Research Article

Development of Grammatical Accuracy in English-Speaking Children With Cochlear Implants: A Longitudinal Study

Ling-Yu Guo^a and Linda J. Spencer^b

Purpose: We sought to evaluate the development of grammatical accuracy in English-speaking children with cochlear implants (CIs) over a 3-year span.

Method: Ten children who received CIs before age 30 months participated in this study at 3, 4, and 5 years postimplantation. For the purpose of comparison, 10 children each at ages 3, 4, and 5 years with typical hearing were included as well. All children participated in a story-retell task. We computed percent grammatical communication units (PGCU) in the task.

Results: Children with CIs showed significant improvement in PGCU over the 3-year span. However, they produced lower PGCU than children with typical hearing who had

matched hearing age at 4 and 5 years postimplantation. At the individual level, some children with CIs were able to produce PGCU comparable to children with typical hearing as early as 3 years after implantation. Better speech-perception skills at earlier time points were associated with higher PGCU at later time points. Moreover, children with and without CIs showed similar rankings in the types of grammatical errors.

Conclusion: Despite having auditory-perceptual and information-processing constraints, children who received CIs before age 30 months were able to produce grammatical sentences, albeit with a delayed pattern.

Although cochlear implants (CIs) provide auditory input for children with prelingual deafness to acquire spoken language, the input is a degraded electrical signal with limited frequency resolution (Wolfe & Schafer, 2010). In addition, children with CIs do not receive significant auditory input until the CIs are implanted, which does not typically happen until a child is age 12 months. Such deprivation may cause the auditory cortex to start responding to stimuli from other modalities (e.g., visual stimuli; Buckley & Tobey, 2011), which may delay the development of the ability to process speech signals. Thus, children with CIs may have difficulty accessing phonological details of speech input and, hence, developing phonological representations (Nittrouer, Sansom, Low, Rice, & Caldwell-Tarr, 2014). The degraded phonological representations may then contribute to speech and language

deficits in children with CIs because learning speech and language requires that children be able to represent the input for processing. Furthermore, the early auditory deprivation may lead to delayed development of cognitive mechanisms for learning speech and language, such as working memory (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016), executive function (Kronenberger, Colson, Henning, & Pisoni, 2014), and sequential learning (Conway, Pisoni, & Kronenberger, 2009). Although there is considerable individual variability, children with CIs tend, as a group, to show deficits in those cognitive mechanisms, which further compromises their speech and language outcomes (Geers, Nicholas, Tobey, & Davidson, 2016; Kral et al., 2016).

Among the components of language, grammatical development seems to be particularly challenging for children with CIs who speak English or other languages (Duchesne, 2015; Duchesne, Sutton, & Bergeron, 2009; Schorr, Roth, & Fox, 2008). In a study by Geers (2004), about 50% of English-speaking children with CIs scored below the typical range on productivity of morphological and syntactic structures in language samples despite having used CIs for an average of 5.5 years. Nittrouer et al. (2014) similarly found that English-speaking children with CIs produced fewer grammatical morphemes in language samples than their age-matched peers with typical hearing. However, being

^aDepartment of Communicative Disorders and Sciences, University at Buffalo, NY; Department of Audiology and Speech-Language Pathology, Asia University, Taiwan

^bMaster's Speech-Language Pathology Program, Rocky Mountain University of Health Professions, Provo, UT

Correspondence to Ling-Yu Guo: lingyugu@buffalo.edu

Editor: Nancy Tye-Murray

Associate Editor: Amy Lederberg

Received May 4, 2016

Revision received August 15, 2016

Accepted October 16, 2016

https://doi.org/10.1044/2016_JSLHR-H-16-0182

Disclosure: The authors have declared that no competing interests existed at the time of publication.

productive in using a variety of morphological and syntactic structures is only one aspect of grammatical development (Schuele, 2013). Another crucial aspect of grammatical development is the ability to use morphological and syntactic structures accurately to form grammatical sentences. Studies from children with typical hearing have shown that the ability to produce grammatical sentences develops gradually and improves from preschool into school ages (Guo & Schneider, 2016; Lee, 1974). Although studies have found that children with CIs tend to demonstrate more limited grammatical skills than children with typical hearing of the same chronological age on standardized tests or in language samples (Duchesne, 2015), we do not know how the ability to produce grammatical sentences changes over time in children with CIs. Moreover, it has yet to be determined whether English-speaking children with CIs demonstrate different patterns of grammatical errors when they produce sentences. To the best of our knowledge, although some studies have found that English-speaking children with CIs produce verb tense (e.g., past tense *-ed*) with lower accuracy than children with typical hearing (Guo, Spencer, & Tomblin, 2013; Svirsky, Stallings, Ying, Lento, & Leonard, 2002), no existing studies have systematically documented grammatical errors in English-speaking children with CIs.

The purpose of the present study was to examine, via a story-retell task, the extent to which English-speaking children with CIs were able to produce grammatical sentences over a 3-year span (i.e., 3, 4, and 5 years after implantation). Three groups of children with typical hearing who had matched length of hearing experience (i.e., hearing age) were also included for comparison. Grammatical errors that occurred during the task in children with and without CIs were classified and tallied to determine whether children with CIs produced different error patterns from children with typical hearing. In what follows, we review studies that have examined grammatical skills in children with CIs from standardized tests or from language samples, and then we lay out the scope of the present study.

Development of Grammatical Skills in Children With CIs: Evidence From Standardized Tests

Geers, Nicholas, and Sedey (2003) examined the development of receptive language skills in 181 children who received cochlear implantation by age 5 years using the Test for Auditory Comprehension of Language-Revised (TACL-R; Carrow, 1985). The TACL-R evaluates children's comprehension of single words, grammatical morphemes, and elaborated phrases and sentences. At the time of testing, children with CIs in the Geers et al. study had used the devices for 4 to 6 years. Overall, about 30% of children with CIs demonstrated age-appropriate TACL-R scores (i.e., at -1 *SD* or better). Because the researchers did not report children's performance specifically on the two subtests related to grammatical skills (i.e., Grammatical Morphemes, Elaborated Phrases and Sentences), it was not possible to determine the percentage of children with CIs who would demonstrate age-appropriate grammatical skills in the

TACL-R. However, given that children with CIs tend to have more difficulty learning grammatical structures than vocabulary, it is reasonable to infer that the percentage would be less than 30%. Similar findings were obtained by Nikolopoulos, Dyar, Archbold, and O'Donoghue (2004).

Geers, Moog, Biedenstein, Brenner, and Hayes (2009) further evaluated the development of receptive and expressive grammatical skills in 125 children who received cochlear implantation before 3 years of age using two editions of the Clinical Evaluation of Language Fundamentals-Preschool (Wiig, Secord, & Semel, 1992, 2004). The Sentence Structure subtest was designed for evaluating receptive grammatical skills, whereas the Word Structure and Recalling Sentences subtests were designed for evaluating expressive grammatical skills. At the time of testing, the length of CI experience in children ranged from 1;0 (years;months) to 5;4. The percentage of children with CIs who scored within the typical range was 40% for the Sentence Structure subtest, 33% for the Word Structure subtest, and 29% for the Recalling Sentences subtest.

Taken together, studies using standardized tests show that more than half of children with CIs fall behind their peers with typical hearing of the same chronological age in comprehending and/or producing grammatical structures (i.e., morphological and syntactic structures). Although they are informative, these studies do not reveal how well children with CIs were able to integrate morphological and syntactic structures into grammatical sentences as compared with children with typical hearing. The studies also did not allow us to identify the specific elements of grammar that were particularly vulnerable in children with CIs, due partly to the limitations of standardized tests. The content of standardized tests typically covers only a small number of grammatical structures, and each structure is tested with only a few items, which is insufficient for identifying children's error patterns (McCauley & Swisher, 1984). Given these limitations, Duchesne (2015) argues that language samples may provide a more complete description of grammatical development in children with CIs than standardized tests.

Development of Grammatical Skills in Children With CIs: Evidence From Language Samples

Ramirez Inscoc, Odell, Archbold, and Nikolopoulos (2009) used language samples obtained from a picture-description task to assess the emergence of grammatical forms in 45 children with CIs who received their implants at or before age 3 years and had approximately 3 years of CI experience. The language samples were scored using the South Tyneside Assessment of Syntactic Structures (Armstrong & Ainsley, 1983), which provides a list of grammatical structures that are observed in children with typical hearing between the ages of 9 and 36 months (further divided into four stages). It allows the clinician to evaluate the emergence of a variety of grammatical structures in children and to determine whether children's grammatical development is age appropriate. The results

indicated that, 3 years after implantation, about 58% of children with CIs were able to produce grammatical forms that were expected in children with typical hearing between the ages of 2;6 and 3;0. That is, the emergence of grammatical forms in children with CIs, as a group, was not at a level comparable to that of their age-matched peers with typical hearing after 3 years of CI use.

