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Language Structures Used by Kindergartners with Cochlear Implants: Relationship to Phonological Awareness, Lexical Knowledge and Hearing Loss

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Abstract

Objective—Listeners use their knowledge of how language is structured to aid speech recognition in everyday communication. When it comes to children with congenital hearing loss severe enough to warrant cochlear implants (CIs), the question arises of whether these children can acquire the language knowledge needed to aid speech recognition, in spite of only having spectrally degraded signals available to them. That question was addressed in the current study. Specifically there were three goals: (1) to compare the language structures used by children with CIs to those of children with normal hearing (NH); (2) to assess the amount of variance in the language measures explained by phonological awareness and lexical knowledge; and (3) to assess the amount of variance in the language measures explained by factors related to the hearing loss itself and subsequent treatment.

Design—Language samples were obtained and transcribed for 40 children who had just completed kindergarten: 19 with NH and 21 with CIs. Five measures were derived from Systematic Analysis of Language Transcripts (SALT): (1) mean length of utterance in morphemes, (2) number of conjunctions, excluding *and*, (3) number of personal pronouns, (4) number of bound morphemes, and (5) number of different words. Measures were also collected on phonological awareness and lexical knowledge. Statistics examined group differences, as well as the amount of variance in the language measures explained by phonological awareness, lexical knowledge, and factors related to hearing loss and its treatment for children with CIs.

Results—Mean scores of children with CIs were roughly one standard deviation below those of children with NH on all language measures, including lexical knowledge, matching outcomes of other studies. Mean scores of children with CIs were closer to two standard deviations below those of children with NH on two out of three measures of phonological awareness (specifically those related to phonemic structure). Lexical knowledge explained significant amounts of variance on three language measures, but only one measure of phonological awareness (sensitivity to word-final phonemic structure) explained any significant amount of unique variance beyond that, and on only one language measure (number of bound morphemes). Age at first implant, but no other

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factors related to hearing loss or its treatment, explained significant amounts of variance on the language measures, as well.

Conclusion—In spite of early intervention and advances in implant technology, children with CIs are still delayed in learning language, but grammatical knowledge is less affected than phonological awareness. Because there was little contribution to language development measured for phonological awareness independent of lexical knowledge, it was concluded that children with CIs could benefit from intervention focused specifically on helping them learn language structures, in spite of the likely phonological deficits they experience as a consequence of having degraded inputs.

Keywords

language; children; cochlear implants

Introduction

Statement of Problem

Cochlear implants (CIs) have dramatically improved the speech recognition abilities of individuals with severe-to-profound hearing loss. Before CIs were available as a treatment option, it was not uncommon for adults with acquired hearing loss to obtain word recognition scores in the single digits (e.g., Svirsky et al. 1992; Rubinstein et al. 1999). Now adults with acquired hearing loss who receive CIs often achieve mean recognition scores better than 40 percent correct for words in isolation (e.g., Skinner et al. 1997; Firszt et al. 2004; Holden et al. 2013). When words are presented in sentences, outcomes are even better: Many adults with CIs are able to recognize more than 70 percent of words in sentences correctly (Skinner et al. 1997; Firszt et al. 2004; Park et al. 2011), especially when the sentences are highly predictable (Gifford et al. 2008). The reason that sentence context facilities recognition so strongly is that listeners can use their knowledge of how language is structured to constrain word possibilities. Recently Boothroyd (2013) invoked Bayesian mathematics to explain this effect. According to this model, the more probable a specific word choice is based on factors such as syntactic and semantic structure, the less sensory evidence that is required for the listener to select that word. Because of these effects, Boothroyd has advocated that aural rehabilitation with adults include activities to help them learn how to effectively apply their knowledge of language structure to the task of speech recognition (e.g., Boothroyd 2007, 2010).

The question of how to approach rehabilitation with children is more complicated. Unlike adults who lose their hearing after acquiring a first language, children who are born deaf and get CIs must acquire knowledge about language structure strictly from the signals provided through those CIs. As beneficial as these devices have proven to be, CIs continue to deliver only degraded spectral signals to their users. Moreover, frequency-place misalignments in the auditory system and incomplete neural survival further diminish the signal quality available to CI users (e.g., Wilson & Dorman 2008; Mahalakshmi & Reddy 2012). This situation strongly predicts that children with CIs would encounter difficulty acquiring sensitivity to word-internal (i.e., phonological) structure. That kind of structure is specified by spectral details in the acoustic signal, such as the formant frequencies that help define vowel quality and the formant transitions that can specify place of consonantal constrictions.

Typical methods for examining sensitivity to phonological structure involve asking children to make decisions about word-internal elements, including syllables and phonemes. For example, children might be asked if words resemble each other in some way (e.g., rhyming) or if they share a common phoneme. As expected, when such tasks have been used with children with CIs it has consistently been observed that these children lag behind children with NH in developing sensitivity to phonological structure (James et al. 2005; Spencer & Tomblin 2009; Johnson & Goswami 2010; Ambrose et al. 2012; Nittrouer et al. 2012). Because phonemes are often viewed as the “building blocks of language,” the question arises of whether the acquisition of the kinds of language structures known to facilitate word recognition (e.g., syntactic and semantic structure) in everyday discourse can proceed independently of sensitivity to phonological structure for children with CIs. The question addressed by the current study was whether or not that difficulty acquiring sensitivity to phonological structure affects the abilities of children with CIs to acquire knowledge about grammatical structures.

Evidence regarding a relationship between phonological and grammatical development

For children with NH, the question of whether the acquisition of word-internal and sentence-level structure is inter-dependent has been addressed by studies seeking to characterize specific language impairment (SLI) and developmental dyslexia (Ramus et al. 2013). SLI is defined by deficits in a number of areas, including syntax, morphology and phonology (Leonard 1998). Dyslexia is associated primarily with phonological deficits, which are widely viewed as being causal to delays in learning to read (Vellutino et al. 2004). Nonetheless, children diagnosed with dyslexia are often found to have difficulty comprehending and producing sentences with complex syntactic structures (e.g., Byrne 1981; Stein et al. 1984; Smith et al. 1989; Bar-Shalom et al. 1993). Consequently, there is overlap in the deficits exhibited by children receiving each diagnosis, perpetuating the debate about whether phonological and grammatical skills are acquired in a dependent or independent manner (Bishop & Snowling 2004).

To examine thoroughly this question of a relationship between phonological and grammatical skills in children with NH, Ramus and colleagues (2013) administered a wide range of standard language measures – some dependent on phonological structure and some dependent on other kinds of linguistic structure – to children previously diagnosed with dyslexia, SLI, both, or neither. The children with one or both of the diagnoses were between 8 and 12 years of age; children with neither diagnoses formed two control groups: one based on chronological age (so their language and reading abilities were superior to children in the diagnosed groups) and one based on language or reading age (so they were younger). These investigators found strong evidence of independence in the emergence of the two sorts of structure across the groups, even for the children receiving both diagnoses. The non-phonological language measures were found to explain performance on the tests of syntax, morphology, and vocabulary. The phonological measures explained performance in working memory and rapid serial naming. Thus, for children with NH at least, these two components of language apparently can develop independently, even though there is substantial co-morbidity in deficits of a phonological and non-phonological nature (Catts et al. 2005).

