Research Article

Grammatical Abilities in Young Cochlear Implant Recipients and Children With Normal Hearing Matched by Vocabulary Size

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Purpose: This study sought to expand understanding of the impact of cochlear implantation on grammatical acquisition by comparing young children who have vocabularies of comparable size. Two research questions were investigated: (a) Do young cochlear implant (CI) recipients have grammatical skills comparable to those of children with normal hearing (NH) matched by spoken vocabulary size? (b) Do these groups show associations between vocabulary size and grammatical measures?

Method: The participants included 13 CI recipients at 24 months postactivation (chronological ages = 33–60 months; $M = 44.62$) and 13 children with NH between 27 and 30 months old ($M = 20.69$). The 2 groups were

matched by their vocabulary size. Four grammatical outcomes were analyzed from the MacArthur Communicative Development Inventory (Fenson, Marchman, Thal, Dale, & Reznick, 2007) and 20-min language samples: (a) grammatical complexity, (b) mean length of utterances, (c) tense marker total, and (d) productivity scores.

Results: The 2 groups showed comparable grammatical skills across the 4 measures. Consistently significant associations between vocabulary size and grammatical outcomes were found in the CI group, with fewer associations in the NH group.

Conclusions: The 2 groups showed similar grammatical abilities. The young CI recipients appeared to be following a typical pattern of linguistic development.

Now that newborn hearing screening is widely implemented around the world and cochlear implantation has become a commonly recommended procedure for deaf children as young as 12 months of age, the process of cochlear implant (CI)-assisted language acquisition can be examined within the age range when many foundational language skills are typically acquired by toddlers with normal hearing (NH). Whereas substantial improvements in spoken language have been observed in previous studies (e.g., Niparko et al., 2010), several studies have reported that CI recipients showed relatively more difficulty in grammatical development than in vocabulary acquisition (Geers, Nicholas, & Sedey, 2003; Young & Killen, 2002).

Because grammatical markers are often perceptually more challenging than lexical items (Gleitman & Wanner, 1982; Kelly, 1996), this difficulty might negatively affect young CI recipients' grammatical growth more so than vocabulary growth. However, other studies have not found relative strengths or weaknesses in particular language domains (Boons et al., 2013; Schorr, Roth, & Fox, 2008).

The variety of outcomes in the previously mentioned studies might be due to the fact that they included children with a relatively wide range of age at implantation (i.e., those implanted at ages up to 6 years old) compared with the much younger and smaller range of ages at implantation that is common today. Little is known about how children, implanted within the first 3 years of life, develop language abilities and whether they show the associations between semantics and grammar found in children with NH (Marchman & Bates, 1994; McGregor, Sheng, & Smith, 2005; Thal, Bates, Zappia, & Oroz, 1996). Measuring post CI-activation growth in semantics and grammar can help to determine whether young CI recipients make typical amounts of progress during the initial phases of language acquisition. Examining the associations between different

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linguistic components (i.e., semantics and grammar) can also contribute to a better understanding of the processes that promote linguistic development in very young children. Several research methods have been used to explore these issues.

Comparisons of Grammatical Abilities Between Children With CIs and Those With NH

Three main approaches are available for comparing CI recipients' grammatical development to that of children with NH: (a) comparisons on the basis of matching by chronological age (CA), (b) comparisons on the basis of matching by hearing age (i.e., months of robust hearing; Ertmer, Jung, & Klobier, 2013), and (c) comparisons on the basis of matching by children's ability within a particular language domain. The first two approaches have been used in many studies of young children with CIs to understand whether CI recipients have caught up to their NH peers' linguistic levels (Caselli, Rinaldi, Varuzza, Giuliani, & Burdo, 2012; Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Inscoc, Odell, Archbold, & Nikolopoulos, 2009; May-Mederake, 2012; Niparko et al., 2010; Schorr et al., 2008). The third approach (i.e., matching ability levels within a language domain) has rarely been employed with young CI recipients to our knowledge, whereas it has been frequently used with other populations (Leonard, Eyer, Bedore, & Grela, 1997; McGregor et al., 2012; Redmond & Rice, 2001).

Reports on grammatical development in CI recipients who were implanted at a young age have shown improvement over pre-CI levels but notable variability in performance as well when compared with CA-matched children with NH. Caselli et al. (2012) found mixed grammatical outcomes in Italian-speaking young CI recipients (mean age at implant = 16 months, range = 12–22 months). They found that young CI recipients had more errors in production than CA-matched peers in a sentence repetition task focusing on the morphosyntax of 2- to 4-year-old children. However, the participants produced comparable mean length of utterances (MLUs) to that of CA-matched hearing peers (CI = 4.47, NH = 4.56). In addition, a recent study of German-speaking children by May-Mederake (2012) found that 68% of participants (13 out of 19) who were implanted before 24 months were above -1 *SD* of the norm on the Test zur Überprüfung des Grammatikverständnisses (Kampfhaus, 2005)—a grammatical assessment for German language, indicating that implantation at a young age might result in typical grammatical development in a substantial number of recipients but not all.

Grammatical findings from comparisons on the basis of hearing experience are generally positive, but some variability is also apparent. Several studies reported near-normal grammatical abilities in young, oral CI recipients. For instance, Caselli et al. (2012) compared the outcomes to hearing age-matching children with NH; they found longer MLUs and greater accuracy in morphosyntax in the CI group than in the hearing age-matched peers with NH, who

were younger than the CI group. Jung and Ertmer (2011) also found that MLUs and Grammatical Complexity scores on the MacArthur Communicative Development Inventory (CDI; Fenson, Marchman, Thal, Dale, & Reznick, 2007) were comparable to their hearing experience-matched NH peers. In this preliminary study, the CI group (i.e., a subgroup of the current participants; $n = 6$) had 2 years of device experience and were 39.5 months old on average ($SD = 4.55$), whereas the NH group (i.e., independent from the current study; $n = 6$) was 2 years old at the time of testing. Comparable positive outcomes were noted in a study by Szagun (2000), in which a majority of the CI participants (8/10) had developed an MLU of 2.0 (range = ~ 1.5 – 3.25) following 18 months of device use.