As a part of their protocol, Geers et al. (2003) also examined the development of expressive grammar in children with CIs using examiner-elicited language samples. Children's skills in expressive grammar were evaluated by computing the mean length of utterances, number of bound morphemes per word, and productive uses of grammatical structures in the language samples. The Index of Productive Syntax (IPSyn; Scarborough, 1990) was used to score children's productive uses of grammatical structures, including 12 noun-phrase structures (e.g., articles *the*, *a*), 17 verb-phrase structures (e.g., copula *be*), and 31 sentence structures (e.g., subject-verb sequences). Higher IPSyn scores indicate that the child produced more varieties of grammatical structures. Overall, children with CIs produced shorter utterances, fewer bound morphemes per word, and lower IPSyn scores than children with typical hearing who had matched chronological age. The percentage of children with CIs who scored within the typical range (i.e., at -1 *SD* or higher) was 65% for mean length of utterances, 26% for uses of bound morphemes, and 47% for IPSyn scores. Similarly, Nittrouer et al. (2014) found that children who had used CIs for approximately 5 years tended to produce shorter utterances, fewer bound morphemes, fewer conjunctions, and fewer personal pronouns in language samples than children with typical hearing who had matched chronological age.

In summary, studies using language samples indicate that children with CIs fall behind children with typical hearing in the emergence and productive uses of grammatical structures (Geers, 2004; Geers et al., 2003; Nittrouer et al., 2014; Ramirez Inscoc et al., 2009). Being productive in using morphological and syntactic structures, however, is just one aspect of grammatical proficiency. Another important aspect is the ability to use morphological and syntactic structures accurately to form grammatical sentences (Lee, 1974; Schuele, 2013). Productivity typically shows whether a target structure is incorporated into the child's language system, whereas accuracy shows the extent to which the target structure is used according to some standard, such as the conventions of standard English (Lahey, 1988). Thus, productivity reveals the presence or absence of grammatical structures in children, whereas accuracy reveals mastery of grammatical structures. When a child is able to use a grammatical structure productively, it does not necessarily mean that he or she is able to use the structure accurately. In fact, IPSyn credits a child for using a given structure even when the use of that structure is not accurate. For example, when a child says "*her running*," the child is credited for the uses of the pronoun "*her*" and the subject-verb sequence even though "*her*" is an incorrect subject form and the auxiliary "*be*" is omitted.

Thus, the existing studies are limited because they do not inform us about the extent to which English-speaking children with CIs are able to use grammatical structures accurately in sentences, how this ability develops over time, or whether those children produce different patterns of grammatical errors from children with typical hearing given the auditory-perceptual and cognitive-processing constraints. Although some studies (e.g., Guo et al., 2013) have found that English-speaking children with CIs produce more errors in marking verb tense than children with typical hearing, few if any have systematically examined other types of grammatical errors (e.g., argument structure, word order) in this population.

The Present Study

The present study had three goals. First, we evaluated development of grammatical accuracy in English-speaking children with CIs who received implantation before age 30 months by measuring percent grammatical communication units, or C-units (PGCU Loban, 1976) from a story-retell task over a 3-year span (i.e., 3, 4, and 5 years after implantation). The data for children with CIs were obtained from a longitudinal project (discussed later) for analysis. The story-retell task (i.e., narratives) was chosen as the language-sampling context instead of conversations because it was administered longitudinally to document children's speech and language development in the project protocol. In addition, narratives are cognitively more demanding than conversations (Thordardottir, 2008). Breakdowns in the use of grammatical structures are more likely to be observed in narratives than in conversations. We used PGCU as the measure because any grammatical errors would make a C-unit ungrammatical. Thus, PGCU is a global measure revealing how well children with CIs are able to integrate morphological and syntactic structures to form grammatical sentences. For the purpose of comparison, we also administered the story-retell task to three groups of English-speaking children with typical hearing who had matched hearing age (i.e., 3-, 4-, and 5-year-olds).

Second, we evaluated the association between speech-perception skills and the development of grammatical accuracy in children with CIs. To this end, we used lagged correlations to examine the relations between children's speech-perception scores and their performance in terms of PGCU (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010). In particular, we examined the relation between speech-perception scores in children with CIs at 3 years postimplantation and their performance in terms of PGCU at 4 and 5 years postimplantation. Similarly, we examined the relation between speech-perception skills at 4 years postimplantation and the performance in terms of PGCU at 5 years postimplantation. Lagged correlation allows us to determine how speech-perception skills are associated with grammatical accuracy over developmental time (Huttenlocher et al., 2010). Previous studies have found that English-speaking children with CIs who have

better speech-perception skills tend to produce grammatical morphemes with higher accuracy than those who have poorer speech-perception skills (Guo et al., 2013). One interpretation of this finding is that English grammatical morphemes tend to be weak in energy and short in duration (i.e., acoustically insalient). Thus, those morphemes might be relatively more challenging for those who have poorer speech-perception skills because they are hard to perceive. However, because measuring PGCU taps children's skills beyond grammatical morpheme usage (e.g., word order), it has yet to be determined whether speech-perception skills remain associated with performance in terms of PGCU in children with CIs.

Third, we classified and compared the grammatical errors that children with and without CIs produced in the story-retell task to determine whether children with CIs demonstrated different patterns of grammatical errors from their age-matched peers with typical hearing. A taxonomy of grammatical errors that was derived from children with typical hearing (Eisenberg, Guo, & Germezia, 2012) was used to identify the error types in the present study. Knowing the error patterns of children with CIs may guide interventionists to create effective treatment techniques to facilitate grammatical development, and, hence, academic success, in this population (Ramirez Inscoe et al., 2009; López-Higes, Gallego, Martín-Aragoneses, & Melle, 2015).

The specific questions we addressed were the following: (a) Did PGCU increase over time in children with CIs? (b) Was the level of PGCU in children with CIs comparable to that in their age-matched peers with typical hearing over the 3-year span? (c) Were speech-perception skills at earlier time points positively correlated with performance in terms of PGCU at later time points? (d) Would children with CIs demonstrate different patterns of grammatical errors from their age-matched peers with typical hearing? On the basis of previous studies (Chilosi et al., 2013; Guo et al., 2013; Nicholas & Geers, 2007; Nikolopoulos et al., 2004), we predicted that PGCU would increase over developmental time in children with CIs. We also predicted that children with CIs would produce PGCU at a lower level as compared with their age-matched peers with typical hearing, given the auditory-perceptual and cognitive-processing constraints. In addition, we predicted that speech-perception skills in children with CIs would positively correlate with their performance in terms of PGCU. As a final matter, we predicted that children with CIs would produce grammatical errors in a pattern similar to that of their age-matched peers with typical hearing.

Method

The present study used archival data from a longitudinal project of children with prelingual deafness who received cochlear implantation (Dunn et al., 2014). The longitudinal project was approved by the institutional review board

of University of Iowa. All children were recruited when they came to the university clinic for cochlear implantation. The research team obtained consent from the parents who were willing to enroll their children in the longitudinal project. In the project protocol, the children were seen for audiology follow-up approximately five times during the first 18 months after implantation, at 24 months, and annually thereafter for device setting and follow-up and for data collection regarding speech, language, and hearing development. One part of the protocol required the children to retell stories using pictures (discussed later). This task was originally designed to document children's speech development (Tye-Murray, Spencer, & Woodworth, 1995) but was reanalyzed for the purpose of the present study. To be included in the present study, children had to (a) receive cochlear implantation before age 30 months and have used the Nucleus CI 24R or Nucleus CI 24M devices (Cochlear Ltd., Sydney, Australia) with the processing strategy of the advanced combination encoder (ACE; Cochlear Ltd., 2010; excluding 39 children) and (b) participate in the story-retell task in the annual evaluation 3, 4, and 5 years after implantation and produce at least five utterances with verbs for analysis at each time point (Lahey, Liebergott, Chesnick, Menyuk, & Adams, 1992; excluding 20 children). We included children who received cochlear implantation before age 30 months in order to reduce the effect of age of implantation (Geers et al., 2016). Although the current population of pediatric CI users typically receives cochlear implantation before age 24 months, Nicholas and Geers (2007) indicate that children who received implantation between ages 12 and 30 months show a similar growth rate in language development, which supports the use of 30 months as the cutoff for age of implantation in the present study. We also limited the participants to children who used the processing strategy of ACE because this is the default processing strategy of the current Nucleus CI devices (Cochlear Ltd., 2010; Wolfe & Schafer, 2010). Limiting the participants to children who used the 24-electrode CI devices with the ACE strategy made the findings in the present study more applicable to the current population of CI users.