One finding of the Ramus et al. (2013) experiment that was striking was the lack of significant correlation between sensitivity to phonological structure and vocabulary size. For adults, the lexicon is organized according to phonemic structure (e.g., Liberman & Shankweiler 1985; Luce & Pisoni 1998, but cf. Port 2007). However, the lexicon apparently does not start out with this highly segmental organization. Instead, the syllable or word is usually considered to be the initial unit of linguistic contrast (e.g., Waterson 1971; Menn 1978; Vihman & Velleman 1989). Pressure from an expanding lexicon is thought to provoke a restructuring of words in the lexicon according to phonological form, a process that continues through middle childhood (Vihman & Velleman 1989; Walley 1993; Beckman & Edwards 2000; Walley et al. 2003). For example, in 1975, Ferguson and Farwell wrote “a phonic core of remembered lexical items and the articulations that produced them is the foundation of an individual’s phonology,… even though it may be heavily overlaid or even replaced by phonologically organized acquisition processes in later stages” (p. 36). Careful analyses in the decades since that statement was written have provided support for that position, with Storkel writing in 2002 “…children may be able to rely on more holistic representations [than adults] to uniquely differentiate each word from every other, and these representations may become more detailed as words are acquired” (p. 253). Thus, there is widespread agreement that lexical restructuring occurs for children with NH. When it comes to children with CIs, however, degraded spectral signals may interfere with this process, leaving lexical representations closer to fitting a holistic description longer into childhood.

If this account is accurate, it could be hypothesized that the acquisition of some language structures would be more resistant than others to delayed development in sensitivity to phonological structure. For example, it could be argued that even if words are represented in the lexicon as more or less undifferentiated wholes, it would nonetheless be possible to learn how to combine those words in sentence construction, a position suggested by Beckman and Edwards, who in 2000 wrote “…there has recently been a surge of evidence supporting a core role for the lexicon in grammatical organization in general” (p. 240). Thus, some aspects of syntax could be learned unfettered by the effects of deficient phonological sensitivity. Problems listening in noise might diminish opportunities to hear those syntactic structures, imposing an obstacle of a different sort on acquisition, but intervention focused on teaching syntax could reasonably be expected to counteract that diminished opportunity for language exposure.

On the other hand, sensitivity to word-internal phonemic structure should affect children’s learning about how word forms change based on syntactic structure (i.e., morphology). Pervasive difficulties acquiring bound morphemes have been observed for children with NH who are diagnosed with language impairments (e.g., Bellaire et al. 1994), and it has been suggested that the problem may stem from poor phonological representations (e.g., Connell & Stone 1992). Consequently it is reasonable to suggest that the difficulties children with CIs experience in developing clear phonological representations, arising from poor access to spectral detail in the acoustic signal, could negatively impact their abilities to learn about morphological structure, especially bound morphemes.

Language development in children with CIs

One study specifically asked if the diminished access of children with CIs to spectral detail affects their acquisition of word-internal morphological structure more than their acquisition of whole morphological units. Using a series of probes, Svirsky and colleagues (2002) observed that children with CIs were no better than age-matched peers with SLI at using bound morphemes to mark verb tense, but excelled at using uncontracted copulas. Bound morphemes are appended to words, making them part of the word-internal structure; uncontracted copulas are separate words. Consequently, this outcome matches the prediction that children with CIs could learn elements of morphosyntactic structure involving whole words more readily than elements that are components of words. Supporting that suggestion is evidence from another study. Recently, Guo et al. (2013) showed that children with CIs used tense markers with verbs less frequently in language samples than age-matched peers developing language typically. A goal of the current study was to investigate whether the acquisition of bound morphemes is related to the discovery of word-internal structure for children with CIs.

An experiment involving children with mild-to-moderate hearing loss provides even more support for the suggestion that some language structures should develop in children with CIs unhindered by phonological constraints. The authors of this experiment (Briscoe et al. 2001) investigated vocabulary, grammatical understanding, phonological processing skills, and literacy in children (5 to 10 years old) with SLI, children with mild-to-moderate hearing loss, and children with neither condition. Results showed that the children with hearing loss performed similarly to the children with SLI on all of the phonological processing tasks, but were indistinguishable from the children with neither condition on the grammatical and literacy tasks. These findings led the authors to conclude that "….phonological problems that are tightly linked to language and literacy difficulties in normally hearing children can be dissociated from other language skills in the hearing impaired." (p. 338). A primary goal of the current investigation was to examine whether a similar dissociation between phonological skills and grammatical abilities would be found for children with hearing loss significant enough to warrant CIs.

The investigations that have been conducted thus far on grammatical skills in children with CIs show developmental lags compared to children with NH. For example, a study by Geers et al. (2003) examined the development of grammatical structure in 181 children with CIs, and 24 age-matched peers with NH, all tested at 8 to 9 years of age. As the measure of grammatical structure, the Index of Productive Syntax (Scarborough 1990) was used. With this instrument, trained listeners review language samples from children. Occurrences of 56 syntactic and morphological forms are evaluated, providing scores of complexity in noun phrases, verb phrases, questions/negations, and sentence structures. When Geers and colleagues applied this index, the mean score of children with CIs was 1.13 standard deviations (SDs) below the mean of the control group (i.e., Cohen's $d = 1.13$). Thus, this study suggests that children with CIs trail their peers with NH in grammatical development.

Of course, the children in the Geers et al. (2003) study received their implants nearly two decades ago, when the devices were different from current ones and bilateral implantation was rare. Bilateral implants could provide a boost to the development of grammatical abilities by aiding speech recognition in noise. As already suggested, delays in grammatical abilities would be expected to arise at least partly due to diminished opportunity for children with CIs to hear the ambient language in noise. Finally, many of the children in the Geers et al. study did not receive their first implants until 4 or 5 years of age, which is late by current standards. Given improved technology, the use of bilateral CIs, and earlier implantation, it seemed worthwhile to assess the development of language structure for children with CIs at present.

One study that did investigate potential effects of a significant change in treatment approach for children with CIs was Boons et al. (2012). These investigators used the Reynell Developmental Language Scales and the Schlinchting Expressive Language Test to evaluate language development in deaf children as a function of whether they received one or two implants. In that study, all children received their first implant before the age of 3 years, and were tested three years after receiving that implant. That means all children would have been 4 or 5 years old when tested. Testing occurred between 2003 and 2009, which means that these children received their first implants between 2000 and 2006, which is more recently than the children in the Geers et al. (2003) study received theirs. Although Boons et al. (2012) found that children with bilateral implants performed significantly better than children with unilateral implants, outcomes were somewhat perplexing. Children with bilateral implants performed roughly one SD below normative means (i.e., Cohen's d = 1.00), which is similar to what Geers and colleagues reported in 2003 for children who presumably had only unilateral implants. The difference in the Boons et al. study was that the children with unilateral implants performed closer to 2 SDs below normative means. Consequently, children with bilateral implants and newer technology in the Boons et al. study performed similarly to children with unilateral implants and older technology in the Geers et al. study. This difference across studies could be due to differences in test materials, but there is no way to ascertain if that is the case. Thus questions remain open regarding potential effects of various treatment approaches to childhood hearing loss on grammatical acquisition.