By contrast, other studies show that not all CI recipients reach near-normal levels after a similar amount of robust hearing experience. Inscoc et al. (2009) found that two thirds (17/24) of children using oral communication reached a level corresponding to the grammatical abilities of children with NH (ages 2;6 [years;months] through 3;0) after 3 years of CI use. However, when including children who used simultaneous communication, the percentage decreased to 58%. Guo, Spencer, and Tomblin (2013) found that some of the young CI recipients (five out of nine; mean age at implantation = 1;4, $SD = 3$ months, range of age at implantation = 1;0 to 2;2) showed similar grammatical outcomes to their hearing experience-matched peers in use of tense marking morphemes (i.e., third person singular *-s*, past tense *-ed*, copula BE, auxiliary BE, and auxiliary DO) after 3, 4, and 5 years of CI use. However, the authors examined five early emerging categories, which have already been mastered by a majority of typically developing 5-year-old children (Hadley & Short, 2005). Indeed, results showed that children with NH already showed 91.45% ($SD = 7.71$) of accuracy at 4 years old, with the score increasing to 96.96% at 5 years old. This suggests that children with NH had reached ceiling level of the test at 4 years old. While the average gap between the CI and NH groups was not significant at 3 years postimplantation, the CI group performed more poorly overall than their peers at 4 and 5 years postimplantation. Therefore, even though the authors noted that some oral young participants reached the average score of children with NH, it is not clear how many of the CI group actually closed the gap in grammatical skills.

An alternative to the first two approaches is to match children by their language levels, such as vocabulary size. This approach has been used by McGregor et al. (2005) in typically developing children and lexically precocious children and revealed associations between vocabulary and grammatical abilities. Employing this approach with young CI recipients might reveal whether they are acquiring language in a typical way. In the current study, the sizes of the spoken vocabularies of the CI and the NH groups were controlled so that grammatical scores could be compared without reference to CA or robust hearing experience. In addition to grammatical score comparisons, the relationships between vocabulary size and grammatical scores were

examined. If semantic–grammatical associations are observed, then young CI users would exhibit a typical relationship similar to the one found in children with NH by McGregor et al. (2005). That is, having a large vocabulary would be associated with higher grammatical scores. If no associations are detected, then CI users might be acquiring grammar in an atypical manner, possibly because of the perceptual limitations of their hearing devices. The next section will discuss theories of linguistic acquisition and lexical–grammatical associations in greater detail.

Associations Between Vocabulary Size and Grammatical Abilities

There is a long-running debate among linguistic researchers regarding the relationship between vocabulary and grammatical development (Marcus et al., 1992; Plunkett & Marchman, 1993). Under the “domain-specificity” hypothesis, some have proposed separate developmental systems for each language domain (i.e., lexical vs. grammatical; for a review, see Marchman & Thal, 2005, p. 141). Children’s overgeneralization of irregular past tense verbs (e.g., *went*) into regular past tense verbs (e.g., *goed*) is a supportive example for the domain specificity hypothesis. Further, the past tense forms of irregular verbs are relatively unique and unpredictable, and so, young children might need to memorize them as vocabulary items. By contrast, the past tense forms of regular verbs are governed by a morphological rule: adding the suffix *–ed*. Overgeneralization can occur when children possess the rule but fail to retrieve the right form from memory (Pinker, 1991), which suggests that two separate domains exist. In short, this theory specifies that vocabulary involves the memory domain, whereas grammar involves the cognitive domain responsible for rule processing (Marcus et al., 1992; Pinker, 1991; Ullman, 2010).

In contrast to the domain specificity hypothesis, several researchers have proposed the “domain-general” hypothesis, which states that vocabulary and grammar develop from a single cognitive domain (Bates & Goodman, 2010; Elman, 2004; McClelland & Patterson, 2002). Proponents of this hypothesis predict that associational patterns will be observed across semantic and grammatical skills as children become language users. Of special interest to the current study, several investigations have found associations between vocabulary size and grammar in typically developing children (Marchman & Bates, 1994; McGregor et al., 2005; Thal et al., 1996).

A recent study by Braginsky, Yurovsky, Marchman, and Frank (2015) helped to further specify the associations between vocabulary size and grammatical abilities by analyzing a large data set of scores from the CDI in four different languages (i.e., English, Spanish, Danish, and Norwegian; e.g., *n* of English-speaking children = 4,137). The authors classified the items within the section of Grammatical Complexity into two categories: syntax and morphology. For instance, the item to select either *doggie kiss me* or *doggie kissed me* was sorted as a morphological

item, whereas the item to select either *doggie table* or *doggie on table* was categorized as a syntactic item. Analysis of the two categories showed that syntactical development could be mediated by age, whereas morphological development was mostly driven by children’s vocabulary size. These results provide general support for the association between vocabulary size and Grammatical Complexity scores.

For groups of children experiencing difficulty with language acquisition, associations were found to be relatively weaker than for those who were typically developing. For instance, Leonard, Miller, and Gerber (1999) compared the association between lexical diversity and grammatical morphology use (verb-related, e.g., past tense *–ed*, and noun-related morphemes, e.g., plural *–s*) in language samples from typically developing children and those with specific language impairment (SLI). The relationship found in the group of typically developing children was stronger than in the specific language impairment group, although both groups showed significant associations between lexical diversity and use of grammatical morphemes. Studies examining late-talking children, children on the autism spectrum, and those with Down Syndrome also revealed that there were significant but relatively weaker associations between lexicon and grammatical abilities (e.g., smaller correlations or similar vocabulary sizes associated with lower grammatical scores) compared with children who have been typically developing (Moyle, Weismer, Evans, & Lindstrom, 2007; Vicari, Caselli, & Tonucci, 2000; Weismer et al., 2011).