Furthermore, children had to produce word-final consonants with at least 60% accuracy for adjectives, adverbs, and unmarked nouns (e.g., *She got a truck*) in the stories that they retold at each data point (excluding three children). This criterion was included because some English grammatical morphemes are realized as word-final consonants in production (e.g., plural *-s* as in *There are two kids*; past tense *-ed* as in *The dog barked*). The inclusion of this criterion reduced the possibility that children's articulation skills for final consonants confounded the production of grammatical morphemes.

Participants

Ten children (six girls; four boys) with CIs who met all three selection criteria were included in the present study. Nine of the 10 children were also participants in a

prior study (Guo et al., 2013). All 10 children received unilateral cochlear implantation between the years of 1997 and 2001 and remained unilateral CI users at the time of data collection (i.e., between the years of 2000 and 2006). The use of a hearing aid for the unimplanted ear was recommended for all of the children with unilateral CIs; however, no children in the present study followed this recommendation. The age of implantation ranged from 1;0 to 2;2 ($M = 1;5$, $SD = 0;4$). The mean chronological ages of the children with CIs were 4;5 ($SD = 0;4$), 5;5 ($SD = 0;4$), and 6;5 ($SD = 0;4$), respectively, when they retold the stories at 3, 4, and 5 years postimplantation. The mean length of CI experience (i.e., hearing age) of the children was 3;0 ($SD = 0;1$), 4;0 ($SD = 0;1$), and 5;0 ($SD = 0;1$), respectively, at each data point. The children with CIs were from the Midwestern United States—seven from Iowa, two from Wisconsin, and one from Missouri—and all were speakers of standard American English. Socioeconomic status was documented on the basis of maternal education, with 50% (5/10) having a college degree, 30% (3/10) taking some college courses, and 20% (2/10) having a high school diploma. According to parent reports on the Minnesota Child Development Inventory (Ireton & Thwing, 1974), none of the children presented with frank signs of cognitive, motor, or social-psychological deficits. Supplemental Material S1 presents the background information and hearing and language measures for each child.

In addition, the parents filled out an Educational and Special Services Information form developed by the team of the longitudinal project before implantation and at each annual follow-up visit. On this form, the parents completed a communication section that indicated whether their children used sign language. In addition, they completed a section that indicated whether their children were enrolled in a program that included the instruction of sign languages. Children who were reported to be enrolled in an intervention program that included the instruction or use of sign languages were coded as being in a total communication program. In contrast, children who were reported to be enrolled in an intervention program that did not involve the instruction or use of sign languages were coded as being in an oral communication program. Three children primarily used oral communication, and seven primarily used total communication. No children changed the intervention program (i.e., total communication, oral communication) between the preimplantation visits and the three annual follow-up visits for the present study.

All children received speech-language services from the early intervention program provided by the state before age 3 years. The services typically involved weekly home visits by an early-childhood specialist, which lasted from 1 to 3 hr/week. For children who were enrolled in total communication programs, the specialist typically provided a combination of sign-language instruction, information on targeting speech and language development, and information on child development during the visits. The oral communication programs were similar to the total communication programs except that no sign-language instruction

was included. By age 3 years, all children attended early-childhood programs and received speech-language services from their local school districts. The early-childhood programs typically provided children with educational services between 3 and 4 hr/day, 4 days/week, until children attended kindergarten.

In the protocol of annual follow-up, the Phonetically Balanced Kindergarten Word List (PB-K test; Haskins, 1949) was adopted to evaluate the development of speech-perception skills in children with CIs. The PB-K test is an open-set spoken word-recognition test that consists of 50 monosyllabic words that are familiar to young children (e.g., *need*, *rose*, *bad*). During the test, words were presented one at a time in a sound-only condition, and children were required to repeat each word after it was presented. Children's responses on the PB-K test were reported in percent phonemes accurate. Specific testing and scoring procedures for children were further described by Fryauf-Bertschy, Tyler, Kelsay, Gantz, and Woodworth (1997). All children with CIs that were included in the present study, except participant CI-1, received the PB-K test at 3, 4, and 5 years postimplantation (see Supplemental Material S1).

For the purpose of comparison, we recruited 30 children with typical hearing whose chronological age matched the length of CI experience of each child in the CI group by ± 3 months at each data point. The mean length of hearing experience (i.e., chronological age for children with typical hearing and length of CI experience for children with CIs) did not differ significantly between children with CIs and children with typical hearing at either age ($F_s < 1.84$, $p_s > .31$, $\eta_p^2 < .06$). That is, children with CI and their peers with typical hearing were matched in length of hearing experience (i.e., hearing age). Children with typical hearing were recruited through flyers and online announcements from the Iowa City area (27 children) and the Buffalo (New York) area (three children). All 30 children with typical hearing were monolingual native speakers of standard American English. They all had typical language development, as documented by parent report and performance above the 10th percentile in the Expressive Communication subtest of the Preschool Language Scale—Third Edition (PLS-3; Zimmerman, Steiner, & Pond, 1992) or in the first or second edition of the Structured Photographic Expressive Language Test—Preschool (Dawson et al., 2005; Werner & Kresheck, 1983). They all passed the hearing screening per American Speech-Language-Hearing Association (1997) standards. In addition, there was no history of receiving intervention for cognitive, motor, or communication disorders for any of the children with typical hearing.

Thus, the present study had 10 children with typical hearing each for three age groups: 3-year-olds (TH-3; six girls, four boys), 4-year-olds (TH-4; six girls, four boys), and 5-year-olds (TH-5; five girls, five boys). Although the distribution of gender in the TH-5 group did not match that in the CI group, Eisenberg et al. (2012) did not find an effect of gender on the production of grammatical sentences in children. The mean chronological age was 3;1

($SD = 0;2$) for the TH-3 group, 4;0 ($SD = 0;3$) for the TH-4 group, and 5;1 ($SD = 0;2$) for the TH-5 group.

Materials

Each child was instructed to retell six short stories. The stimuli were six sets of four-picture sequences. The pictures were black-and-white drawings that had been colored and laminated by a research assistant. Each picture set typically illustrated a setting (e.g., a boy got new pants), a problem (e.g., the boy climbed over a fence and tore his pants), and a solution (e.g., the boy's mother fixed the pants for him).

Procedure

Each child was tested individually by an examiner in a quiet room. All children with CIs were seen by the second author, a certified speech-language pathologist with over 15 years of experience in using Signed English in the clinical and research settings. The children with typical hearing were evaluated by the second author or by three research assistants majoring in speech-language pathology. Each trial involved the examiner presenting one set of picture sequences on the table and describing each of the four pictures by reading the prewritten scripts. The examiner told the stories with spoken English and Signed English for all children with CIs, regardless of their communication mode. This decision was made in order to keep the story-presentation procedure consistent for all children with CIs. In contrast, the examiner told the stories in only spoken English for children with typical hearing.

At the end of each story presentation, the examiner collected all the pictures from the table and instructed the child to retell the story by saying, "Let's look at the pictures again and you tell me the story." The examiner then showed the child the pictures of each set one at a time and asked the child to tell a story on the basis of the pictures. If the child did not respond for a given picture, the examiner used up to two prompts per picture to elicit the story from the child (e.g., *What's happening in this picture? Tell me what you see in the picture.*). The narrative samples (i.e., stories) produced by children with CIs or typical hearing were audio-recorded for transcription and coding. In addition, we video-recorded the sessions of children with CIs to determine whether they used signs to mark grammatical elements in the narratives.

Transcription, Coding, and Computation

The narrative samples that children with CIs produced for the story-retell task were first phonetically transcribed with broad transcription by the second author. The phonetic transcriptions were then used to generate orthographic transcriptions. The narrative samples that children with typical hearing produced, however, were transcribed only orthographically by the second author and research assistants. All of the narrative samples were then segmented

and coded on the basis of the conventions of Systematic Analysis of Language Transcripts (Miller & Iglesias, 2010).

