(37.9)*	4.51	<.001	1.06
Mean Length of Utterance	3.5	*(0.8)*	2.1	*(0.7)*	6.97	<.001	1.86
Conjunctions	5.3	*(4.6)*	0.7	*(1.4)*	5.71	<.001	1.35
Pronouns	34.8	*(11.7)*	14.2	*(11.6)*	6.74	<.001	1.77
Auditory Comprehension Standard Score	106.0	*(13.6)*	78.2	*(20.3)*	6.96	<.001	1.61
Expressive Vocabulary Standard Score	99.4	*(13.2)*	78.8	*(16.2)*	5.95	<.001	1.39

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Highlights

- Hearing loss and subsequent cochlear implantation have different effects on the acquisition of phonological and morphosyntactic skills
- Preschool measures of morphosyntactic abilities predict later skills in both of these domains
- Early treatment factors affect language acquisition at school age for children with cochlear implants
- Language functions are acquired more independently for children with normal hearing than for children with hearing loss

What this paper adds?

Numerous studies have assessed the spoken language skills of children with cochlear implants. Mean performance is reliably found to be one standard deviation below that of peers with normal hearing, and variability is typically large. The current study extended those earlier investigations by asking if those performance levels are consistent across language domains, if they could be predicted from language measures obtained during the preschool years, and how early treatment factors affect outcomes. In particular, skills based largely on sensitivity to phonological versus morphosyntactic structure were examined separately: the first should be greatly and negatively affected by the signal degradation introduced by implant processing, while the latter should be more immune to such effects. This study contributes new knowledge to our understanding of language acquisition by children with cochlear implants with the separate analyses of language skills in the phonological and morphosyntactic domains, and with the longitudinal analyses. It was discovered that acquisition of phonological and morphosyntactic skills is largely independent of each other, but that early morphosyntactic abilities strongly predict school-age performance in both domains for children with cochlear implants. Basic models of language development are enhanced by the finding that children’s initial linguistic schemas are reorganized into phonological and morphosyntactic structures during the early grade-school years. Finally, two treatment variables frequently implemented early in a child’s life were found to have differing effects on later language abilities: a period of bimodal stimulation weakly, but positively affected phonological skills, while early exposure to sign language negatively affected morphosyntactic skills for spoken language.

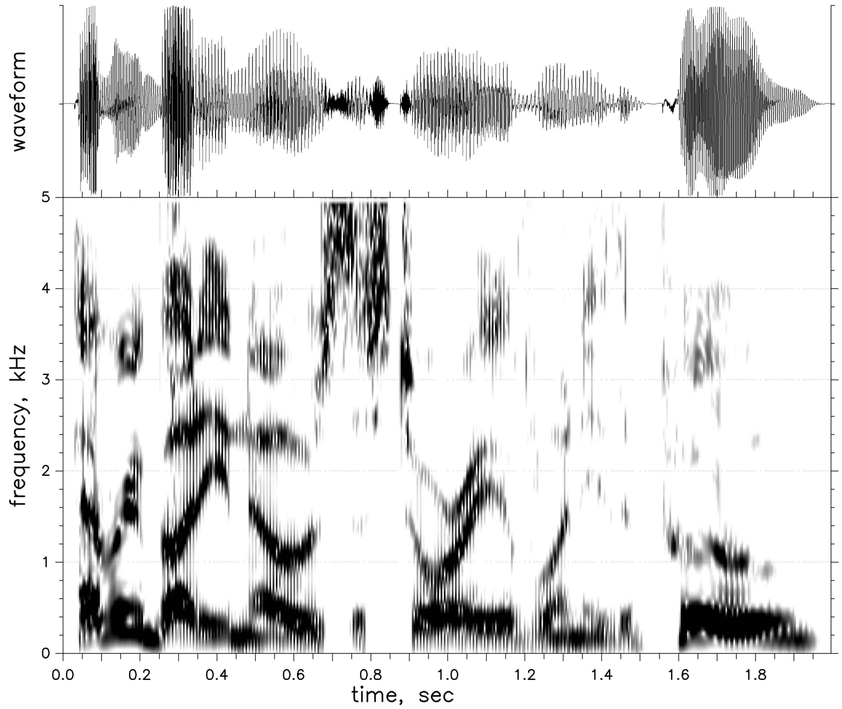

FIGURE 1.
A waveform and spectrogram of a sentence spoken by a man.