Goals of the Current Study

In total, the current study had three goals. First, the use of several language structures in the narrative samples from children with CIs was examined with Systematic Analysis of Language Transcripts, or SALT (Miller & Iglesias 2010), and compared to that of same-age peers with NH. SALT was used to assess how well children incorporate specific structures into the language they produce because it seemed most complementary to how the contributions of language knowledge to speech recognition is measured: that is, with open-set sentence recognition (e.g., Nittrouer & Boothroyd 1990). Furthermore, the practice of analyzing fairly unstructured language samples is widely viewed as more ecologically valid than formal testing with specific constructions, and has successfully been shown to identify language deficits in children of kindergarten age (Hewitt et al. 2005).

In order to achieve this first goal, five language measures served as the focus of investigation. Two measures involved syntax, and they were the mean length of utterance in morphological units (henceforth MLU) and the number of conjunctions, excluding *and*. MLU is a reliable metric of syntactic development that can uncover language delays across a wide range of ages (e.g., Rice et al. 2010); the number of conjunctions provided an additional metric of sentence complexity (e.g., Menyuk 1969; Bloom et al. 1980).

Two measures used in this study involved morphological structure, and involved children's appropriate use of personal pronouns and bound morphemes. Pronouns are independent morphological units, so it could be predicted that learning to use pronouns would not be strongly dependent on sensitivity to phonological structure. Personal pronouns were specifically selected out of the larger set of pronouns that are counted by SALT because the accurate use of these pronouns reflects children's grammatical skills. By contrast, the heavy use of some pronouns (such as demonstratives) can occur for reasons of less interest. For example, the heavy use of demonstrative pronouns may simply reflect a weak vocabulary: it is easy to substitute a general term (e.g., *that* or *this*) for an unknown lexical item.

In contrast to pronouns, the ability to use bound morphemes suggests that some analysis of word-internal structure has likely been performed by the child, so the use of these morphological forms should depend heavily on phonological sensitivity. Including both pronouns and bound morphemes in the analysis also meant it was possible to test the validity of the methods implemented in this study more generally. The use of bound morphemes was expected to correlate with phonological awareness; the use of pronouns was not. If evidence to support that prediction was obtained it would mean that the methods were sensitive to relationships between phonological awareness and language structures, when they existed.

Semantic knowledge was also of interest in this study because this sort of knowledge has consistently been shown to contribute to the recognition of words in sentences (e.g., Kalikow et al. 1977; Boothroyd & Nittrouer 1988; Nittrouer & Boothroyd 1990). For the current study, the most appropriate measure for assessing semantic development was the number of different words used in the analysis sample. Although frequently described as a measure of lexical diversity (e.g., Watkins et al. 1995; Scott & Windsor 2000; Swanson et al. 2005), the number of different words used in discourse has also been described as a metric of semantic development (Miller 1991; Hewitt et al. 2005).

The second and primary goal of the current study was to examine whether any delays in the development of grammatical abilities observed for children with CIs can be related to delays in the acquisition of phonological awareness. Based on earlier findings, it was predicted that measures of phonological awareness would yield lower scores for children with CIs than for children with NH. The real question addressed here was whether those anticipated deficits in phonological awareness could account for any observed delays in learning about grammatical structures. This information should be useful in the design of intervention programs. If the acquisition of grammatical structure is heavily dependent on children having sensitivity to word-internal structure, then early intervention needs to focus first on refining phonological forms. If not, then intervention can emphasize grammatical organization, without regard to how well refined children's phonological structures are; intervention to hone sensitivity to phonological sensitivity could proceed in parallel.

The third goal of this study was to examine the effects of factors arising from childhood hearing loss and its treatment on the development of language skills. The children in the current study were all identified with hearing loss at very young ages, typically before 12 months. All children received their first implants within a restricted time period, generally between 2004 and 2006. This factor is important for experimental design. Many studies examining language performance in school-age children with CIs collect data in a retrospective manner, test children over a wide range of ages, or test over a broad time span. In any case, there is often variability in the generations of CIs represented, which can make it difficult to interpret outcomes. In this study, children were all of similar chronological age at the time of testing and were tested close to the same time, which ensured that the implant technology they received was similar.

Finally, one other language skill was examined in this study: lexical knowledge. It has been proposed that grammatical acquisition for children with CIs may proceed based on lexical representations that may be less refined than those of same-age peers with NH. The question arises of how that difference in representation affects grammatical development. Consequently, it seemed important to examine potential relationships between vocabulary and grammatical skill.

Method

Participants

Forty-six children who had just finished kindergarten were tested. Twenty-seven had severe-to-profound sensorineural hearing loss and wore one or two CIs. Nineteen children had NH. With alpha set to .05, these sample sizes provided 90% power to detect differences between these groups when Cohen’s $d = 1$. Differences of that magnitude or greater were expected going into the study, based on outcomes of others (e.g., Geers et al. 2003). Except for four children with NH, all children had participated in a longitudinal study from 12 to 48 months of age (Nittrouer 2010). No child with CIs had any condition other than hearing loss that on its own would reasonably be suspected to pose a risk to language development. Intervention services for all children with CIs started soon after they were identified with hearing loss and focused on the development of spoken language. In particular, all children with CIs received services from intervention specialists with a Master’s degree or higher at least once a week from the time they were identified until they reached 3 years of age. From 3 years of age until they began kindergarten, these children spent at least 16 hours per week in preschool programs specially designed to serve children with hearing loss. All children attended mainstream kindergarten classes, without sign language interpreters.

Table 1 shows demographic information for the two groups. Socio-economic status (SES) was indexed using a two-factor scale that incorporates the highest educational level and the occupational status of the primary income earner in the home (Nittrouer & Burton 2005). 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. In general, a score of 30 represents a household in which the primary income earner has a four-year university degree and a job such as a mid-level manager or a teacher. A score of 20 represents a household in which the primary income earner has a high school diploma and works in a service industry, construction, or as a skilled craftsman. An independent-samples *t* test performed on these scores revealed no significant difference in SES between the two groups.

Three sub-tests of the Leiter International Performance Scale-Revised (Roid & Miller 2002) were used as an index of non-verbal cognitive abilities: matching, figure ground, and classification. Raw scores obtained at 48 months of age are shown in Table 1, excluding the four children with NH who were not part of the original study. Scaled scores were not computed for individual children because raw scores provide more precision, making them more sensitive to group differences in statistical analysis. However, scaled scores corresponding to group means are shown in Table 1. Scaled scores have a mean of 10 and a SD of 3. Independent-samples *t* tests performed on raw scores revealed no significant difference between the two groups on any subtest. The values shown in Table 1 indicate that means were similar across groups, and these children were within the range of normal.

The five bottom rows of Table 1 show audiometric data for the children with CIs. Most children were identified with hearing loss before one year of age, and all before 2 years. All but three children had their first implants before 3 years of age. At the time testing occurred, 18 children had two CIs. Thirteen children with CIs in the study had continued to use a hearing aid for a year or more after they received their first CIs (i.e., had bimodal experience): seven of those children had bilateral CIs at the time of testing (i.e., they eventually received a second implant), five used one CI at the time of testing (i.e., they eventually stopped wearing the hearing aid), and one child used bimodal stimulation at the time of testing.

Equipment and Software

All testing took place in sound-attenuated rooms. All test stimuli were presented via a computer with a Creative Labs Soundblaster digital-to-analog card using a 44.1-kHz sampling rate with 16-bit digitization and a Roland MA-12C powered speaker for audio presentation, placed one meter in front of the child at 0-degrees azimuth. The phonological awareness tasks were presented in audio-visual format using a 1500-kbps data rate and 24-bit digitization for video presentation.