Regarding associations between vocabulary and grammatical abilities in children with CIs, previous studies that included children with a relatively wide range of age at implantation showed inconsistent results when assessing multiple domains of language (Boons et al., 2013; Geers et al., 2003; Schorr et al., 2008; Young & Killen, 2002). Among these studies, it is noteworthy that Boons et al. (2013) examined the correlation coefficients between vocabulary and morphosyntax in 70 Dutch-speaking children with CIs (range = 6 months to 5 years). They employed the Expressive One Word Picture Vocabulary test (Martin & Brownell, 2011), two subtests of the Clinical Evaluation of Language Fundamentals (Dutch Version; Kort, Schittekatte, & Compaan, 2010), and a narrative storytelling task. The authors found roughly equivalent levels across expressive vocabulary, morphology, syntax, and narratives. Their results indicated moderate correlations between these linguistic domains (range of r s = .41–.69). However, although the age range was wide (up to 5 years old), many participants of the study were implanted at a young age (median age at implantation = 20 months; interquartile range = 21 months). Therefore, it was not clear whether the results were influenced by the specific distribution of age at implantation.

By contrast, Duchesne, Sutton, and Bergeron (2009) studied 27 French-speaking CI recipients (age at testing = 42 to 99 months; implanted before 28 months of age) and found that approximately 70% of children showed some

dissociation between vocabulary and grammatical abilities. That is, some of the young CI recipients showed normal lexical ability (i.e., receptive and expressive) but poor performance in understanding morphosyntactic aspects, whereas other children showed comparable scores in expressive vocabulary with the norms of age peers with NH, but their morphosyntactic comprehension scores and receptive vocabulary were below NH age norms. Although the range of age at implantation for the participants was narrow and all were implanted at a young age, the study did not complete correlation analyses. Therefore, the current study will increase understanding of the relationship between vocabulary and grammatical abilities in young CI recipients.

Clearly, there is a need for new information regarding the early stages of grammatical development in today's very young CI recipients. Furthermore, little is known about the degree to which vocabulary size and grammatical abilities are associated in the development of young CI recipients. The current study asked two main questions to increase knowledge in these areas: (a) After 2 years of CI use, do young CI recipients and vocabulary-matched children with NH show comparable grammatical skills? (b) Do young CI recipients and children with NH show significant correlations between overall vocabulary size and grammatical scores? These questions were examined by matching young CI recipients and typically developing toddlers according to the sizes of their expressive vocabularies, rather than CA or the amount of robust hearing experience.

Method

Participants

CI Group

A total of 13 children were included in the current study (five boys and eight girls) from a longitudinal investigation examining young CI recipients' speech development. All of them had bilateral severe-to-profound or profound hearing losses, and CIs were implanted before their third birthdays. Their mean age at activation was 21 months ($SD = 8.92$; range = 9–36 months). The range of age at testing was between 33 and 60 months old ($M = 44.6$ months, $SD = 8.92$). All children had 24 months of robust hearing experience. Their most recent CI-aided hearing threshold was on average 24.23 dB HL ($SD = 5.56$, range = 17 to 39). In the case of JAWE, although she showed the level of 39 dB HL at her last audiometry testing, her hearing levels at activation and 12 months post-CI were 23 and 21 dB HL, respectively. Those levels indicated that she had robust access to speech sounds across her CI experience. Therefore, the aided hearing thresholds for all children with CIs corresponded to the "mild" hearing loss level (pure-tone average of 16 to 40 dB HL), indicating access to speech at conversational intensity levels.

The children came from monolingual English-speaking homes and received auditory–oral intervention through

one of five auditory–oral schools in the midwestern United States. The socioeconomic status of the families was examined using a modified version of Nitttrouer and Burton's (2005) Index of Social Position (NISP) on the basis of the parents' self-reported occupational and educational levels (more information can be found in Ertmer & Jung, 2012). Using this index, parental occupation and education levels were multiplied according to the levels identified in the index and summed together (i.e., mother's occupation level $\times$ mother's education level + father's occupation level $\times$ father's education level). Each category has eight levels (1 through 8). The possible range of NISP scores is between 2 and 128. Two children were from single-parent families. For these families, scores were doubled after calculating the single parent's score. Table 1 presents the demographic and NISP information of all participants in the CI and NH groups. Finally, although the original longitudinal investigation did not include a formal screening of global development, reports from parents, school personnel, and medical records confirmed that the children in the CI group had no secondary behavioral, motor, or learning disabilities.

NH Group

Fifteen children with NH, between the ages of 27 and 30 months, were recruited to serve as a control group. This age range was selected because it closely matched the distribution of vocabulary sizes found in the CI group, on the basis of the CDI norms (combining genders). Two children were later excluded because they did not produce representative language samples or were not cooperative for hearing screening and developmental screening. The mean age at testing of the remaining 13 children was 27.85 months old ($SD = 1.14$), on average 17 months younger than CI participants.

All children (seven boys and six girls) in the control group came from monolingual English-speaking homes. Their parents reported that the children did not have any identified developmental delays or disabilities. Along with parental reports, a developmental screening was done using the Battelle Developmental Inventory Screening (BDIS; Newborg, Stock, Wnek, Guidubaldi, & Svinicki, 1984). The full version of the test provides standard scores, but the screening version provides age-equivalent scores and cutoff scores (-1.0 , -1.5 , and -2.0 SD s) for the raw scores. According to Glascoe and Byrne (1993), when using the BDIS, a -2.0 SD cutoff showed better specificity (81%) than a -1.5 SD cutoff (73%) in identifying typically developing children correctly. The NH participant's mean score on the BDIS was 99 points ($SD = 8.63$). The raw scores for all children ranked above the -2.0 SD s cutoff score, indicating performance within the normal range.

Parents also reported that all of the children in the NH group had passed newborn hearing screening. An additional hearing screening was administered when the children visited the Purdue Speech Development Lab for testing. Twelve children passed the hearing screening in both ears at 20 dB HL at 500, 1k, 2k, and 4k Hz. The remaining child was fussy during testing and refused to

Table 1. Demographic information for the CI recipients and NH participants.