The narrative samples were segmented into C-units (Loban, 1976). A C-unit is typically an independent clause plus all of its dependent clauses. Nonclausal utterances that expressed complete thoughts (e.g., *A boy, a girl, and a dog*) were also counted as C-units. Only intelligible, complete, and spontaneous C-units that described the stories were included for computing the descriptive measures (e.g., mean length of C-units). To be included for the analysis for PGCU, a C-unit also had to have at least a verb (e.g., *He's mad at her*, *The boy dropped the truck*, *Broke his pants*), except in the case of C-units with omitted copula *be* (e.g., *She sad*; Eisenberg et al., 2012).

To compute PGCU and determine the patterns of grammatical errors that children made, we first identified the errors in the narratives using the coding scheme of Eisenberg et al. (2012):

- (a) *Tense-marking errors* were operationally defined as omissions or incorrect usage of tense markers, including third person singular present *-s*, regular past tense *-ed*, copula *be*, auxiliary *be*, auxiliary *do*, auxiliary *have*, irregular past tense (e.g., *He broke his car*), and irregular third person verb forms (e.g., *He has a truck*). Verbs produced without an inflection, modal, or auxiliary (e.g., *The boy wash the dog*) were transcribed as bare verbs, and inappropriate uses of bare verbs were counted as tense-marking errors. However, unmarked verbs with first person, second person, or plural subjects were not coded as errors (e.g., *They see a dog*) unless the context clearly required a tense marker (e.g., *They take a bath yesterday*).
- (b) *Pronoun errors* were operationally defined as substitution errors for subject pronouns (e.g., *Him is getting wet*), object pronouns, reflexive pronouns, possessive pronouns, and possessive determiners. Gender errors of pronouns were determined on the basis of inconsistency between the child's C-units within the same story and were not based on whether the gender of pronouns matched the picture characters. For instance, if a child refers to a character as *a girl* and uses the pronoun *he* later to refer to the same character, it would be coded as a gender error.
- (c) *Grammatical-morpheme errors* were operationally defined as omission or incorrect uses of grammatical morphemes other than pronouns and tense markers, such as determiners (e.g., *a*, *the*, *this*), plural *-s*, prepositions, and present and past participles. Errors of present and past participles were coded only when there were obligatory contexts (e.g., *She is cry now*).
- (d) *Argument-structure errors* were operationally defined as omissions of required constituents (i.e., argument) before or after verbs (e.g., *Rode the bike*, *He put all of it*). Decisions about the required arguments for verbs were based on the *Longman Dictionary of Contemporary English* (2014). Any omissions that could be considered as pragmatically allowable

elision were not counted as argument-structure errors.

- (e) *Other errors* were operationally defined as any other syntactic errors (e.g., *Fixed it the dad*) or semantic irregularities (e.g., *The dog splashed the boy and the girl*) that could not be classified into any error categories. We counted semantic irregularities as errors for two reasons. First, syntax is not independent of meaning; rather, semantics contributes to the well-formedness of sentences (Saeed, 2009). Second, this decision is consistent with other assessments, such as Developmental Sentence Scoring (Lee, 1974) and the Sentence Formulation subtest of the Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel, Wiig, & Secord, 2003), both of which score semantic irregularities as errors.

C-units that contained one or more error codes were marked as ungrammatical. PGCU were computed for each child by subtracting the total number of ungrammatical C-units from the total number of C-units that were included for analysis and then dividing by the total number of C-units that were included for analysis. To determine the patterns of grammatical errors, the number of occurrences of each error type was tallied and then divided by the total number of C-units that were included for analysis across children by hearing status (i.e., CI or typical hearing) and length of hearing experience.

Reliability of Transcription and Coding

Recall that the narrative samples of children with CIs were obtained from a longitudinal project and were first transcribed using broad transcription. The reliability of broad transcription for children with CIs was reported by Spencer and Oleson (2008). The average point-to-point reliability of phoneme accuracy was 79% ($SD = 9\%$), which is considered to be within the acceptable range (i.e., 60%–90%; Shriberg & Lof, 1991) for phonetic transcription. To check the reliability of orthographic transcription for children with typical hearing, we randomly sampled the stories from 30% of children with typical hearing in each age group ($n = 9$). The first author retranscribed those narrative samples. The average agreement was 96% ($SD = 4\%$) in transcribing lexical morphemes and 95% ($SD = 4\%$) in transcribing grammatical morphemes.

To check the reliability of coding grammatical errors and ungrammatical C-units, we adapted a consensus procedure from Shriberg, Kwiatkowski, and Hoffman (1984). Two graduate assistants first coded the grammatical errors for all children. The first author then checked the coded transcripts for all children. Discrepancies were discussed between the first and second authors. Overall, 13 (2%) of 574 C-units in the narratives of children with CIs and 13 (1%) of 894 C-units in the narratives of children with typical hearing were discussed. All of the discrepancies were resolved. In addition, it is possible that children with CIs might omit grammatical elements in spoken language but

mark them with signs. To examine this possibility, the second author checked the videos for all children with CIs. No children with CIs marked grammatical elements with signs during the task when they omitted those elements in speech.

Results

Preliminary Analyses of Narrative Samples

Table 1 summarizes the descriptive measures of stories retold by children with CIs and children with typical hearing. Recall that, although children with CIs and children with typical hearing were matched in length of hearing experience, children with CIs were older than children with typical hearing. For children with typical hearing, there were no significant effects of length of hearing experience (in this case, their chronological age) on mean number of C-units or mean length of C-units (MLCU) in words or morphemes, $F_s < 1.09$, $p_s > .35$, $\eta_p^2 < .08$. For children with CIs, there was no significant effect of length of hearing experience on mean number of C-units either. However, there were significant effects of length of hearing experience on MLCU in words and MLCU in morphemes, $F_s > 5.47$, $p_s < .01$, $\eta_p^2 > .38$. Post hoc analyses indicated that children who had 3 years of CI experience produced shorter MLCU in words and in morphemes in the story-retell task than those who had 4 or 5 years of CI experience. Children who had 4 or 5 years of CI experience did not differ significantly in MLCU in words or in morphemes.

After 3, 4, and 5 years of hearing experience, children with CIs produced fewer C-units in the story-retell task than those with typical hearing who were 3, 4, and 5 years of age, respectively: $F_s > 13.25$, $p_s < .002$, $\eta_p^2 > .42$. Children with CIs also produced shorter MLCU in morphemes than those with typical hearing at 3 years post-implantation, $F(1, 18) = 4.73$, $p = .04$, $\eta_p^2 = .21$. There were no other significant group differences in MLCU in words or in morphemes, $F_s < 3.41$, $p_s > .08$, $\eta_p^2 < .16$.

Table 1. Means (and *SDs*) of descriptive measures of stories by hearing status and length of hearing experience.

Group	Number of C-units	MLCU, words	MLCU, morphemes
CI			
3 years	20.70 (4.64)	3.75 (1.37)	4.15 (1.44)
4 years	22.80 (6.12)	4.86 (1.28)	5.27 (1.32)
5 years	24.60 (5.27)	5.04 (1.04)	5.48 (1.11)
TH			
3 years	30.80 (5.25)	4.77 (1.08)	5.41 (1.14)
4 years	31.60 (4.58)	4.92 (0.68)	5.42 (0.81)
5 years	33.80 (5.81)	5.34 (0.90)	5.86 (0.96)

Note. Both groups were subdivided on the basis of length of hearing experience—that is, length of CI experience for the CI group and chronological age for the TH group. C-unit = communication unit; MLCU = mean length of C-units; CI = cochlear implant; TH = typical hearing.

PGCU

Because the present study was the first application of PGCU to the CI population, we examined whether it was a valid measure of grammatical skills for children with CIs. Given the availability of the data from the longitudinal project, we were able to determine the criterion-related validity of PGCU in children with CIs by evaluating the extent to which PGCU were correlated with the raw scores of the Expressive Communication subtest of the PLS-3 (Zimmerman et al., 1992) at 4 years postimplantation. Although the Expressive Communication subtest of the PLS-3 included items that tested grammatical skills as well as other skills (e.g., lexical, pragmatic), the majority (28 of 48) of the items were designed to specifically test children's grammatical skills. Spearman rank-order correlation indicated that PGCU were highly correlated with the raw scores on the Expressive Communication subtest of the PLS-3 ($\rho = .86$, $p = .001$), indicating that PGCU were a valid measure of grammatical skills, or at least language skills, in children with CIs.