A SONY HDR-XR550V video recorder was used for videotaping the sessions. Children wore SONY FM transmitters in specially designed vests that transmitted speech signals to the receivers, which provided direct line input to the hard drives of the cameras to ensure good sound quality for all recordings.

Transcripts were submitted to analysis in SALT (Miller & Iglesias 2010). SPSS version 19 was used for statistical analysis.

General Procedures

All procedures were approved by the Institutional Review Board of the Ohio State University. Data reported here were collected in two sessions, and children had one hour or more between sessions. All testing was video-recorded with high-quality audio so scoring could be done later, except for the tasks of phonological awareness. Responses on those tasks were entered directly into the computer by the examiner.

Stimuli and Task-Specific Procedures

Language measures—Children's abilities to use specific language structures were assessed using a 20-min language sample, consisting of several personal narratives. To elicit these narratives, the examiner entered the room with a bandage on one hand. She explained that she hurt her hand and had been to see a doctor. Using a framework of descriptions of how the injury would affect upcoming plans, the examiner elicited personal narratives related to five themes: (1) what happened at a doctor's visit the child recently had; (2) a fun birthday party the child has attended; (3) the child's experience playing a favorite sport or game; (4) the best vacation the child has taken; and (5) the best movie the child has seen. The examiner used a stopwatch to keep track of time and ensure that each child had 4 mins (+/− 30 sec) to produce a narrative related to each theme. Topics were introduced to all children in the same order.

A 15-min transcript was generated from each language sample, starting 5 minutes into the sample. This 5-min delay was implemented on the premise that children might take some time to warm up to the activity. Two students in Speech and Hearing Science and the laboratory manager trained together on transcription methods for SALT, and were involved in transcribing these samples according to SALT conventions (Miller & Iglesias 2010). One of the two students watched each video and transcribed every utterance the child produced (intelligible and unintelligible) in the 15-min segment. After completing the transcript, the student went back and checked it by watching the video while reading the transcript. Then the second student checked the same transcript for accuracy by reading through it while watching the video. Finally, the two students watched the video together and resolved all discrepancies in how specific utterances should be transcribed by discussing them and reaching consensus. The entire transcription process was monitored by the laboratory manager, who served as an arbitrator if the students were unable to reach consensus regarding how any specific utterance should be transcribed. In addition, the laboratory manager transcribed ten percent of the samples (that she had not been involved in arbitrating) herself. No discrepancies were noted in this check between what the laboratory manager recorded and what the combined efforts of the graduate students yielded. These methods were similar to those of other investigators (e.g., Hewitt et al. 2005).

After all transcription had been completed, each transcript was analyzed using SALT. Only complete and intelligible utterances were used. An utterance was defined in this work as a Communication Unit, which in turn is defined as an independent clause and its modifiers (Loban 1976). Five language measures were selected for use.

1. *Mean length of utterances in morphemes (MLU)* was computed as a measure of syntactic abilities. This metric was developed as part of Brown's stages of language development (1973), who described it as a critical indicator of syntactic skill because almost any enhancement in knowledge serves to increase length. Brown viewed the utility of the measure as hitting asymptote at roughly an MLU of 4, and others have criticized the use of this measure with children beyond preschool (Klee

1992; Rollins et al. 1996; Crain & Lillo-Martin 1999). Nonetheless, investigations have found MLU to be sensitive to syntactic abilities in older children, at least when language deficits are suspected (e.g., Condouris et al. 2003). For example, Hewitt et al. (2005) examined competencies for a variety of language skills in kindergartners with SLI and those with typical language development. MLUs were well above 4 for both groups: 5.82 for children with SLI and 6.86 for those with typical language development. These authors found that the children with SLI had poorer scores than their normally developing peers on most of the other skills evaluated, and MLU was highly predictive of those deficits. Thus, MLU was selected for use in the current study as an indicator of syntactic abilities. MLU was computed on the analysis set of complete and intelligible utterances for the entire 15-minute sample, which seemed appropriate because it is not a count of specific structures, so is not dependent on the number of utterances used to compute it.

2. The numbers of *conjunctions* were computed on the first 100 utterances as a measure of syntactic complexity (e.g., Bloom et al. 1980). The conjunction *and* was excluded from this analysis because *and* is used even by linguistically unsophisticated children to string clauses together (Menyuk, 1969; Bloom et al. 1980). Conjunctions other than *and* provide a stronger metric of a child’s ability to connect clauses and mark semantic relations. Specifically, the conjunctions that were counted by SALT were: *after*, *as*, *because*, *but*, *if*, *or*, *since*, *so*, *then*, *until*, and *while*. Although the use of conjunctions usually increases MLU, counting conjunctions provides a slightly different indicator of syntactic complexity because it is possible to increase MLU without additional clauses by elaborating noun and/or verb phrases. Furthermore, syntactic complexity can vary across sentences of the same length, which would be missed in analysis if only MLU were considered. For this study, types of conjunctions were not evaluated separately (other than by the exclusion of *and*) because too few of any one type were produced (other than *and*) to provide a reliable metric on its own.

3. The number of *personal pronouns* was computed on the first 100 utterances, and used as a measure of the development of unbound morphemes. The ability to use personal pronouns correctly requires that the speaker recognize attributes of the words to which they refer, such as gender, as well as syntactic constraints, such as case. In order to gauge how use of personal pronouns compared to the use of pronouns more generally, the total number of pronouns (of all sorts) was also computed for the 100-utterance analysis set, and personal pronouns were evaluated as a proportion of those totals. The specific personal pronouns counted in this analysis were: *he*, *her*, *him*, *I*, *it*, *me*, *she*, *them*, *they*, *us*, *we*, and *you*.

4. The number of word-final *bound morphemes* was also computed on the first 100 utterances. In this analysis, all inflectional morphemes were examined, and were specifically: verb-related *–ed*, *-s*, *-ing*; noun-related plural *–s* and possessive *–s*; and adjective-related *–er* and *–est*. As with conjunctions, too few of each type were produced to provide a reliable metric on its own. Furthermore, having a variety of bound morphemes was considered desirable in this instance because some of the words containing bound morphemes could be represented in the lexicon of these

children as unanalyzed wholes; others could be represented as root plus affix. It is especially that latter case that would be expected to correlate with phonological sensitivity, and uncovering that relationship could be missed if only a subset of bound morphemes was included in the analysis.

A reason for including this measure of bound morphemes was to test the sensitivity of the methods used in the study to uncover relationships between phonological and language structures, where they exist. The use of bound morphemes (or, at least some of them) would be expected to depend on children's sensitivity to word-internal phonological structure, and word-final bound morphemes would be expected to depend specifically on sensitivity to structure at the ends of words. If that relationship were found for bound morphemes, but not other structures (in particular, personal pronouns) it would lend credence to the argument that developing abilities to use these other structures is not heavily dependent on emerging sensitivity to phonological structure. In order to try to gauge whether there were differences between groups in the use of bound morphemes in obligatory contexts, the numbers of obligatory contexts were considered, as well. These are defined as instances in which a bound morpheme is required in order to preserve grammatical accuracy.