CI							NH				
Child	Gender	Age at activation in months (2nd CI)	Age at testing in months	Mean CI-aided hearing thresholds (SF or better ear) in dB HL	Device model, processing strategy	NISP	Child	Gender	Age at testing in months	BDIS scores	NISP
JOIR	M	12	36	29	Freedom, ACE	25	MAMU	M	27	88	66
DAST	M	21	45	26	Freedom, ACE	44	RUBO	F	27	101	42
OLHE	F	25	49	26	Freedom, ACE	66	EVBR	M	27	92	18
ABHO	F	27	51	23	Harmony, HiRes-P	48	EMGO	F	27	99	91
ETKO	M	26	50	22	Freedom, ACE	26	JOSU	M	27	103	66
JORO	F	36	60	18	Freedom, ACE	16	JOSWI	M	28	93	54
AAWI	F	36	60	23	Freedom, ACE	40	JOSWA	M	27	101	72
OWJO	M	9 (22)	33	17	Freedom, ACE	72	EMHA	F	28	97	30
MAJE	M	13 (13)	37	22	Freedom, ACE	52	NAOB	M	30	104	56
CAST	F	13 (19)	37	25	Freedom, ACE	30	RAGI	F	27	97	48
GIAI	F	13 (27)	37	20	Freedom, ACE	66	HAHA	F	28	95	66
MAMA	F	18 (20)	42	25	Freedom, ACE	12	ETCA	M	30	106	20
JAWF	F	19 (38)	43	39	Harmony, HiRes-P	40	MEDU	F	29	123	70
<i>M</i>		20.62 (23.17)	44.62	24.23		41.31	<i>M</i>		27.85	99.92	53.77
<i>SD</i>		8.92 (8.57)	8.92	5.56		19.28	<i>SD</i>		1.14	8.63	21.59

Note. CI = cochlear implant; NH = normal hearing; SF = sound field; NISP = Nittrouer Index of Social Position; BDIS = Battelle Developmental Inventory Screening; F = female; M = male; ACE = advanced combination encoder; HiRes-P = HiResolution–Paired.

continue wearing headphones after screening one ear. The child was eventually included in the study because he responded to two frequencies (2k and 4k Hz) in one ear and showed sensitive responses while interacting with his mother, who reported NH behaviors at home. The NH group's NISP scores were calculated using the same method as for the CI group. One child was from a single-parent family, so the score was doubled after calculating the score for the single parent. The NISP scores were not significantly different between the CI and the NH group, $t(24) = -1.552$, $p = .134$.

Data Collection Procedure

CDI

The parents of CI recipients completed the CDI: Words and Sentence version, reporting vocabulary and grammatical skills at 6-month intervals after CI activation. In other words, the CDIs of the CI group were completed at 6, 12, 18, and 24 months after CI activation. To avoid fatigue from repetitively filling out the entire CDI, words marked at each interval were assumed to remain in the children's vocabularies. Different-colored markers were used to indicate words produced at each interval so that parents were not asked to consider every vocabulary item on the CDI each time they filled out the form. Therefore, the vocabulary size at 24 months postactivation was an accumulated score after having multiple opportunities for parents to report spoken words. This repeated process was likely to reduce the probability of making errors in reporting vocabulary items. Only the total number of vocabulary items reported on the CDIs at the 24-month session was analyzed.

The NH group's parents completed the CDIs when they visited the lab for data collection. This procedure

differed from that of the CI group in that the parents of the NH group were required to consider each vocabulary item during a single administration of the CDI. The possibility of underestimating the children's vocabulary size was considered because the mothers could tire of filling out the entire form in one sitting. However, even though there are no studies directly comparing the results of accumulated versus one-time assessment with the CDI, the test–retest reliability of CDI shows that parents are highly reliable at reporting their children's vocabulary ($r = .95$, $p < .01$; Fenson et al., 2007, p. 101) when they have to fill out the form in one sitting.

Using CDI responses, the mean vocabulary size for the CI group was 449.45 words ($SD = 167.42$), whereas the mean for the NH group was 512.85 words ($SD = 142.371$). Result from a t test showed that the two groups did not have significant differences in overall vocabulary size, $t(24) = -0.447$, $p = .695$. CA-based percentiles were not available for the CI group due to the older and wider-than-typical age range of the participants. However, when using their amount of hearing experience (i.e., 24 months) as their age, percentile scores ranged between the 38.04th percentile and 99th percentile ($M = 76.13$, $SD = 24.11$). Children with NH ranked between 19.29th percentile and 95.67th percentile ($M = 66.68$, $SD = 25.24$). The Shapiro–Wilk test indicated that neither group violated the assumption of normal distribution ($p = .091$ for CI and $p = .069$ for NH group).

Language Samples

Twenty-minute adult–child play interactions were audio- and video-recorded for every participant. All of the young CI recipients' recordings were made at their schools.

A standard set of toys was provided to the children during each recording session. The children wore a specially designed vest with a front pocket that held a small wireless microphone (SONY; ECM-HW1), making it possible to record their speech at a close distance. Most of the sessions for the CI group involved parents interacting with their children, but occasionally, children's early interventionists filled in when parents were unavailable (four sessions out of a total of 13 sessions at the 24-month interval). In this way, the children always interacted with a familiar adult. The CI group's samples were collected as part of a 2-year longitudinal study. The 24 months postactivation samples from this study were compared with the single samples collected from the NH group.

Play interactions between children in the NH group and their parents were also audio- and video-recorded. Again, the parents were instructed to play in the same manner as at home. The children with NH were offered the same set of toys used by the CI participants. While the adult and child interacted, the first author observed the session via a video monitor and headphones but did not participate in the interaction. Recordings took place in the Speech Development Lab at Purdue University. Although this setting is different from the one used with the CI group, previous research (Borduin & Henggeler, 1981) has found that different settings (i.e., lab vs. home) do not necessarily affect parent-child interactions. Parents for the NH group also confirmed that their children talked as usual after recording sessions were completed.

Four native English-speaking research assistants who had hearing sensitivity within normal limits transcribed utterances from both groups of children. Utterances were segmented and transcribed by phonological units (i.e., intonation and pause), one of the three conventions of Systematic Analysis of Language Transcripts (Miller & Chapman, 2008). When a transcriber completed the first transcription for each child, another research assistant reviewed it. If the reviewer found any discrepancies on the transcription, a meeting with the first transcriber was arranged. The two research assistants then relistened to the parts where disagreements occurred and then discussed them. Only those utterances upon which the two research assistants could reach a consensus were included in the study. On average, 22.80 utterances per child were identified for further discussion. Among these utterances, 88.53% were agreed upon after the discussion process, leading to the exclusion of 68 utterances (2.61 utterances per child). Finally, only utterances on which the transcribers agreed, and that were totally intelligible, were included in the analyses.