Table 2 presents the mean number of C-units included for the analysis of PGCU and mean PGCU by hearing status and length of hearing experience. Note that the number of C-units included for computing PGCU was lower than the total number of C-units in the narratives (see Table 1) because some C-units were excluded for the analysis of PGCU due to the lack of verbs. In addition, because the measure of PGCU is a percentage, it was arcsine-transformed in the analyses of variance. For children with typical hearing, there was a significant effect of length of hearing experience on PGCU, $F(2, 27) = 8.15$, $p = .002$, $\eta_p^2 = .38$. Post hoc Tukey's tests indicated that 5-year-olds with typical hearing produced higher PGCU than 3-year-olds with typical hearing. There were no other significant effects of length of hearing experience on PGCU in children with typical hearing, possibly as a result of the small number of participants. For children with CIs, there was also a significant effect of length of hearing experience on PGCU, $F(2, 18) = 3.99$, $p = .037$, $\eta_p^2 = .31$. Post hoc paired t tests

Table 2. Mean number (and SD) of communication units (C-units) for computation of percent grammatical C-units (PGCU) and mean PGCU (and SD) by hearing status and length of hearing experience.

Group	Number of C-Units for PGCU			PGCU	
	<i>M</i> (SD)	Range	Total	<i>M</i> (SD)	Range
CI					
3 years	16.50 (6.04)	6–25	165	46 (27)	6–96
4 years	19.90 (3.21)	14–24	199	55 (30)	4–95
5 years	20.60 (3.95)	14–25	206	64 (34)	9–94
TH					
3 years	29.00 (5.64)	22–38	290	63 (23)	23–94
4 years	28.40 (6.00)	19–36	284	80 (9)	63–88
5 years	32.20 (6.60)	23–44	322	89 (7)	78–100

Note. CI = cochlear implant; TH = typical hearing.

indicated that children with CIs produced higher PGCU at 5 years postimplantation than at 3 years postimplantation. There were no other significant effects of length of hearing experience on PGCU in children with CIs, possibly because of the small number of participants and the variability between children at each data point. Between the groups, children with CIs produced lower PGCU than children with typical hearing at 4 years, $F(1, 18) = 4.78$, $p = .04$, $\eta_p^2 = .21$, and 5 years postimplantation, $F(1, 18) = 5.74$, $p = .03$, $\eta_p^2 = .24$, but not at 3 years postimplantation, $F(1, 18) = 1.75$, $p = .20$, $\eta_p^2 = .09$.

Figure 1 presents PGCU for each child in the CI group. The three numbers in the figure (i.e., 63%, 80%, 89%) are the group means for children with typical hearing at different ages. Those numbers are used as criteria to determine whether the performance of PGCU of a child with a CI is comparable with that of children with typical hearing. Overall, there was considerable variability of PGCU in individual children with CIs, as evidenced in the standard deviation and range in Table 2, and the variability did not decrease over time. If we focus on the number of children with CIs who produced PGCU comparable with those of children with typical hearing, we see that three children at 3 years postimplantation (CI-1, CI-2, CI-7), three at 4 years postimplantation (CI-1, CI-2, CI-7), and five at 5 years postimplantation (CI-1, CI-2, CI-4, CI-6, CI-9) were able to produce PGCU at a level comparable to the mean of the control groups. That is, some children with CIs are able to produce PGCU comparable with those of children with typical hearing as early as 3 years after implantation.

For the five children with CIs who produced PGCU comparable with those of children with typical hearing at 5 years postimplantation, two children (CI-1, CI-2) used oral communication and three (CI-4, CI-6, CI-9) used total communication. Participants CI-1 and CI-2 produced PGCU consistently well across the 3-year span, and Participants CI-4, CI-6, and CI-9 made substantial improvement on PGCU from 3 to 5 years postimplantation. For the five children with CIs who fell behind children with typical hearing on PGCU at 5 years postimplantation, four of them (CI-3, CI-5, CI-8, CI-10) produced PGCU at a level below the means of the control groups consistently across the 3-year span. Participant CI-3 used oral communication, whereas Participants CI-5, CI-8, and CI-10 used total communication. Thus, the present individual data did not show a clear advantage or disadvantage of one communication mode over the other on performance of PGCU.

Relations Between Speech Perception and Performance on PGCU

Given the wide variability of PGCU in children with CIs, we examined the extent to which that variability was associated with children's speech-perception skills at earlier time points. Spearman rank-order correlations (see Table 3) showed that the PB-K scores of children with CIs at 3 years

Figure 1. Percent grammatical C-units of individual children with cochlear implants by length of implant experience. The three percentages in the figure (i.e., 63%, 80%, and 89%) represent the mean percent grammatical C-units for children with typical hearing at each age level.

postimplantation were significantly correlated with PGCU at 4 years ($p = .82, p = .003$) and 5 years ($p = .79, p = .006$) postimplantation. In a similar manner, the PB-K scores of children with CIs at 4 years postimplantation were significantly correlated with PGCU at 5 years postimplantation ($p = .64, p = .02$). That is, children with CIs who had better speech-perception skills at earlier time points tended to produce higher PGCU at later time points.

The primary analysis focuses on the extent to which PB-K scores at earlier time points are associated with PGCU at later time points, but it is important to evaluate other relations between PB-K scores and PGCU. Table 3 further shows that the concurrent correlations between PB-K scores and PGCU were significant, ranging from .61 to .64 ($ps < .05$), but the correlation coefficients were not as large as those in the lagged correlations. In addition, PGCU at earlier time points were not significantly correlated with PB-K scores at later time points ($ps < .54, ps > .052$). Together, the results indicate unique associations between PB-K scores (i.e., speech-perception skills) at earlier time

points and PGCU (i.e., grammatical skills) at later time points.

Error Analysis

We have seen that children with CIs showed poorer ability than children with typical hearing in producing grammatical C-units. An ensuing question is whether children with CIs also showed deviant patterns in making grammatical errors as compared with children with typical hearing. Table 4 presents the raw frequency and rate of each error type collapsed across children by hearing status and length of hearing experience. The rate (i.e., number of errors per C-units) of each error type is computed by dividing the frequency of a given error type by the total number of C-units that were included for PGCU in the analysis. For example, across children with CIs who had 3 years of CI experience, the total number of errors in tense markers is 35 and the total number of C-units included for analysis is 165 (see Table 2). Thus, the number

Table 3. Spearman rank-order correlations between percent grammatical communication units (PGCU) and Phonetically Balanced Kindergarten Word List (PB-K) scores in children with cochlear implants by hearing age.

PGCU time point	PB-K at 3 years	PB-K at 4 years	PB-K at 5 years
3 years postimplantation	.62*	.49	.50
4 years postimplantation	.82**	.66*	.54
5 years postimplantation	.79**	.64*	.61*

* $p < .05$. ** $p < .01$.

of tense-marking errors per C-unit is 0.21 (35/165) for children who had 3 years of CI experience.

Across the 3-year span, tense-marking errors were the most prevalent and pronoun errors the least prevalent in both children with CIs and children with typical hearing. For children with typical hearing, argument-structure errors were the second most prevalent across the 3-year span. Argument-structure errors were also the second most prevalent errors for children with CIs 3 years after implantation. However, grammatical-morpheme errors became the second most prevalent errors for children with CIs 4 and 5 years after implantation. That is, children with CIs and children with typical hearing showed similar patterns in grammatical errors, although the ranking of argument-structure and grammatical-morpheme errors varied slightly across the two groups. It should be noted that despite the similarity in the ranking of error types, children with CIs produced higher rates for all error types than children with typical hearing across the 3-year span, except for pronoun errors.

Discussion

The present study evaluated the extent to which English-speaking children with CIs were able to produce grammatical sentences at 3, 4, and 5 years postimplantation via a story-retell task. At the group level, children with CIs improved on PGCU over the 3-year span. However, they tended to produce lower PGCU than children with

typical hearing who had matched hearing age. At the individual level, some children with CIs were able to produce PGCU comparable with those of children with typical hearing as early as 3 years after implantation. Children with CIs who had better speech-perception skills at earlier time points tended to produce higher PGCU at later time points. Moreover, although children with CIs fell behind their age-matched peers with typical hearing on PGCU, both groups showed similar patterns of grammatical errors. We explore these findings below.