5. The *number of different words (NDW)* was counted across the first 100 utterances obtained in the language sample, as others have done (e.g., Watkins et al. 1995; Hewitt et al. 2005). This measure is sometimes referred to as a metric of productive vocabulary because it indicates how well children can incorporate items in their lexicons into the language they produce (Pérez-Leroux et al. 2012). In this case, the number of total words (NTW) across the 100-utterance set was computed, as well, and NDW given as a proportion of NTW in order to examine potential relationships of these two variables for each group. This proportion is traditionally termed the *type-token ratio* (Templin 1957), and typically does not vary for children with NH depending on whether they have normal language or SLI (e.g., Watkins et al. 1995).

Phonological awareness—Three tasks were used to assess phonological awareness. These specific tasks were selected to vary in the precise phonological structure they examined and in the level of meta-linguistic skill required to complete the task. The signal processing performed by CIs would be expected to preserve various levels of structure differently, and work by others (e.g., Liberman et al. 1974; Stanovich et al. 1984) has shown that even children with NH develop sensitivity to different kinds of structure at different ages. Meta-linguistic awareness refers to the ability to focus on linguistic structure itself, and this ability has been shown to develop as a result of language experience (Cazden 1974). Having variability on both these attributes (i.e., sensitivity to phonological structure per se and meta-linguistic awareness) diminished the possibility of missing a critical difference in competencies between groups, if one should exist. Each phonological awareness task used in this study has been used previously, and has been shown to reliably distinguish between children with good and poor sensitivity to phonological structure (e.g., Nittrouer & Burton

2005). Exact protocols for each phonological awareness task are available in the online appendix of Nittrouer et al. (2012).

All phonological awareness tasks were administered in an audiovisual format to minimize the possibility that children with CIs would perform poorly because of problems recognizing the test items, which could happen in an audio-only format. Each task had 48 items. The *syllable-counting* (SC) task involved the child seeing and hearing the talker in the video (a man) say a word. The child needed to tap on the table in time to each syllable while repeating the word, and report how many syllables were in the word. Syllable structure is well represented in the amplitude structure of the speech signal because syllables generally involve an articulatory constriction on one or both sides, with an open configuration at syllable middle. The amplitude structure that arises as a result of syllable production involves change between minima and maxima. Consequently, syllable structure should be well-preserved by CI signal processing. Furthermore, sensitivity to this level of structure developmentally precedes sensitivity to individual phonemes (Liberman et al. 1974). Thus it was predicted that children with CIs should be sensitive to this level of phonological structure. Nonetheless, the task demands of tapping in synchrony to the production of each syllable and then counting the number of taps issued introduced the need for some level of meta-linguistic awareness.

In the *initial consonant same-different* (ICSD) task, the child heard and saw the talker say two words. The child was then asked to report whether the two words started with the same or different sounds. All words were monosyllabic, and most (75%) involved singletons as the initial consonant; 25% involved two-consonant clusters. Although this task required sensitivity to explicitly phonemic structure, meta-linguistic demands were less rigorous than for the SC task.

In the *final consonant choice* (FCC) task, the child heard and saw the talker say a target word. As with the ICSD task, all words were monosyllabic, and 25% included two-consonant word-final clusters. The child had to repeat the target word correctly. Three opportunities were provided to repeat it correctly. If children could not do so within that time frame, that test item would not be included. However, that was not a problem for any of these children because they all were able to recognize all the words with audiovisual presentation. After the target was repeated, three more words were presented and the child had to report which of the three had the same ending sound as the target. This was the hardest of the three phonological awareness tasks, both because sensitivity to syllable-final phonemic structure is acquired later than sensitivity to syllable-initial structure (Stanovich et al. 1984), and because greater demands were placed on short-term memory.

Practice was provided before testing with each task, and feedback given during that practice. During testing, the task was discontinued if a child responded incorrectly to six consecutive items. This procedure is often incorporated into standardized assessment tools. The percentages of correct answers were used as dependent measures of phonological awareness.

Lexical knowledge—Expressive vocabulary is commonly used as a metric of lexical abilities. In this study it was assessed with the Expressive One-Word Picture Vocabulary

Test, or EOWPVT (Brownell 2000). This task requires the child to provide the words that label a series of pictured items shown one at a time on separate pages. This test is designed for children from two years to 18 years of age. Both raw and standard scores are reported, but only raw scores were used in statistical analyses because they are generally more continuous in distribution and sensitive to group differences.

Results

Six children with CIs did not produce 100 complete and intelligible utterances, so their data were not included in the analysis. This meant there was data from 21 children with CIs in the analysis, which provided adequate power (87%) to detect statistically significant differences in performance between children with NH and children with CIs, with a Cohen's *d* of 1.00 and an alpha level of .05.

The six children whose data were removed from analysis were indistinguishable from the other children with CIs in terms of demographic and audiometric factors. Their mean SES score (and SD) was 36 (7), which was slightly higher than the overall group mean. Mean age of identification of hearing loss was 7 months (5 months), and mean age of first implant was 23 months (16). These audiometric variables match those for the larger group. All six children who failed to produce 100 complete and intelligible utterances had two implants at the time of testing.

Before analyses were conducted on the scores for the remaining 40 children, all dependent measures were screened to ensure that scores were normally distributed and there was homogeneity of variances between groups. The mean numbers (and SDs) of complete and intelligible utterances were 180 (39) and 154 (31) for children with NH and CIs, respectively. These numbers represent means of 98 percent (2 percent) of all utterances collected for children with NH, and 93 percent (4 percent) of all utterances for children with CIs. This difference is statistically significant, $t(38) = 4.59$, $p < .001$. (Throughout this report, precise statistical outcomes are reported for $p < .10$; for $p > .10$, results are described simply as *not significant*.) Thus, slightly fewer utterances from children with CIs were complete and intelligible.

Language measures

Table 2 shows mean scores for each group on the measures obtained from SALT. Before evaluating differences between groups, however, four of the five measures were examined in more depth. That was done to get a broader picture of language production for these children, and to ensure that the measures selected for consideration were not constrained by other language measures in any way that would make them invalid metrics of the structures of interest.

Personal pronouns—The mean numbers of total pronouns (and SDs) were 114.2 (20.2) for children with NH and 91.3 (21.8) for children with CIs, and this difference is significant, $t(38) = 3.43$, $p = .001$. Personal pronouns (shown in Table 2) accounted for 66 and 69 percent of these totals for children with NH and CIs, respectively; this difference is not statistically significant. Across all classes, children with CIs produced fewer pronouns than children with NH, but personal pronouns were the most frequently used class of pronouns by children in both groups. This analysis suggests that counts of personal pronouns served as a valid index of pronoun use in general by these children.

Bound morphemes—In addition to the numbers of bound morphemes shown in Table 2, counts were obtained of the numbers of contexts where one of the word-final bound morphemes counted in this study would be obligatory. For children with NH there was a mean of 54.6 (9.3) obligatory contexts; for children with CIs, there was a mean of 45.5 (13.3) such contexts. This difference is significant, $t(38) = 2.47$, $p = .018$. Thus, children with CIs incorporated into their discourse fewer morphosyntactic structures that would require these bound morphemes. The strategy of not using constructions until they are close to being fully acquired, which appears to be present in the language production of these children with CIs, has been documented for children with NH (e.g., Bowerman 1982). It has been dubbed *grammatical conservatism* by Snyder (2007), who explains the strategy with the proposal that children generally produce only what they already know – although there are some exceptions, such as overgeneralization of regular verb tense. This strategy of generally not attempting to use forms that have not been adequately acquired has also been observed for phonological development, as well, where it is termed *avoidance* (e.g., Schwartz & Leonard 1982; Schwartz et al. 1987). Only by using formal testing methods (that incorporate specific structures) can the number of obligatory contexts be equated across groups. When the number of bound morphemes used by each child is given as a proportion of the number of obligatory contexts incorporated into the 100-utterance sample, these are found to be 99% (2%) for children with NH and 94% (10%) for children with CIs, a difference that was not significant, $t(38) = 1.79$, $p = .082$. This analysis suggests that counting the number of bound morphemes in these samples is a valid way to examine how skilled children are at using them in their everyday discourse.