The mean number of utterances analyzed per child was 146.46 ($SD = 57.47$) for the CI group and 132.76 ($SD = 33.64$) for the NH group. The range was between 64 and 266 and between 67 and 182, respectively. There was no significant between-groups difference in the number of utterances produced per session, $t(24) = 0.741$, $p = .466$. Additionally, there was no statistical difference in the number of utterances per session for those in which children interacted with parents and those in which they interacted

with their interventionists ($U = 13.00$, $z = -0.772$, $p = .503$).

Data Analyses

Global Grammatical Measures

Four grammatical measures were examined: one from CDI data and three from language samples. The Words and Sentences version of the CDI has a subsection for grammatical ability that examines children's inflectional use of nouns and verbs, three longest utterances, and their grammatical complexity. Among these, the inflectional use of nouns and verbs and the three longest sentences the child has used (CDI Sentence and Grammar sections A–E) were excluded from analysis because it was decided to directly examine the productivity of grammatical morphemes and MLU in language samples from adult-child interactions. The Grammatical Complexity score reveals how well children use morphosyntactical aspects of language. In this task, parents choose sample utterances that the child is most likely to say (e.g., "Daddy car" vs. "Daddy's car" and "Lookit me!" vs. "Lookit me dancing!"). Scoring is based on counting the number of items when parents checked the more complicated form (e.g., Daddy's car). Although the Grammatical Complexity section provides only 74 examples (two examples per item, total 37 items), when compared with other standardized tests—such as the Reynell Developmental Language Scale (Reynell & Gruber, 1990)—and various behavioral variables from language samples—for example, number of different words, MLU, or the Index of Productive Syntax (Scarborough, 1990)—this section has been shown to be a valid measure of children's grammatical skills (Thal, DesJardin, & Eisenberg, 2007; Thal, O'Hanlon, Clemmons, & Fralin, 1999).

Three measurements were used to quantify the children's grammatical morpheme use in language samples: MLU-morphemes (MLU_m), Tense Marker Total (Hadley & Short, 2005), and Productivity Scores (Hadley & Short, 2005). MLU_m was employed to measure children's general morphosyntactic development from actual child language samples, not from perceived examples of parents as grammatical complexity. Whereas MLU_m did not specify particular morpheme use, the Tense Marker Total and Productivity Scores assessed five categories of tense marking morphemes that emerge and develop to full productive use in young children between the ages of 2 and 3 years old (Hadley & Short, 2005). The Tense Marker Total was used to fulfill the goal to determine whether young CI recipients show a similar onset of diverse tense marking morphemes to their vocabulary size-matching peers with NH. It examined 15 grammatical morphemes—that is, (1) past tense *-ed*, (2) third person singular *-s*, (3) auxiliary DO (*do*, *does*, *did*), (4) copula BE (*is*, *am*, *are*, *was*, *were*), and (5) auxiliary BE (*is*, *am*, *are*, *was*, *were*). If the targeted morphemes appeared at least one time in the language sample, that single use would receive 1 point. An overgeneralized morpheme (e.g., *goed*) would also receive 1 point because it

shows that the child has knowledge of grammatical morphemes. The use of copula and auxiliary forms would need to be uncontracted to receive a point unless accompanied by nominal subjects. For example, the utterance "Cow's allgone" would receive 1 point, but the utterance "It's all gone" would not. The maximum score for this system is 15.

In addition to knowing how diverse tense marking morphemes were used, determining how productively children use the morpheme was another important goal. Productive use of a morpheme means "to use the morpheme in two or more sufficiently different contexts" (Hadley & Short, 2005, p. 1347). Hadley and Short devised the method of Productivity Scores to examine five grammatical morpheme categories in up to five different contexts per morpheme to assess full productivity of each category: (1) past tense *-ed*, (2) third person singular *-s*, (3) auxiliary DO, (4) copula BE, and (5) auxiliary BE. The first two morphemes—past tense *-ed* and third person singular *-s*—must be used with different lexical verbs to receive credit. For example, if a child produces "she talked, daddy listened, and I listened," that child would receive 2 points for past tense *-ed* because two different verbs (i.e., talk and listen) were used. The latter three (auxiliary DO, copula BE, and auxiliary BE) would need to be used with different subject tense markers. For example, "She is nice," "He is nice," and "She is sweet" would receive 2 points because two different pronouns (i.e., she and he) were used. The maximum score for the Productivity Scores is 25.

The point-by-point reliability of grammatical measures was assessed. Grammatical Complexity scoring was reviewed for intrarater and interrater reliability. Intrarater reliability examined using 26.92% of data was 100%. Additional reviewing of 23% of Grammatical Complexity scores for interrater reliability was also 100%. The transcriptions from six children (23% of participants) were reexamined for intrarater reliability of scoring of Tense Marker Total and Productivity Scores. Intrarater reliability was 97.77% for Tense Marker Total and 98.66% for Productivity Scores. Interrater reliability was also examined through rescoring an additional six children's samples. The agreement was 98.28% for Tense Marker Total and 99.33% for Productivity Scores.

Statistical Analyses

Group comparisons for the four grammatical outcomes were made using between-groups *t* tests and Mann-Whitney *U* tests. Correlations between vocabulary size and the four global measures were examined to determine whether significant associations between grammatical skills and vocabulary size existed in the two groups of children.

Results

To select statistical analysis for group comparisons, the assumptions for the equality of variances and the normality of data distribution were tested. The results from

the Levene's tests showed that only grammatical complexity violated homogeneity between the two groups, $F(1, 24) = 6.017$, $p = .022$ (see Figure 1). Therefore, a *t* test, which does not assume the equality of variances, was conducted for Grammatical Complexity scores. The Shapiro-Wilk tests indicated that the Tense Marker Total and Productivity Scores for the CI group violated (at the level of $p \leq .05$) the assumption of normality: p value = .047 for Tense Marker Total and p value = .046 for Productivity Scores. Therefore, instead of *t* tests, the nonparametric Mann-Whitney *U* test was conducted for the comparisons involving Tense Marker Total and Productivity Scores. All the statistical results presented in the study were from two-tailed tests.