Children With CIs Showed Delayed Development in Grammatical Accuracy

Consistent with our predictions, we found that PGCU increased significantly in children with CIs over the 3-year span, as in children with typical hearing. We also found that children with CIs, as a group, produced significantly lower PGCU than children with typical hearing who had matched hearing age at 4 and 5 years postimplantation, a finding that is consistent with previous literature (Duchesne, 2015; Geers et al., 2003; Nitttrouer et al., 2014; Ramirez Inscoe et al., 2009). More importantly, the present study extended previous studies that examined the productivity of grammatical structures in children with CIs (Geers et al., 2003; Nitttrouer et al., 2014) and found that children with CIs also had difficulty using morphological and syntactic structures accurately to form grammatical sentences. However, despite the group trend, approximately 30% to 50% of

Table 4. Frequency and rate of each error type, and number and percentage of children who produced each error type by hearing status and hearing experience.

Hearing age and error type	CI				TH			
	Frequency of error	Errors/C-unit	Number of children	% of Children	Frequency of error	Errors/C-unit	Number of children	% of Children
3 years								
Tense marking	35	0.21	9	90	52	0.18	10	100
Grammatical morpheme ^a	21	0.13	6	60	24	0.08	7	70
Argument structure	25	0.15	9	90	28	0.10	8	80
Pronoun	2	0.01	2	20	8	0.03	3	30
Other	12	0.07	5	50	10	0.04	5	50
Total	95	0.58			122	0.42		
4 years								
Tense marking	43	0.22	10	100	27	0.10	10	100
Grammatical morpheme	37	0.19	7	70	10	0.04	7	70
Argument structure	32	0.16	7	70	17	0.06	8	80
Pronoun	1	0.01	1	10	4	0.01	3	30
Other	11	0.06	5	50	10	0.04	6	60
Total	124	0.62			68	0.24		
5 years								
Tense marking	30	0.15	8	80	12	0.04	7	70
Grammatical morpheme	26	0.13	7	70	5	0.02	3	30
Argument structure	20	0.10	8	80	9	0.03	6	60
Pronoun	3	0.01	3	30	2	0.01	2	20
Other	14	0.07	6	60	6	0.02	5	50
Total	93	0.45			34	0.11		

Note. CI = cochlear implant; TH = typical hearing; C-unit = communication unit.

^aOmission or incorrect uses of grammatical morphemes other than pronominal forms and tense markers.

children with CIs were able to produce PGCU comparable with those of children with typical hearing. This finding, too, is consistent with previous literature (Geers, 2004; Geers et al., 2003; Ramirez Inscoe et al., 2009).

Why did children with CIs tend to have difficulty learning morphological and syntactic structures? One possible explanation is the auditory-perceptual deficits those children experience (Duchesne, 2015; Spencer, Tye-Murray, & Tomblin, 1998). This explanation is supported by the finding that children with CIs who had better speech-perception skills at earlier time points tended to produce higher grammatical accuracy at later time points. Although we were not able to establish the causal link between speech perception and grammatical development in the present study using the correlation data, the relationship between speech-perception skills and the development of grammatical skills has been elucidated in different accounts. The surface hypothesis or perceptual-salience hypothesis (Leonard, 2014; Svirsky et al., 2002) suggests that English-speaking children with CIs have problems with grammatical structures because the surface forms of many of the grammatical elements in English are short in duration and weak in energy (i.e., acoustically insalient). When those elements occur in the middle of sentences (e.g., *The boy's eating a cookie*), they are relatively harder to perceive and/or process as compared with the surrounding content words. Given the auditory-perceptual and information-processing constraints (Conway et al., 2009), the grammatical elements may not always be properly perceived and/or completely processed by children with CIs, leading to delayed acquisition of grammatical elements and hence the ability to produce grammatical sentences. This hypothesis is supported by the findings that tense morphemes and grammatical morphemes (other than tense morphemes and pronouns) tended to exhibit the most common errors in children with CIs and that the error rates for both types of morphemes were higher in children with CIs than in children with typical hearing across the 3-year span. However, children with CIs also produced higher rates than those with typical hearing in argument-structure errors (e.g., omission of subject as in *Broke his pants*) and other errors (e.g., semantic anomaly and word-order errors) in the present study. Those types of errors involve structures or elements beyond insalient morphemes. Thus, the surface hypothesis or perceptual-salience hypothesis alone may not be sufficient to account for the grammatical deficits that children with CIs demonstrate.

Another hypothesis that could account for how auditory-perceptual deficits affect grammatical acquisition in children with CIs is the phonological-representation deficit hypothesis (Chiat, 2001; Nitttrouer et al., 2014). This hypothesis suggests that the auditory-perceptual deficits have a negative impact on accessing phonological details in children with CIs, which in turn affects the development of phonological representations. The degraded phonological representations may then lead to difficulties learning words, morphemes, and syntactic structures, because learning those linguistic elements requires children to be able to represent them for processing (Chiat, 2001). Thus, the

phonological-representation deficit hypothesis seems to be a more comprehensive account of the grammatical deficits in children with CIs observed in the present study than the surface hypothesis.

Testing different hypotheses of grammatical deficits in children with CIs is beyond the scope of the present study. However, we do want to point out that the grammatical deficits in children with CIs go beyond insalient grammatical elements. We believe that an account that considers the phonological-representation and information-processing deficits in children with CIs (Kral et al., 2016) would be a worthwhile pursuit in explaining and predicting grammatical acquisition and deficits in children with CIs.

The Role of Signing in the Development of Grammatical Accuracy

Recall that three of the children with CIs in the present study were enrolled in oral communication programs and seven were enrolled in total communication programs. There has been a debate on whether oral communication or total communication should be used in communication and education for children with CIs or with hearing aids (see Connor, Hieber, Arts, & Zwolan, 2000) because the findings regarding outcomes of communication modes have been mixed (e.g., Dunn et al., 2014; Geers et al., 2003; Niparko et al., 2010). In the present study, two children using oral communication produced PGCU comparable with those of children with typical hearing across the 3-year span; however, one fell behind. In addition, three children using total communication were able to produce PGCU comparable with those of children with typical hearing at 5 years postimplantation despite having fallen behind children with typical hearing on PGCU at 3 years postimplantation. Together, the individual data did not show a clear advantage for oral communication or a clear disadvantage for total communication on the development of grammatical accuracy. Thus, it is premature to conclude that using sign languages in total communication programs has a negative impact on the development of spoken language.

Limitations and Future Directions

Because we used archival data from a clinical setting, we faced some limitations that must be considered. First, we had a small number of children with CIs ($n = 10$). Recall that we excluded 62 children in the archival database from analysis because of the subject selection criteria (i.e., age of implantation, types of CI devices, production of narratives across three data points, number of scorable C-units, accuracy of final-consonant production). This decision was made so that we could examine grammatical development in children with CIs over time and reduce the confounding variables for interpretation. One concern for a small sample size is the lack of power in detecting differences of grammatical development within or between groups. However, we did observe significant differences in

PGCU within and between groups. The other concern for a small sample size is that the current sample may not be representative of the population of children with typical hearing or children with CIs, which limits the generalizability of the findings. In a recent study, Guo, Schneider, and Eisenberg (2016) examined the development of PGCU from ages 4 to 9 years in English-speaking children with typical development using a story-generation task. In that study, each age group had 50 children. The mean percentage of PGCU was 77% for 4-year-olds and 84% for 5-year-olds, which is close to the findings in the present study (80% for 4-year-olds and 89% for 5-year-olds). In both studies, tense-marking errors were the most common errors. Despite the fact that the present study had a much smaller sample size and used a different narrative task, the results in both studies are consistent. Thus, the present data from children with typical hearing are appropriate for the purpose of comparison. However, future studies that include a larger number of children with CIs are needed in order to determine whether the present findings are still observable in those children.

Second, we included only children with unilateral CIs because of the limitation of the archival database. Given that there is a trend of bilateral cochlear implantation for children with prelingual deafness (Peters, Wyss, & Manrique, 2010), one concern is whether our findings are generalizable to the current population of children who receive bilateral CIs. In a review by Johnston, Durieux-Smith, Angus, O'Connor, and Fitzpatrick (2009), children using bilateral CIs tended to show better performance in sound localization and speech recognition in noise than those with unilateral CIs. However, the advantage of bilateral CIs over unilateral CIs on speech and language acquisition remains unclear, given mixed findings from different studies. For example, whereas Sarant, Harris, Bennet, and Bant (2014) found a bilateral advantage for language acquisition, Nittrouer and Chapman (2009) did not. In a recent study, Nittrouer et al. (2014) further found that children with unilateral and bilateral CIs did not differ significantly in the use of grammatical morphemes. Thus, we believe that children with bilateral CIs, just like those with unilateral CIs in the present study, may encounter difficulty producing grammatical utterances. A direct comparison of PGCU between children with unilateral CIs and with bilateral CIs is worthy of future investigations.