NDW—The mean NTW was obtained for these 100-utterance samples. For children with NH, this value was 496.2 (50.3), and for children with CIs it was 418.0 (88.0), and this difference was significant, $t(38) = 3.40$, $p = .002$. Based on these values, children in both groups showed similar proportions of NDW to NTW: Means were .37 (.03) for both groups of children. Based on this outcome, it might be concluded that the lexical diversity exhibited in the language samples of children with CIs was constrained by their general productivity. However, the effect could just as likely have been in the other direction: Abilities to incorporate lexical diversity into the language they produce may have constrained general productivity, a suggestion supported by the finding that these proportions have not been found to differentiate children with typical language development and those with SLI (Watkins et al. 1995). Consequently, NDW was retained as a reasonable metric of semantic development. In any event, the primary goal of the study was to see if sensitivity to word-internal phonological structure explained language development for these children with CIs. That goal could be addressed with this measure.

Group differences—To examine whether significant differences existed between groups in the use of the language structures shown on Table 2, independent-samples *t* tests were performed on each. Significant differences were found for all five measures: MLU, $t(38) =$

3.48, *p* = .001, conjunctions, *t*(38) = 3.23 *p* = .003, personal pronouns, *t*(38) = 2.72, *p* = .010, bound morphemes, *t*(38) = 2.60, *p* = .013, and NDW, *t*(38) = 3.36, *p* = .002. Results from these analyses indicate that the children with CIs trailed their peers with NH in the acquisition of all these structures.

Table 2 also shows effect sizes in the form of Cohen's *d*s for all language measures. This metric is the difference in group means, normalized by SD. In general, mean scores for children with CIs were close to one SD below the means of children with NH (i.e., *d* = 1). Although the metrics of language abilities were different across studies, this finding generally matched results of Geers et al. (2003) and Boons et al. (2012).

Phonological awareness

Mean percent correct scores for the three phonological awareness tasks are shown in the top three rows of Table 3. Cohen's *d*s are also shown. One child with NH became ill halfway through the ICSD task, so testing could not be completed. Independent-samples *t* tests were done on scores for each of the three tasks. No significant difference was found for SC, *t*(38) = 1.82, *p* = .077, but significant differences were observed for ICSD, *t*(37) = 4.75, *p* < .001, and FCC, *t*(38) = 7.34, *p* < .001. Cohen's *d*s showed that the mean scores of children with CIs on the ICSD and FCC measures were more than one and a half SDs below the means of children with NH. The failure to find a significant difference in scores on SC suggests that children with CIs were able to handle the meta-linguistic component of this task adequatenly, thus diminishing the probability that differences in meta-linguistic abilities accounted for the group differences observed in the other two tasks.

Lexical Knowledge

The bottom two rows of Table 3 show mean scores for expressive vocabulary, both raw and standard. An independent-samples *t* test on raw scores showed a significant difference between the groups, *t*(38) = 3.45, *p* = .001. Cohen's *d*s revealed that children with CIs scored more than one SD below the means of children with NH.

Explaining variance

Next, analyses were done to examine the extent to which variance in the five language measures might be explained by phonological awareness and expressive vocabulary. These analyses were performed on data only from children with CIs because they were the group of primary interest. Information regarding the strength of relationship among these skills could be essential to the design of intervention programs for children with CIs. Nonetheless, it is worth noting that no significant correlations were observed between the language measures and phonological awareness or lexical knowledge of the children with NH. However, two measures of phonological awareness were correlated with expressive vocabulary scores for children with NH: SC, *r* = .69, and ICSD, *r* = .60. These correlations likely reflect the fact that lexical development is somewhat dependent on phonological structure for these children with NH.

The first analyses involved computing Pearson product-moment correlation coefficients between every pairwise combination of scores, and Table 4 shows these correlation coefficients. The cells displaying correlation coefficients between language measures and scores of phonological awareness are highlighted. Several results are worthy of mention. First, scores for SC were not correlated with any measure of grammatical ability for children with CIs. Second, measures of sensitivity to phonemic structure (ICSD and FCC) explained no variance on either the number of conjunctions or the number of personal pronouns used by these children. Third, ICSD and FCC explained between 18 and 22 percent of the variance in MLU and NDW (i.e., r was between .43 and .47). Finally, where bound morphemes are concerned, only FCC was associated with any significant amount of variability, and that was the highest correlation coefficient found among measures of phonological awareness and language structures ($r = .59$). That finding had been predicted because these bound morphemes were all in word-final position, so children's sensitivity is to phonemic structure at the ends of words (as measured by the FCC task) should be related to their abilities to learn inflectional morphology in that position. This finding indicates that the methods used were valid, meaning they were able to capture relationships between phonological awareness and grammatical abilities where they existed.

The bottom row of Table 4 shows correlation coefficients for (raw) expressive vocabulary scores and measures both of grammatical abilities and phonological awareness. For these children with CIs, correlations between expressive vocabulary and three measures of language structure were significant: MLU, bound morphemes, and NDW. When it comes to phonological awareness, only the correlation coefficient between expressive vocabulary and ICSD was significant, but it was weaker than what was found for children with NH. This last outcome suggests that vocabulary acquisition for these children with CIs in kindergarten may have been just starting to reflect sensitivity to word-internal structure.

Next, step-wise regression analyses were performed. These analyses were done largely to see if phonological awareness had any impact on the development of grammatical abilities, independent of lexical knowledge. To examine that possibility, separate analyses were done for each of the five language measures, using all three phonological awareness and the expressive vocabulary scores as predictor variables. These analyses were done only for children with CIs. Two of the regression analyses had no significant solutions: conjunctions and personal pronouns. For two other language measures, expressive vocabulary was found to explain significant proportions of variance, with no phonological awareness score explaining any significant amount of additional variance: MLU, standardized β for expressive vocabulary = .670, $p < .001$, and NDW, standardized β for expressive vocabulary = .751, $p < .001$. A significant solution involving a phonological awareness measure was found only for bound morphemes, where the standardized β for FCC was .458, $p = .017$, and the standardized β for expressive vocabulary was .420, $p = .027$. The finding that the use of these morphemes depended equally on lexical knowledge and sensitivity to phonological structure at the ends of words might mean that words with bound morphemes were starting to be analyzed by the child into root and affix, but may still have been functioning as unanalyzed wholes to some extent. Thus, even though the correlation coefficients shown in Table 4 give the appearance that acquisition of grammatical abilities in these children with CIs was explained at least partly by their sensitivity to phonological structure, the stepwise regressions showed that once the variance explained by lexical knowledge was removed, no additional variance was explained by phonological awareness. The exception was for bound morphemes, and skill using that form of morphological structure had been predicted to be related to sensitivity to word-final phonemic structure.