Two additional correlation analyses were conducted to determine any confounding factors. First, the relationship between families' NISP scores and language outcomes was examined to investigate whether it confounded children's language skills. None of the measures showed a significant relationship for either group. Secondly, the correlations between the four grammatical measures were tested. Notably, the grammatical measures were significantly correlated with each other ($ps < .05$). In the CI group, every measure was correlated with the others, and in the NH group, three significant correlations were found: (1) Grammatical Complexity and Productivity Scores, (2) MLU_m and Tense Marker Total, and (3) Tense Marker Total and Productivity Scores. Given that these scores came from the same individuals, the correlations between grammatical measures were not surprising. While the correlation between variables should be considered when regression analyses are attempted, this study aimed only to examine between-group differences and the correlational relationship between vocabulary size and each grammatical measure independently.

Group Comparisons of Four Global Grammatical Measures

Each score on the four measures was compared between groups. The mean scores of grammatical complexity were 17.46 ($SD = 12.70$) for the CI group and 20.69 ($SD = 8.15$) for the NH group. There was no statistically significant difference in grammatical complexity between the two groups, $t(20.45) = -0.772$, $p = .449$, $d = -0.303$. The MLU_m for the CI group was 2.37 morphemes ($SD = 0.69$) and, for the NH group, it was 2.39 ($SD = 0.59$). Again, there was no statistical difference in MLU_m between the two groups, $t(24) = -0.089$, $p = .930$, $d = -0.036$, as both produced utterances of comparable and, indeed, almost identical length.

When Tense Marker Total scores were analyzed, mean scores were 3.23 ($SD = 2.31$) for the CI group and 2.92 ($SD = 1.75$) for the NH group. A Mann-Whitney *U* test indicated that there was no difference between the two groups ($U = 81.50$, $z = -0.156$, $p = .880$, $\eta^2 = .001$). Finally, the mean Productivity Scores were 5.23 ($SD = 4.48$) for the CI group and 4.46 ($SD = 2.60$) for the NH group. The result

Figure 1. Group comparisons of four grammatical measures. CDI = MacArthur Communicative Development Inventory; MLU_m = mean length of utterances in morphemes; CI = cochlear implant; NH = normal hearing.

of the Mann–Whitney U test showed no statistically significant between-group differences ($U = 84.50$, $z = 0.000$, $p = 1.000$, $\eta^2 = 0$). Individual scores for vocabulary and grammatical measures are presented in Table 2. Group results are displayed in Figure 1.

Across all four grammatical measures, young CI recipients showed very similar production of grammatical features when compared with their vocabulary size-matched NH peers. Children from the two groups produced utterances of comparable morphosyntactic complexity and used similarly diverse grammatical morphemes.

Associations Between Vocabulary Size and Grammatical Scores

Pearson correlation analyses were conducted to determine whether associations between the four grammatical measures and vocabulary size existed. Table 3 presents the results of the correlation analyses between vocabulary size and four grammatical measures. For nonnormally distributed scores (Tense Marker Total and Productivity Scores

for CI), nonparametric Kendall's tau-b analyses results were also reported.

The CI group showed significantly high correlations ($r_s = .667$ – $.785$) between vocabulary size and the four grammatical measures. The two measures violating normal distribution—Tense Marker Total and Productivity Scores—were additionally analyzed using the nonparametric Kendall tau-b test and also showed significant correlation coefficients. In contrast, the NH group showed significant correlations in two measures—Grammatical Complexity and Productivity Scores—but not in MLU_m and Tense Marker Total. However, the size of the coefficients of the two latter measures was moderate (.434 and .485, respectively), and the post hoc test using Fisher's r -to- z' transformation indicated that none of these values were statistically different between groups ($z_s = 0.44$ to 0.89 , $p_s > .3$). The post hoc test included the analysis using both converted r values as a function of Kendall's tau-b (Gilpin, 1993) and the actually observed Pearson correlation coefficients. Therefore, the magnitude of associations found in the two groups for all four measures was determined to be similar.

Table 2. Individual vocabulary size and grammatical scores.

CI						NH					
Child	CDI	GC	MLU _m	TMT	PS	Child	CDI	GC	MLU _m	TMT	PS
MAJE	190	1	1.57	2	2	MAMU	194	0	1.70	1	1
AAWI	283	2	1.67	1	1	RUBO	329	13	1.57	0	0
ETKO	313	4	1.70	1	1	EVBR	347	21	2.21	3	4
GIAI	340	11	2.15	1	1	EMGO	467	21	2.56	4	5
JAWE	383	7	2.49	3	5	JOSU	553	21	2.72	4	7
JOIR	389	24	2.21	3	3	JOSWI	525	23	2.85	5	9
MAMA	533	20	2.17	3	5	JOSWA	532	22	2.70	2	3
OWJO	542	18	2.28	2	5	EMHA	559	25	2.22	1	2
CAST	631	34	2.55	5	10	NAOB	598	23	3.77	5	6
ABHO	666	31	2.98	6	8	RAGI	618	30	2.31	3	6
DAST	675	37	3.98	8	12	HAHA	637	18	1.69	1	3
JORO	678	29	3.19	6	14	ETCA	641	18	2.15	4	5
OLHE	680	9	1.83	1	1	MEDU	667	34	2.62	5	7
<i>M</i>	484.85	17.46	2.37	3.23	5.23	<i>M</i>	512.85	20.69	2.39	2.92	4.46
<i>SD</i>	175.37	12.70	0.69	2.31	4.48	<i>SD</i>	142.37	8.15	0.59	1.75	2.60

Note. CI = cochlear implant; NH = normal hearing; CDI = MacArthur Communicative Development Inventory (maximum size = 680); GC = Grammatical Complexity (maximum score = 37); MLU_m = mean length of utterances in morphemes; TMT = Tense Marker Total (maximum score = 15); PS = Productivity Scores (maximum score = 25).