Third, children with CIs in the present study received cochlear implantation between the years of 1997 and 2001 and thus may not have CI devices that are as advanced as those in the current population, which may limit the generalizability of the present findings to the current CI population. We want to point out that children with CIs in the present study all used the ACE processing strategy, which is still the default processing strategy for the Nucleus CI devices (Cochlear Ltd., 2010; Wolfe & Schafer, 2010). Although variation of CI technology may influence speech-language outcomes (Geers et al., 2016), to date there is no published evidence suggesting that different CI processors (e.g., SPRINT, CP910 in cochlear devices) with the same processing strategy (e.g., ACE) would result in significant

differences in speech-language outcomes. Similarly, there is no published evidence indicating that different processing strategies from different makes in the same time period would lead to significantly different outcomes. Thus, we believe that the present findings are still relevant to the current population of pediatric CI users, especially to those using the Nucleus CI devices, because the default processing strategy (i.e., ACE) is the same for children in our study and for the current population using the Nucleus CI devices. The findings from the present study may serve as a reference point for comparing the production of PGCU in children with different processors but the same processing strategy, or in children using different makes of CI devices. This line of research will advance our understanding of the role of CI technology in grammatical development.

Concluding Remarks and Clinical Implications

Development of grammatical accuracy in children with CIs has long been ignored in research and clinical practice. The present study set out to evaluate the development of grammatical accuracy in children with CIs by measuring PGCU in children's narratives. As the first application of PGCU to the CI population, we established the validity of PGCU in measuring grammatical development in children with CIs. We also provided a framework for analyzing grammatical errors beyond grammatical morphemes in children with CIs. Using the measure of PGCU, we found that children with CIs demonstrated poorer skills in producing grammatical sentences than children with typical hearing who had matched length of hearing experience. However, some children with CIs were able to produce grammatical sentences at levels comparable with those of children with typical hearing as early as 3 years after implantation. Using the error-analysis framework, we further found that children with CIs made grammatical errors similar to those by children with typical hearing and that grammatical difficulties in children with CIs may go beyond the acoustically insalient grammatical elements. Thus, for interventionists, assessment of grammatical skills in children with CIs should expand beyond grammatical morphemes and include other syntactic structures (e.g., argument structure, word orders, complex sentences). PGCU can be used to as a global measure to document children's treatment progress over time, and the error analysis can be used to identify intervention goals. For researchers, factors other than speech-perception skills (e.g., phonological representations, sequential learning) must be considered in order to obtain a fuller picture of grammatical development in children with CIs.

Acknowledgments

This research is supported in part by National Institute on Deafness and Other Communication Disorders Research Grant 5 P50 DC00242, awarded to Bruce Gantz, and by an American Speech-Language-Hearing Foundation New Century Scholar Research Grant, awarded to Ling-Yu Guo. The content is solely the responsibility of the authors and does not necessarily represent

the official views of the National Institute on Deafness and Other Communication Disorders, the National Institutes of Health, or the American Speech-Language-Hearing Foundation. We are grateful to the children who participated in the present study. We also thank Bruce Gantz and J. Bruce Tomblin for granting access to the archival data, Louise Duchesne for sharing her manuscript, and Kayla Kuehlewind and Katelynn Imagna for processing the data.

References

- American Speech-Language-Hearing Association.** (1997). *Guidelines for audiologic screening*. Rockville, MD: Author.
- Armstrong, S., & Ainsley, M.** (1983). *South Tyneside assessment of syntactic structures*. Ponteland, United Kingdom: STASS Publications.
- Buckley, K. A., & Tobey, E. A.** (2011). Cross-modal plasticity and speech perception in pre- and postlingually deaf cochlear implant users. *Ear and Hearing, 32*, 2–15. <https://doi.org/10.1097/AUD.0b013e3181e8534c>
- Chiat, S.** (2001). Mapping theories of developmental language impairment: Premises, predictions and evidence. *Language and Cognitive Processes, 16*, 113–142.
- Carrow, E.** (1985). *Test for auditory comprehension of language—Revised*. Allen, TX: DLM Teaching Resources.
- Chilosi, A. M., Comparini, A., Scusa, M. F., Orazini, L., Forli, F., Cipriani, P., & Berrettini, S.** (2013). A longitudinal study of lexical and grammar development in deaf Italian children provided with early cochlear implantation. *Ear and Hearing, 34*, e28–e37. <https://doi.org/10.1097/AUD.0b013e31827ad687>
- Cochlear, Ltd.** (2010). *Nucleus cochlear implants: Physician's package insert*. Lane Cove, Australia: Author.
- Connor, C. M., Hieber, S., Arts, H. A., & Zwolan, T. A.** (2000). Speech, vocabulary, and the education of children using cochlear implants: Oral or total communication? *Journal of Speech, Language, and Hearing Research, 43*, 1185–1204.
- Conway, C. M., Pisoni, D. B., & Kronenberger, W. G.** (2009). The importance of sound for cognitive sequencing abilities: The auditory scaffolding hypothesis. *Current Directions in Psychological Science, 18*, 275–279. <https://doi.org/10.1111/j.1467-8721.2009.01651.x>
- Dawson, J., Stout, C., Eyer, J., Tattersall, P., Fonkalsrud, J., & Croley, K.** (2005). *Structured photographic expressive language test—preschool: Second edition*. DeKalb, IL: Janelle.
- Duchesne, L.** (2015). Grammatical competence after early cochlear implantation. In M. Marschark & P. E. Spencer (Eds.), *The Oxford handbook of deaf studies in language* (pp. 113–131). New York, NY: Oxford University Press.
- Duchesne, L., Sutton, A., & Bergeron, F.** (2009). Language achievement in children who received cochlear implants between 1 and 2 years of age: Group trends and individual patterns. *Journal of Deaf Studies and Deaf Education, 14*, 465–485. <https://doi.org/10.1093/deafed/enp010>
- Dunn, C. C., Walker, E. A., Oleson, J., Kenworthy, M., Van Voorst, T., Tomblin, J. B., ... Gantz, B. J.** (2014). Longitudinal speech perception and language performance in pediatric cochlear implant users: The effect of age at implantation. *Ear and Hearing, 35*, 148–160. <https://doi.org/10.1097/AUD.0b013e3182a4a8f0>
- Eisenberg, S. L., Guo, L.-Y., & Germezia, M.** (2012). How grammatical are 3-year-olds? *Language, Speech, and Hearing Services in Schools, 43*, 36–52. [https://doi.org/10.1044/0161-1461\(2011/10-0093\)](https://doi.org/10.1044/0161-1461(2011/10-0093))
- Fryauf-Bertschy, H., Tyler, R. S., Kelsay, D. M. R., Gantz, B. J., & Woodworth, G. G.** (1997). Cochlear implant use by prelingually deafened children: The influences of age at implant and length of device use. *Journal of Speech, Language, and Hearing Research, 40*, 183–199.
- Geers, A. E.** (2004). Speech, language, and reading skills after early cochlear implantation. *Archives of Otolaryngology—Head & Neck Surgery, 130*, 634–638. <https://doi.org/10.1001/archotol.130.5.634>
- Geers, A. E., Moog, J. S., Biedenstein, J., Brenner, C., & Hayes, H.** (2009). Spoken language scores of children using cochlear implants compared to hearing age-mates at school entry. *Journal of Deaf Studies and Deaf Education, 14*, 371–385. <https://doi.org/10.1093/deafed/enn046>
- Geers, A. E., Nicholas, J. G., & Sedey, A. L.** (2003). Language skills of children with early cochlear implantation. *Ear and Hearing, 24*(Suppl. 1), 46S–58S.
- Geers, A. E., Nicholas, J., Tobey, E., & Davidson, L.** (2016). Persistent language delay versus late language emergence in children with early cochlear implantation. *Journal of Speech, Language, and Hearing Research, 59*, 155–170. https://doi.org/10.1044/2015_jslhr-h-14-0173
- Guo, L.-Y., & Schneider, P.** (2016). Differentiating school-aged children with and without language impairment using tense and grammaticality measures from a narrative task. *Journal of Speech, Language, and Hearing Research, 59*, 317–329.
- Guo, L.-Y., Schneider, P., & Eisenberg, S.** (2016, June). *Using percent grammatical utterances for differentiating children with and without language impairment from four to nine years: Evidence from a narrative generation task*. Poster presented at the 37th Annual Symposium on Research in Child Language Disorders, Madison, WI.
- Guo, L.-Y., Spencer, L. J., & Tomblin, J. B.** (2013). Acquisition of tense marking in English-speaking children with cochlear implants: A longitudinal study. *Journal of Deaf Studies and Deaf Education, 18*, 187–205. <https://doi.org/10.1093/deafed/ens069>
- Haskins, H.** (1949). *A phonetically balanced test of speech discrimination for children* (Unpublished master's thesis). Northwestern University, Evanston, IL.
- Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V.** (2010). Sources of variability in children's language growth. *Cognitive Psychology, 61*, 343–365. <https://doi.org/10.1016/j.cogpsych.2010.08.002>
- Ireton, H., & Thwing, E.** (1974). *Manual for the Minnesota Child Development Inventory*. Minneapolis, MN: Behavior Science Systems.
- Johnston, J. C., Durieux-Smith, A., Angus, D., O'Connor, A., & Fitzpatrick, E.** (2009). Bilateral paediatric cochlear implants: A critical review. *International Journal of Audiology, 48*, 601–617. <https://doi.org/10.1080/14992020802665967>
- Kral, A., Kronenberger, W. G., Pisoni, D. B., & O'Donoghue, G. M.** (2016). Neurocognitive factors in sensory restoration of early deafness: A connectome model. *The Lancet Neurology, 15*, 610–621. [https://doi.org/10.1016/S1474-4422\(16\)00034-X](https://doi.org/10.1016/S1474-4422(16)00034-X)
- Kronenberger, W. G., Colson, B. G., Henning, S. C., & Pisoni, D. B.** (2014). Executive functioning and speech-language skills following long-term use of cochlear implants. *Journal of Deaf Studies and Deaf Education, 19*, 456–470. <https://doi.org/10.1093/deafed/enu011>
- Lahey, M.** (1988). *Language disorders and language development*. Needham, MA: Macmillan.
- Lahey, M., Liebergott, J., Chesnick, M., Menyuk, P., & Adams, J.** (1992). Variability in children's use of grammatical morphemes. *Applied Psycholinguistics, 13*, 373–398.
- Lee, L. L.** (1974). *Developmental sentence analysis: A grammatical assessment procedure for speech and language clinicians*. Evanston, IL: Northwestern University Press.