Audiological and Treatment Effects for Children with CIs

Next, outcomes for children with CIs were examined to see if factors related to their hearing loss or treatment of that hearing loss could explain any significant amounts of variance in grammatical abilities. SES was included in these analyses.

Pearson product-moment correlation coefficients were computed between each of the five measures of language structure and the factors of SES, age at identification, age at first implant, age at second implant, length of first implant experience, and pre-implant better-ear PTA. Only age at first implant was significantly correlated with any of the language measures: MLU, $r = -.641$, $p = .002$, and NDW, $r = -.570$, $p = .007$. These negative correlation coefficients indicate that the earlier children received their first implants, the better their abilities were to use these language structures. No other factor was found to be related to grammatical abilities for these kindergarten children. This finding does not necessarily mean that none of these other factors contributed to the grammatical capabilities of these children with CIs. In this case, it may reflect the fact that variability in these other factors across the children in this study was highly constrained. For example, all children in the current study were identified with hearing loss before 24 months of age. Although the variability within that two-year span was not sufficient to explain any variance in measures of grammatical abilities, it would be reasonable to predict that these abilities would be negatively affected if children were identified much later than two years of age.

Turning to possible prosthesis effects, Tables 5 and 6 show means for the language measures for children with one or two CIs, and for children with some or no bimodal experience, respectively. One child was still using a hearing aid on the ear contralateral to the one with a CI at the time of testing. That child was excluded from these analyses because the child did not fit cleanly into any of the groups for which data are shown on these two tables. From Table 5 it does not appear that there was any effect of using one or two CIs, and *t* tests performed on these scores failed to reveal any significant differences. From Table 6, however, it appears that children who had a period of bimodal experience performed better on all measures than children with no such experience. When *t* tests were performed, the effect was significant for just two measures: MLU, $t(18) = 2.08$, $p = .052$, and pronouns, $t(18) = 2.22$, $p = .040$.

Discussion

The current study examined the abilities of kindergarten children with CIs to use various kinds of language structure in their production. The motivation for this study was to see if children with CIs could acquire knowledge about language structures that would not necessarily depend on sensitivity to phonological structure, because that knowledge could facilitate their speech recognition in everyday settings. Three specific goals were addressed. First, the grammatical abilities of these children were measured and compared to those of children with NH. Outcomes of this comparison were evaluated against earlier studies of language abilities in children with CIs to see if newer implant technologies and approaches to treatment are influencing language development in children with CIs.

The second goal of this study was to evaluate the extent to which these children's grammatical abilities depended on their phonological awareness and lexical knowledge. The answer to this particular question should have significant implications for intervention. Children with CIs have been found to have deficits in their phonological awareness, and those deficits likely arise due to the degradation in signal quality incurred by implant processing, even with current strategies. Accordingly, if grammatical abilities were largely explained by phonological awareness, sweeping improvements in grammatical abilities for these children would mostly require waiting for still better processing strategies to be developed and implemented. If instead, grammatical abilities develop even somewhat independently of sensitivity to phonological structure, then it might be possible to facilitate the acquisition of grammatical skills through intervention focused on that level of language structure, even for children with delayed phonological awareness. This approach differs from what might be termed "bottom up" approaches, which are those placing an early emphasis on building skills in the detection and production of individual phonemes or syllables. Only after children acquire a certain level of skill at detecting or producing these linguistic units does intervention move to a focus on sentence-level structures.

The third goal of the current study was to examine how well specific variables related to hearing loss and its treatment account for the emergence of grammatical abilities. As with the examination of phonological awareness, this line of investigation could shed light on how early intervention might be modified to facilitate further the acquisition of language structures.

Outcomes of the current study showed that children who received CIs within the past decade continue to lag behind their peers with NH in terms of grammatical abilities, but there are several reasons to suspect that it is not due strictly to deficits in phonological awareness. Cohen's *d*s for differences in performance on the phonological awareness tasks between children with NH and those with CIs were close to a value of 2. This finding indicates that children with CIs performed more poorly relative to the control group on phonological awareness than on any other measure – dependent or predictor – obtained in this study. In particular, when it comes to language measures, Cohen's *d*s ranged between 0.82 and 1.12. If grammatical development were predominantly dependent on the development of sensitivity to phonological structure, this discrepancy in effect sizes would not have been seen. Instead, performance of children with CIs on the language measures would have been constrained by their performance on the phonological awareness tasks such that Cohen's *d*s would have been either similar across the two kinds of measures, or larger for the measures of language structures. Thus it seems fair to conclude that children acquire sensitivity to phonological structure and their knowledge of language structures at least somewhat independently. In fact, children's expressive vocabulary skills explained more variance in outcomes for the language measures than did the measures of phonological awareness. Although the lexical representations of children with CIs are likely less differentiated than those of children with NH – due to poorer sensitivity to phonological structure – these children with CIs were apparently able to learn how to combine and inflect those lexical items, to some extent.

A reasonable explanation for the deficits in grammatical abilities observed for children with CIs could involve the impoverishment in language experience resulting from the hearing loss itself. Such deficits have also been reported for children with histories of otitis media with effusion and children growing up in poverty (Nittrouer & Burton 2005), two groups of children who would be expected to suffer diminished language experience for reasons other than permanent sensorineural hearing loss. In the current study, support for the suggestion that diminished experience might be largely responsible for the weaker grammatical skills observed for children with CIs, compared to peers with NH, was obtained from the fact that age at first implant explained a significant amount of variance in scores on the language measures. Age at which a deaf child receives an implant is one factor that accounts for the amount of language experience obtained. Other factors can include the amount of time spent in intervention, quality of that intervention, and interaction style of the parents (Nittrouer 2010). If indeed diminishment in language exposure and experience accounts for the deficits observed in the current study, then enhancing intervention should be the primary approach taken to improve the observed outcomes.

Results addressing the third goal of the study emphasize the critical role played by early implantation to the acquisition of language skills. Age at first implant was the only variable related to hearing loss or its treatment found to correlate significantly with the language measures.

Comparison with earlier studies

Results of this study match those reported in previous studies of children implanted with earlier generations of CIs. In particular, the reports reviewed in the Introduction (Geers et al. 2003; Boons et al. 2012) tested children who almost invariably received CIs and processors with older technology than those received by the children in the current study. Both of those papers reported that children with CIs scored slightly more than one SD below the means of children with NH on tests of morphosyntactic abilities. Although the specific measures used in those studies differed from those of the current study, effect sizes were similar.

Weakness of the current study and future directions

This study collected narrative samples from children using a highly regimented scaffold to ensure some consistency in topic; nonetheless, those samples were shaped by the children themselves. From those samples, transcripts were generated, and submitted to analyses of the language structures produced by the children. This method of evaluating language production provided an ecologically valid way of assessing the structures these children use in their daily discourse. At the same time, the method imposed some limitations. For example, numbers of obligatory contexts could not be equated across the two groups. In addition, specific types of conjunctions and bound morphemes could not reasonably be examined separately. A method of formal testing that uses well-designed probes provides the best way of ensuring that children in all groups have equal opportunities to use specific elements of grammatical structure. Nonetheless, it must surely be the case that the field benefits from having the kind of corroborating evidence that can only come from different studies using different methods. In this case, the outcomes of this study support findings of others who have examined language abilities in children with CIs using other methods, such as Svirsky et al. (2002) and Geers et al. (2003).