Visual inspection of Figure 2 suggests a potential effect of outliers on the correlations (e.g., DAST in the CI and RUBO in the NH), and so additional correlation analyses excluding the two children were conducted. This reanalysis showed that all of the correlations remained significant for the CI group, but the correlation for Productivity Scores in the NH group was no longer significant. However, according to the outlier identification formula proposed by Hoaglin et al. (Hoaglin & Iglewicz, 1987; Hoaglin, Iglewicz, & Tukey, 1986), 25th quartile – k * (75th quartile – 25th quartile) for lower bound or 75th quartile + k * (75th quartile – 25th quartile) for upper bound, neither of the two scores appear to be true outliers. We examined the outliers by applying two values to k as suggested by Hoaglin and Iglewicz (i.e., 1.5, which is a customary value, and 2.2, which was proposed as an approximation of the fine-tuned value for a small sample size; for more details, see Hoaglin & Iglewicz, 1987) and found that all the scores of MLU_m, Tense Marker Total, and Productivity Scores were within the boundaries. Regarding Grammatical Complexity scores, MAMU's score was identified as an outlier when k was applied with

either 1.5 or 2.2, but his score can be found within 1.5 *SD*s from the mean on the basis of the CDI norm at his age. Based on Hoaglin's criteria and the inclusion of scores within 1.5 *SD* of the norm mean, these scores were retained in correlation analyses.

Age-controlled post hoc tests for the CI group using a partial correlation analysis revealed significant correlation coefficients between vocabulary size and all four grammatical measures ($p < .05$). By contrast, when age was controlled, the NH group showed a significant correlation only between vocabulary and grammatical complexity ($r = .789$, $p = .002$). Any interpretation of this finding should be made carefully because the sample size of the study was small. Nevertheless, whereas the NH group showed significant associations with some of the measures (i.e., Grammatical Complexity and Productivity Scores), the current CI participants showed consistently significant associations between vocabulary size and all four grammatical measures.

Discussion

Research Question 1: After 2 Years of CI Use, Do Young CI Recipients and Children With NH Matched for Vocabulary Size Show Comparable Grammatical Skills?

The results of data analyses showed that the young CI recipients and their vocabulary-matched NH peers had comparable scores on all four measures: Grammatical Complexity, MLU_m, Tense Marker Total, and Productivity Scores. The children from both groups spoke grammatically appropriate words at their proper positions (e.g., instead of "I *no* do it," saying "I *can't* do it") and grammatical

Table 3. Pearson correlation analyses between vocabulary size and grammatical measures.

Group	GC	MLU _m	TMT	PS
CI	.785**	.697**	.667* (.484*)	.713** (.559**)
NH	.773**	.434	.485	.577*

Note. Parentheses indicate the results of nonparametric test (Kendall's tau-b). GC = Grammatical Complexity; MLU_m = mean length of utterances in morphemes; TMT = Tense Marker Total; PS = Productivity Scores; CI = cochlear implant; NH = normal hearing.

* $p \leq .05$. ** $p < .01$.

Figure 2. Associations between vocabulary size and grammatical measures. CDI = MacArthur Communicative Development Inventory; MLU_m = mean length of utterances in morphemes; CI = cochlear implant; NH = normal hearing.

morphemes (e.g., instead of “more cookie,” saying “more cookies”) to build sentences and produced nearly identical lengths of utterances (MLU_m for CI = 2.37 and for NH = 2.39, respectively). The number of tense marker types was also quite similar. In addition, the two groups of children were comparable in their productive use of various grammatical morphemes.

Although the current study did not match hearing experience between the CI and NH groups, all CI recipients had 24 months of robust hearing experience and showed comparable abilities to 27–30-month-old children with NH. That is, the outcomes were congruent with previous studies showing comparable or better outcomes in grammatical measures when matching by hearing experience (Caselli et al., 2012; Inscoc et al., 2009; Jung & Ertmer, 2011; Szagun, 2000). However, given that similar outcomes were not maintained after an extended period of CI use in the Guo et al. (2013) study, the CI participants’ long-term grammatical development should be examined for further growth across time.

Considering the auditory perceptual difficulties likely to be experienced by children with CIs, such as less than NH acuity and the effects of background noise and reverberation

in everyday environments, this finding is encouraging. The results suggest that young CI recipients do not have particular weaknesses in grammatical development and that grammatical development benefits from a young age at implantation compared with previous studies that included children with a wide range of age at implantation (Geers et al., 2003; Young & Killen, 2002). However, it seems quite likely that listening and spoken language intervention also contributed to the acquisition of both vocabulary and grammatical abilities, as all of the children in the CI group participated in auditory–oral programs from a young age.

Research Question 2: Do Young CI Recipients and Children With NH Show Significant Correlations Between Overall Vocabulary Size and Grammatical Scores?

The CI and the NH group supported the domain generality hypothesis by displaying clear associations between vocabulary size and two grammatical measures: Grammatical Complexity scores and Productivity Scores. These findings conformed to previous studies (Fenson et al., 1994; McGregor et al., 2005) that examined CDI

vocabulary size and Grammatical Complexity scores in typically developing and lexically precocious children. In addition, Thal et al. (1996) found that a child whose vocabulary size was large used grammatical morphemes more productively, even when that child's MLU was relatively small. Thus, the outcomes for these two measures supported the domain generality hypothesis for both groups (see Figure 2).

The fact that the NH group did not show a significant association between vocabulary size and MLU_m might also be explained by a study supporting the domain generality hypothesis. Braginsky et al. (2015) found that vocabulary sizes were more closely associated with CDI items examining morphological aspects than items measuring syntax. The authors argued that syntactic (e.g., MLU) development is somewhat mediated by a child's age. Thus, the narrow age range of the current participants with NH (i.e., 27–30 months) might not have been sufficient to provide a range of MLU in the NH group. Actually, nine of the 13 children with NH (~70%) showed an MLU_m range between 2.15 and 2.85 ($SD = 0.26$), whereas only six (~46%) showed a 2.15–2.98 MLU_m range in the CI group. This finding is indirectly supportive of the findings of Braginsky et al. (2015), which suggest that the association between vocabulary size and MLU is loosely coupled in children who are typically developing.