- Leonard, L. (2014). *Children with specific language impairment*. Cambridge, MA: MIT Press.
- Loban, W. (1976). *Language development: Kindergarten through grade twelve* (NCTE Committee on Research Report 18). Urbana, IL: National Council of Teachers of English.
- Longman Dictionary of Contemporary English (6th ed.). (2014) Harlow, United Kingdom: Pearson Longman.
- López-Higes, R., Gallego, C., Martín-Aragoneses, M. T., & Melle, N. (2015). Morpho-syntactic reading comprehension in children with early and late cochlear implants. *Journal of Deaf Studies and Deaf Education*, 20, 136–146. <https://doi.org/10.1093/deafed/env004>
- McCauley, R. J., & Swisher, L. (1984). Use and misuse of norm-referenced test in clinical assessment: A hypothetical case. *Journal of Speech and Hearing Disorders*, 49, 338–348. <https://doi.org/10.1044/jshd.4904.338>
- Miller, J., & Iglesias, A. (2010). *Systematic analysis of language transcripts* (Version 10) [Computer software]. Madison, WI: SALT Software.
- Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech, Language, and Hearing Research*, 50, 1048–1062.
- Nikolopoulos, T. P., Dyar, D., Archbold, S., & O'Donoghue, G. M. (2004). Development of spoken language grammar following cochlear implantation in prelingually deaf children. *Archives of Otolaryngology—Head & Neck Surgery*, 130, 629–633.
- Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N.-Y., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *JAMA*, 303, 1498–1506. <https://doi.org/10.1001/jama.2010.451>
- Nittrouer, S., & Chapman, C. (2009). The effects of bilateral electric and bimodal electric-acoustic stimulation on language development. *Trends in Hearing*, 13, 190–205. <https://doi.org/10.1177/1084713809346160>
- Nittrouer, S., Sansom, E., Low, K., Rice, C., & Caldwell-Tarr, A. (2014). Language structures used by kindergartners with cochlear implants: Relationship to phonological awareness, lexical knowledge and hearing loss. *Ear and Hearing*, 35, 506–518.
- Peters, B. R., Wyss, J., & Manrique, M. (2010). Worldwide trends in bilateral cochlear implantation. *The Laryngoscope*, 120(Suppl. S2), S17–S44. <https://doi.org/10.1002/lary.20859>
- Ramirez Incoe, J., Odell, A., Archbold, S., & Nikolopoulos, T. (2009). Expressive spoken language development in deaf children with cochlear implants who are beginning formal education. *Deafness & Education International*, 11, 39–55. <https://doi.org/10.1002/dei.252>
- Saeed, J. I. (2009). *Semantics* (3rd ed.). Malden, MA: Wiley-Blackwell.
- Sarant, J., Harris, D., Bennet, L., & Bant, S. (2014). Bilateral versus unilateral cochlear implants in children: A study of spoken language outcomes. *Ear and Hearing*, 35, 396–409.
- Scarborough, H. S. (1990). Index of productive syntax. *Applied Psycholinguistics*, 11, 1–22.
- Schorr, E. A., Roth, F. P., & Fox, N. A. (2008). A comparison of the speech and language skills of children with cochlear implants and children with normal hearing. *Communication Disorder Quarterly*, 29, 195–210. <https://doi.org/10.1177/1525740108321217>
- Schuele, C. M. (2013). Beyond 14 grammatical morphemes: Toward a broader view of grammatical development. *Topics in Language Disorders*, 33, 118–124.
- Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical evaluation of language fundamentals—Fourth edition*. San Antonio, TX: Pearson.
- Shriberg, L. D., Kwiatkowski, J., & Hoffman, K. (1984). A procedure for phonetic transcription by consensus. *Journal of Speech and Hearing Research*, 27, 456–465.
- Shriberg, L. D., & Lof, G. L. (1991). Reliability studies in broad and narrow phonetic transcription. *Clinical Linguistics & Phonetics*, 5, 225–279. <https://doi.org/10.3109/02699209108986113>
- Spencer, L. J., & Oleson, J. J. (2008). Early listening and speaking skills predict later reading proficiency in pediatric cochlear implant users. *Ear and Hearing*, 29, 270–280.
- Spencer, L. J., Tye-Murray, N., & Tomblin, J. B. (1998). The production of English inflectional morphology, speech production and listening performance in children with cochlear implants. *Ear and Hearing*, 19, 310–318.
- Svirsky, M. A., Stallings, L. M., Ying, E., Lento, C. L., & Leonard, L. B. (2002). Grammatical morphologic development in pediatric cochlear implant users may be affected by the perceptual prominence of the relevant markers. *Annals of Otology, Rhinology & Laryngology*, 111(5, Suppl.), 109–112. <https://doi.org/10.1177/00034894021110S522>
- Thordardottir, E. (2008). Language-specific effects of task demands on the manifestation of specific language impairment: A comparison of English and Icelandic. *Journal of Speech, Language, and Hearing Research*, 51, 922–937.
- Tye-Murray, N., Spencer, L., & Woodworth, G. G. (1995). Acquisition of speech by children who have prolonged cochlear implant experience. *Journal of Speech and Hearing Research*, 38, 327–337.
- Werner, E. O., & Kresheck, J. D. (1983). *Structured photographic expressive language test—Preschool*. Sandwich, IL: Janelle.
- Wiig, E., Secord, W., & Semel, E. (1992). *Clinical evaluation of language fundamentals—Preschool*. San Antonio, TX: Pearson.
- Wiig, E. H., Secord, W., & Semel, E. (2004). *Clinical evaluation of language fundamentals—Preschool—Second edition*. San Antonio, TX: Pearson.
- Wolfe, J., & Schafer, E. C. (2010). *Programming cochlear implants*. San Diego, CA: Plural.
- Zimmerman, I. L., Steiner, V., & Pond, R. E. (1992). *PLS-3: Preschool language scale-3*. San Antonio, TX: The Psychological Corporation.