Several ideas for future research with children who have CIs are suggested by the outcomes of this study. In general, it seems important to explore further the relationships among various language structures in this population in order to understand how intervention should proceed. Recognizing the foundational skills that enable children with CIs to acquire knowledge about specific language structures will specify what skills should be emphasized in intervention, across the developmental continuum. A particular objective for future work should be to examine more carefully reorganizational processes in lexical acquisition by children with CIs. The regression analysis with bound morphemes indicated that sensitivity to word-internal phonemic structure explained some of the variance in children's abilities to use these structures. This finding indicates that these children were starting to analyze that word-internal structure, and their abilities to do so explained their abilities to learn about bound morphemes. The ability to analyze structure in the ambient language – and even in the language children have started to use as unanalyzed structure – is critical to development, and seems to happen most intensively during the preschool years for children with NH (Bowerman 1982). It would help teachers and clinicians design intervention, if this process and its timing were better understood for children with CIs.

Clinical implications

Regarding clinical implications, the finding that expressive vocabulary scores explained significant amounts of variance in the language measures over and above what could be explained by phonological awareness alone indicates that neither lexical knowledge nor grammatical abilities are dependent solely on children acquiring sensitivity to phonological structure. That means that intervention with deaf children should be focused on facilitating the learning of new vocabulary and morphosyntactic structures, regardless of children's sensitivity to phonological structure. That suggestion does not mean that intervention should not seek to help children hone their sensitivity to phonological structure; rather it means that intervention to facilitate the acquisition of lexical and morphosyntactic structure should not be postponed until some level of sensitivity to phonological structure is attained.

Another important implication of this study is that intervention must be provided to children with CIs, beyond the preschool years. All children in this study had just completed kindergarten and those with CIs showed significant delays in performance on grammatical, lexical, and phonological abilities. Thus it is fair to conclude that any child with CIs entering school should be considered to be at risk of language delay. There are many benefits to placing these children in mainstream educational settings, but it must be understood that they still need focused intervention to support their continued acquisition of language.

Summary

This study was undertaken to measure the abilities of children who receive CIs to incorporate grammatical structures into their language production, and compare those abilities to those of children with NH. Additional goals involved examining whether measured grammatical abilities depended on phonological awareness, lexical knowledge or factors related to the hearing loss or its treatment. Results showed that children with CIs continue to lag in their development of grammatical abilities, in spite of technological advances and changes in treatment that have been implemented in recent years. The primary variables demonstrating predictive power for the language measures were expressive vocabulary scores and age at first implant. The finding that phonological awareness explained no variance over and above what was explained by expressive vocabulary scores (with one exception) suggests that intervention focused on helping children with CIs acquire grammatical abilities should be effective. There is no reason to wait until sensitivity to phonological structure has been acquired to a specified level before implementing strategies to help children learn about other kinds of language structures.

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Table 1

Means and SDs for demographic measures. Numbers of participants are shown.

	NH		**CI**	
	19		**21**	
	M	**(SD)**	**M**	**(SD)**
Age at time of testing (months)	80	(3)	82	(5)
Proportion of males	.42	---	.44	---
Socio-economic status	36	(13)	33	(12)
Leiter Matching Raw Score	27.4	(3.7)	26.0	(4.9)
Leiter Matching Scaled Score	11	---	10	---
Leiter Figure-Ground Raw Score	12.3	(3.7)	11.4	(3.4)
Leiter Figure-Ground Scaled Score	12	---	12	---
Leiter Classification Raw Score	14.3	(2.2)	13.6	(4.5)
Leiter Classification Scaled Score	10	---	10	---
Age at identification (months)			8	(8)
Pre-implant better-ear PTAs			99	(18)
Age at 1st implant (months)			21	(13)
Mean length of 1st implant use (months)			61	(13)
Age at 2nd implant (months); N = 18			35	(14)

Table 2

Means and SDs for the five language measures obtained from SALT. In the last column, Cohen's *d*s provide the estimates of effect size between children with NH and children with CIs.

	NH		CI		Cohen's *d*
	M	**(SD)**	**M**	**(SD)**	
Mean Length of Utterances - Morphemes	5.6	(0.6)	4.7	(.98)	1.12
Number of Conjunctions	19.7	(6.1)	13.0	(6.9)	1.03
Number of Personal Pronouns	74.8	(14.5)	62.2	(14.7)	0.86
Number of Bound Morphemes	53.8	(9.3)	43.6	(14.6)	0.83
Number of Different Words	182.0	(16.3)	153.3	(33.7)	1.08

Table 3

Means and SDs for children with NH and CIs on phonological awareness and expressive vocabulary. Percentages of correct responses are shown for the initial consonant same-different, syllable counting, and final consonant choice tasks. Raw and standard scores are shown for expressive vocabulary.

	NH		**CIs**		**Cohen's *d***
	M	**(SD)**	**M**	**(SD)**	
Phonological Awareness					
Syllable Counting	67	(37)	47	(32)	0.58
Initial Consonant Same-Different	93	(10)	66	(23)	1.58
Final Consonant Choice	59	(22)	16	(15)	2.28
Expressive Vocabulary					
Raw Scores	77	(10)	63	(15)	1.10
Standard Scores	110	(11)	93	(17)	1.19

Table 4

Pearson product-moment correlation coefficients among each possible pair of measures for children with CIs.

	MLU	**Conj**	**Per Pro**	**B Mor**	**NDW**	**SC**	**ICSD**	**FCC**	**E V**
MLU	1								
Conjunctions	.49*	1							
Personal pronouns	.71**	.45*	1						
Bound morphemes	.70**	.03	.39	1					
NDW	.90**	.43*	.44*	.64**	1				
Syllable Counting	.11	-.14	-.19	.25	.13	1			
Initial Consonant S/D	.45*	.04	.30	.36	.43*	.29	1		
Final Consonant Choice	.41	.02	.25	.59**	.47*	-.15	.61**	1	
Expressive Vocab	.67**	.26	.24	.56**	.75**	.34	.47*	.31	1

* $p < .05$

** $p < .01$

Table 5

Means and SDs for the measures for children with one or two CIs at the time of testing. Numbers of children in each group are shown.

	Number of Implants			
	One CI		**Two CIs**	
	8		**12**	
	M	**(SD)**	**M**	**(SD)**
MLU	4.7	(0.4)	4.9	(1.2)
Conjunctions	11.4	(4.6)	14.4	(8.3)
Personal Pronouns	62.1	(11.2)	63.3	(17.1)
Bound Morphemes	40.6	(8.6)	46.6	(17.7)
NDW	146.9	(23.6)	162.1	(36.6)

Table 6

Means and SDs for the measures for children with some bimodal experience or no bimodal experience at the time of receiving a first implant. Numbers of children in each group are shown.

	Bimodal Experience			
	Some		**None**	
	10		**10**	
	M	**(SD)**	**M**	**(SD)**
MLU	5.2	(.72)	4.4	(.99)
Conjunctions	13.9	(7.0)	12.5	(7.4)
Personal Pronouns	69.5	(13.1)	56.2	(13.7)
Bound Morphemes	48.5	(11.0)	39.9	(17.3)
NDW	163.3	(30.1)	148.7	(34.2)