Moreover, the correlation coefficient between vocabulary and MLU_m for children with NH in the current study was $r = .434$. Interestingly, this value is similar to the one found in the McGregor et al. (2005) study ($r = .47$, $n = 33$) that examined the association between vocabulary diversity in language samples and MLU in 2-year-old children. Although McGregor et al. did not measure vocabulary size per se, the comparable correlation coefficient suggests the existence of a moderate association between vocabulary and syntactic development in children with NH. Our analyses on effect sizes also showed that both the CI and NH groups showed similar trends in their associations between vocabulary size and MLU_m . A larger sample controlling for age effect might reveal a significant association between vocabulary size and MLU_m in children with NH. This merits further study.

Finally, the Tense Marker Total (Hadley & Short, 2005) did not show a significant association with vocabulary size in the NH group. This result did not support domain generality in children with NH. Again, however, any interpretation should be made cautiously. The purpose of Tense Marker Total is to determine the onset of diverse morphemes. Children could use diverse morphemes with single verbs to get credit (e.g., He walks, He walked, Did you walk?). That is, a large vocabulary might not be necessary for high Tense Marker Total scores. Recall that the effect sizes of the associations for all measures between groups were not significantly different. We also found a moderate correlation coefficient for Tense Marker Total in the current study ($r = .485$, $p = .093$), not significant, but close. This suggests that the significant correlation might be found with a larger sample size.

The semantic–grammatical associations found in the CI group were not in line with the study conducted by Duchesne et al. (2009). This discrepancy might be attributed to the different analyses used in the studies. Duchesne et al. determined the associations on the basis of whether young CI recipients' scores of each domain were included in the normal range for CA-matching peers instead of calculating correlation coefficients directly. The analysis may not represent the associations accurately. For instance, if children received a standardized score of 86 for one test, and 84 for the other, the former is within the 1 SD of the mean, but the latter is below this level. However, this case would indicate that both scores are relatively low, suggesting a close relationship. Therefore, the current study sought the association through a straightforward analysis independently from the age norms, showing that young CI recipients develop both domains in close relationships rather than having a relative difficulty in the acquisition of grammatical skills.

In conclusion, both groups' grammatical skills were closely associated with vocabulary skills. This finding supports the domain generality, rather than the domain specificity hypothesis. Additionally, an overgeneralization of irregular past tense verbs (e.g., *went*) into regular past tense verbs (e.g., *goed*) was rarely observed in the language samples of the current study. Based on the effect size between groups, the magnitudes of associations found in the two groups were not different, confirming that the lexical–grammatical associations of young CI recipients were quite similar to those of children with NH.

Study Limitations

A few limitations should be noted when interpreting the findings of the current study. First of all, further investigation is necessary to understand the finding that the NH group showed significant associations in only two measures, whereas the CI group showed it for all measures. The inconsistency in the NH group might be due to the small number of NH participants with a small age range that caused lower power in the analysis and limited the ability to detect consistent associations, as noted in the study by McGregor et al. (2005). Larger studies are needed to increase understanding of the processes of linguistic development in young CI recipients compared with their peers with NH. However, even though two measures for the NH group did not show significant associations, the four grammatical measures were closely correlated to each other, and the magnitude of correlations was similar between the two groups of children. These findings supported the decision to examine the associations between vocabulary size and grammatical abilities in the two groups on the basis of the overall patterns, rather than focusing on the specific significance of each measure.

There was an additional limitation in the research design as well. The developmental screening test (i.e., BDIS) was only conducted for the NH group because the use of the test was determined after the CI group completed data

collection. Although the current study only included children with CI whose parents, school interventionists, and medical records reported no other disabilities during the 2 years of investigation, use of the BDIS with the CI group would have confirmed the absence of additional disabilities.

Lastly, when generalizing the current findings to other young CI recipients, it should be noted that a sizable portion of today's young CI recipients communicate with both speech and sign. It is not known whether CI users who use Signed English or American Sign Language will show similar association between vocabulary size and grammatical abilities. Additional studies that include CI recipients who use simultaneous communication are needed to explore linguistic acquisition in such children.

Clinical Implications and Future Directions

Although grammatical abilities were comparable between the CI and NH groups, it should be kept in mind that there is no guarantee that age-appropriate language skills will eventually be achieved by all young CI recipients. The CI participants were between the ages of 33 and 61 months at the time of testing, and so most of them were likely to be behind their CA peers regarding vocabulary and grammatical abilities. In addition, although 12 out of 13 young CI recipients showed typical relationships between vocabulary and grammatical abilities, ongoing assessments of both vocabulary and grammatical abilities are needed to ensure that both of these abilities continue to develop in the years following cochlear implantation. Whereas a young age at implantation has been frequently suggested to lead to age-appropriate language abilities (e.g., before 18 months in Niparko et al., 2010; 24 months in Nicholas & Geers, 2007), a recent study by Dunn et al. (2014) revealed that the effect of age at implantation diminished in speech perception and spoken language abilities as children used CIs over a relatively long period. As these contrasting findings indicate, more research is needed to determine the potential of young CI recipients to achieve and maintain age-appropriate linguistic skills.

The consistently significant associations found between vocabulary and grammatical abilities in the CI group suggest that there is a need to investigate the relationship between vocabulary and other domains of language. For example, one potentially fruitful comparison might involve phonological development. A recent study of two young CI recipients showed that both produced their first words within a month of CI activation (Ertmer & Inniger, 2009) and acquired a much larger vocabulary size in the first year of CI use than is typical in the first year of life for children with NH (244 and 346 words produced after 1 year of CI experience). These findings suggest that young CI recipients begin vocabulary development while they are first developing auditory-guided phonological skills. Ertmer and colleagues (Ertmer & Jung, 2012; Ertmer et al., 2013; Iyer, Jung, & Ertmer, 2017) have also found that young CI recipients showed more-rapid-than-typical prelinguistic vocal development and acquisition of

early phonological skills. However, little is known about how vocabulary and prelinguistic vocal development are associated. Examining the interactions between vocabulary and other linguistic domains in young CI recipients has the potential to shed light on how young children move forward from foundational skills to advanced levels of language.

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