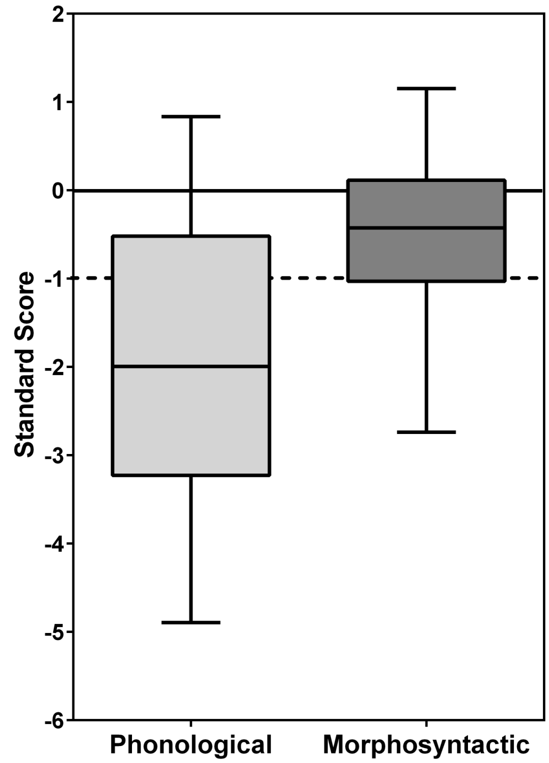

FIGURE 2.
Mean latent phonological and morphosyntactic scores for children with CIs, relative to benchmarks for children with NH of means of 0 and standard deviations of 1.

Table 1

Means and SDs for demographic and audiometric measures for the two groups of children at second grade.

	NH ***49***		**CI** ***51***	
	M	***(SD)***	**M**	***(SD)***
Age at time of testing (months)	101	*(4)*	103	*(5)*
Proportion of males	0.45	---	0.47	---
Socio-economic status (out of 64)	35	*(13)*	34	*(11)*
Intelligence Quotient (SS)	105	*(14)*	101	*(16)*
Word recognition (%)	95	*(3)*	70	*(16)*
Speech intelligibility (%)	95	*(3)*	89	*(8)*
Age at identification (months)			7	*(7)*
Pre-implant better-ear PTA (dB)			99	*(17)*
Aided better-ear PTA			23	*(7)*
Age at 1st implant (months)			22	*(17)*
Age at 2nd implant (months)			43	*(22)*

Table 2

Mean scores and SDs for observed measures obtained at 2nd grade, along with outcomes of *t* tests and Cohen's *d*s. df = 98 for all.

	Normal Hearing		Cochlear Implants				
	M	***(SD)***	**M**	***(SD)***	***t***	***p***	**Cohen's *d***
Phonological measures							
Initial Consonant Choice (% correct)	87.4	*(13.2)*	64.3	*(25.9)*	5.58	<.001	1.12
Final Consonant Choice (% correct)	69.8	*(17.9)*	36.9	*(25.9)*	7.36	<.001	1.48
Phoneme Deletion (% correct)	71.5	*(21.5)*	49.1	*(32.2)*	4.07	<.001	0.82
Morphosyntactic measures							
Mean Length of Utterance	6.3	*(1.5)*	5.6	*(1.3)*	2.41	.018	0.50
Conjunctions	30.2	*(14.9)*	23.0	*(10.7)*	2.79	.006	0.56
Pronouns	122.2	*(32.0)*	104.0	*(30.6)*	2.92	.004	0.58
Other measures							
Auditory Comp. Standard Score	111.6	*(11.9)*	100.2	*(20.0)*	3.43	.001	0.69
Expressive Vocab. Standard Score	110.0	*(13.7)*	95.9	*(17.8)*	4.42	<.001	0.89
Word Reading Standard Score	110.0	*(11.7)*	101.9	*(14.7)*	3.04	.003	0.61
Verbal Working Memory (% correct)	56.1	*(16.5)*	44.1	*(14.7)*	3.83	<.001	1.26

Table 3

Loadings on three factors of observed measures obtained in 2nd grade, for children with NH.

	Phonological	Morphosyntactic	Other
Phonological measures			
Initial Consonant Choice	**.665**	.050	.112
Final Consonant Choice	**.837**	−.092	.022
Phoneme Deletion	**.682**	−.119	.281
Morphosyntactic measures			
Mean Length of Utterance	−.071	**.993**	.080
Conjunctions	−.047	**.785**	−.183
Pronouns	−.070	**.909**	.028
Other measures			
Auditory Comprehension	.190	.260	**.615**
Expressive Vocabulary	.112	−.159	**.720**
Word Reading	.517	−.212	**.663**
Verbal Working Memory	**.379**	−.021	.140

Table 4

Loadings on two factors of observed measures obtained in 2nd grade, for children with CIs.

	Phonological	Morphosyntactic
Phonological measures		
Initial Consonant Choice	**.808**	.013
Final Consonant Choice	**.543**	.131
Phoneme Deletion	**.771**	.199
Morphosyntactic measures		
Mean Length of Utterance	.228	**.930**
Conjunctions	.279	**.793**
Pronouns	.077	**.869**
Other measures		
Auditory Comprehension	**.666**	.404
Expressive Vocabulary	**.878**	.179
Word Reading	**.807**	.178
Verbal Working Memory	**.466**	.225

Table 5

Pearson product-moment correlation coefficients between latent measures computed on scores obtained at 2nd grade and observed measures obtained at test ages 36 months, 48 months and kindergarten, for children with NH.

	Real-Word Utterances	Syllable Counting	Final C Choice	MLU	Conjunc-tions	Pronouns	Auditory Compreh.	Expressive Vocabulary
Phonological								
Kindergarten	NA	.34	**.47***[*]	.36	.00	.30	.35	.05
48 months	.00	NA	NA	.00	.30	.00	.18	.26
36 months	.00	NA	NA	.18	.17	.00	.00	.19
Morphosyntactic								
Kindergarten	NA	.34	.21	.10	.08	.28	.29	.11
48 months	.16	NA	NA	.11	.18	.04	.05	.00
36 months	.27	NA	NA	.05	**.47**[*]	.21	.31	.05

[*] $p < .05$

Table 6

Pearson product-moment correlation coefficients between latent measures computed on scores obtained at 2nd grade and observed measures obtained at test ages 36 months, 48 months and kindergarten, for children with CIs.

	Real-Word Utterances	Syllable Counting	Final C Choice	MLU	Conjunc-tions	Pronouns	Auditory Compreh.	Expressive Vocabulary
Phonological								
Kindergarten	NA	**.44***	.36	**.50***	.31	.32	**.63****	**.55****
48 months	.24	NA	NA	**.55 ****	**.35 ***	**.41 ****	**.37 ***	**.44 ****
36 months	.15	NA	NA	**.33***	.24	.25	.19	.28
Morphosyntactic								
Kindergarten	NA	.00	.25	**.61 ****	**.61 ****	**.62 ****	**.42 ***	**.46 ***
48 months	**.38***	NA	NA	**.49 ****	**.30 ***	**.44 ****	**.49 ****	**.58 ****
36 months	.18	NA	NA	**.38 ***	**.34 ***	**.33 ***	**.36 ***	**.35 ***

* $p < .05$;

** $p < .01$;

*** $p < .001$

Table 7

Outcomes of stepwise regression analysis for children with CIs: predictor that explained the largest amount of variance on either the phonological or morphosyntactic latent measure obtained at second grade.

	Measure	β
Phonological		
Kindergarten	Auditory Comprehension	.63**
48 months	Mean Length of Utterance	.55***
36 months	Mean Length of Utterance	.34*
Morphosyntactic		
Kindergarten	Mean Length of Utterance	.61**
48 months	Expressive Vocabulary	.57***
36 months	Mean Length of Utterance	.39*

* $p < .05$;

** $p < .01$;

*** $p < .001$

Table 8

Pearson product-moment correlation coefficients between latent measures of phonological and morphosyntactic sensitivity and four measures of language function.

	Auditory Comprehension	Expressive Vocabulary	Word Reading	Working Memory
Normal hearing				
Phonological	.22	.19	**.56****	**.37****
Morphosyntactic	.28	−.12	−.21	−.05
Cochlear implants				
Phonological	**.54** **	**.65** **	**.66** **	**.39** **
Morphosyntactic	**.52** **	**.36** *	**.34** *	**.31** *

* $p < .05$;

** $p < .01$

Table 9

Mean scores on demographic and audiological variables for children with CIs, divided according to number of CIs and bimodal experience.

	One CI *13*		**Two CIs, Electric Only** *16*		**Two CIs, Some Bimodal** *17*	
	M	***(SD)***	**M**	***(SD)***	**M**	***(SD)***
Socio-economic status (out of 64)	30	*(13)*	37	*(10)*	33	*(11)*
Age at identification (months)	3	*(3)*	6	*(8)*	8	*(6)*
Pre-implant better-ear PTA (dB)	102	*(14)*	108	*(11)*	98	*(15)*
Age at first CI (months)	13	*(4)*	16	*(6)*	23	*(16)*
Age at second CI (months)			33	*(14)*	53	*(24)*

Table 10

Mean scores on latent measures of phonological and morphosyntactic sensitivity for children with CIs, divided according to number of CIs and bimodal experience.

	One CI		**Two CIs, Electric Only**		**Two CIs, Some Bimodal**	
	M	***(SD)***	**M**	***(SD)***	**M**	***(SD)***
Phonological	−2.29	*(1.21)*	−2.25	*(1.72)*	−1.20	*(1.50)*
Morphosyntactic	−0.85	*(0.74)*	−0.47	*(0.89)*	−0.25	*(1.06)*

Table 11

Mean scores on latent measures of phonological and morphosyntactic sensitivity for children with CIs, divided according to sign language experience.

	Sign Language *17*		**No Sign Language** *34*	
	M	*(SD)*	M	*(SD)*
Phonological	−2.02	*(1.16)*	−1.85	*(1.70)*
Morphosyntactic	−0.92	*(1.15)*	−0.28	*(0.65)*