Hearing Experience and Receptive Vocabulary Development in Deaf Children With Cochlear Implants

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This study investigated receptive vocabulary delay in deaf children with cochlear implants. Participants were 23 children with profound hearing loss, ages 6–14 years, who received a cochlear implant between ages 1.4 and 6 years. Duration of cochlear implant use ranged from 3.7 to 11.8 years. *Peabody Picture Vocabulary Test, Third Edition* (*PPVT-III*) data were analyzed first by examining children's errors for evidence of difficulty in specific lexical content areas, and second by calculating standard scores with reference to hearing age (HA) (i.e., chronological age [CA] − age at implantation) rather than CA. Participants showed evidence of vocabulary understanding across all *PPVT-III* content categories with no strong evidence of disproportionate numbers of errors in any specific content area despite below-average mean standard scores. However, whereas mean standard scores were below the test mean established for hearing children when based on CA, they were within the average range for hearing children when calculated based on HA. Thus, children's vocabulary knowledge was commensurate with years of cochlear implant experience, providing support for the role of spoken language experience in vocabulary acquisition.

Increasing numbers of children with profound hearing loss acquire spoken language using cochlear implants. Postimplant spoken language acquisition is influenced by complex interactions between multiple factors including but not limited to age at onset of hearing loss, age at cochlear implantation, and duration of implant use (Connor, Hieber, Arts, & Zwolan, 2000; Geers, 2003; Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2000). In general, however, children show better outcomes on measures of language and academic achievement the younger the age at cochlear implantation (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Connor & Zwolan, 2004; Connor et al., 2000; Fagan, Pisoni, Horn, & Dillon, 2007; Kirk et al., 2000). Despite evidence of substantial improvements in language and academic achievement associated with early implantation, many children with cochlear implants still do not perform at levels expected for their chronological age (CA) on all measures standardized on hearing children.

One index of spoken language learning that is consistently below average in children with cochlear implants is vocabulary comprehension, with delays noted both in number of words comprehended (i.e., vocabulary size) and in rate of receptive vocabulary acquisition (Blamey et al., 2001; Connor et al., 2000, 2006; El-Hakim et al., 2001; Fagan et al., 2007; Kirk et al., 2000; Thal, DesJardin, & Eisenberg, 2007). Scores on standardized measures of vocabulary size show that children with cochlear implants typically achieve receptive scores equivalent to one half to three fourths of their CA (Connor et al., 2000; Kirk et al., 2000). Kirk et al., for example, found that the age-equivalent vocabulary scores of children who received cochlear implants when they were 5 years old were 0.50 to 0.60 relative to their CA (i.e., age-equivalent score/CA) after 2 years of cochlear implant use. Age-equivalent scores provide useful information about children's performance; however, standard scores provide important additional information about

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normal variation around a test mean. Fagan et al. found that the receptive vocabulary standard scores of children within 3–11 years of cochlear implant experience were more than 1 *SD* below the mean established for hearing children, thus below the range of normal variation for their CA. Together, below-average scores show that many children with cochlear implants comprehend fewer spoken vocabulary words than expected for their CA.

Moreover, studies of spoken vocabulary comprehension often report slower *rates* of word learning for children with cochlear implants. The expected rate of change per year for hearing children is 1.0, a 1-year increase in age-equivalent score per year. However, for children with cochlear implants, the mean rate of change per year is typically 0.46 to 0.72 (Blamey et al., 2001; Connor et al., 2000; El-Hakim et al., 2001), with rates at the higher end of the range (i.e., .72) more likely for children implanted at relatively younger ages (Blamey et al., 2001; Connor et al., 2000; Kirk et al., 2000). Nevertheless, even when growth rates approach 1.0, children already behind in vocabulary development may not catch up with their CA-matched peers (Connor et al., 2006; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). As an example, for children implanted at age 5, Connor et al. reported not only that receptive vocabulary scores were 2 years below CA but also that mean rate of vocabulary growth was 0.48, less than half the expected rate of change for hearing children. Sustained growth at rates below 1.0 cannot overcome 2-year delays in vocabulary comprehension (Blamey et al., 2001; Connor et al., 2000). In fact, sustained rates of growth below 1.0 across 8 years of implant use produced gradually widening gaps between age-equivalent scores and CA (Connor et al., 2000). Thus, persistent vocabulary delay in children with cochlear implants reflects slow progress in vocabulary learning in relation to CA even after cochlear implantation. Understanding the reasons for slow growth in vocabulary scores is a prerequisite for improving vocabulary acquisition in children who use cochlear implants.

Vocabulary acquisition is important not only as a useful index of verbal learning (Woodward & Markman, 1998) and achievement (e.g., college entrance exams) but also because vocabulary knowledge is correlated with many measures of word recognition, speech comprehension, and reading in hearing children (Ouellette, 2006; Wise, Sevcik, Morris, Lovett & Wolf, 2007) and in children with cochlear implants (Blamey et al., 2001; Connor & Zwolan, 2004; Geers, 2003; Paatsch, Blamey, Sarant, & Bow, 2006; Spencer, Barker, & Tomblin, 2003). Therefore, despite measureable postimplant improvement, problems with spoken vocabulary comprehension are concerning (Connor et al., 2000; Dawson, Blamey, Dettman, Barker, & Clark, 1995). By contrast, children who use cochlear implants have shown larger and more rapid gains in auditory function, perception, nonverbal auditory and visual short-term memory, language production, and literacy, often achieving scores appropriate for their CA (Dawson, Busby, McKay, & Clark, 2002; Fagan et al., 2007; Geers, Nicholas, & Sedey, 2003; Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004; Sharma, Dorman, & Spahr, 2002; Spencer et al., 2003). Thus, children with cochlear implants experience particular challenges in acquiring receptive vocabulary knowledge equal to their CA.

In fact, delays in vocabulary development were found not only when children with cochlear implants were compared with their hearing peers but also when they were compared with children with moderately severe to severe hearing loss who used hearing aids (Eisenberg, Kirk, Martinez, Ying, & Miyamoto, 2004). Eisenberg et al. found that two groups of children—one with hearing aids and the other with cochlear implants—differed in vocabulary development despite comparable aided and postimplant hearing levels (i.e., 35 and 37 dB HL, respectively). They noted, however, that before age 2 when both groups received their sensory devices, hearing levels differed significantly. Before age 2, the hearing aid group had significantly better unaided hearing (i.e., 78 vs. 110 dB HL), thus early access to auditory and spoken language information that was inaccessible to the cochlear implant group. Both groups experienced later receptive vocabulary delay; however, the children with hearing aids had significantly better scores than the cochlear implant group. Therefore, despite comparable hearing levels after age 2, access to auditory information in the first 2 years of life benefited later vocabulary acquisition in children with more residual hearing to a degree unmatched by those with less residual hearing even after cochlear implantation. Thus, persistent delays in spoken vocabulary comprehension in deaf children with cochlear implants appear to reflect both diminished access to auditory and spoken language information before cochlear implantation and slow vocabulary growth after implantation. Although vocabulary development in children with cochlear implants is likely to be influenced by many factors (e.g., short-term memory, Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003), the reasons for persistent delays in vocabulary acquisition are still unclear.

In hearing children, both rate of vocabulary acquisition and word use have been shown to reflect the number and complexity of word-learning opportunities children experienced (Hart & Risley, 1995; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Huttenlocher & Smiley, 1987; Tardif, Gelman, & Xu, 1999). For example, hearing children acquired more nouns and verbs than adverbs and adjectives in part because parents used twice as many nouns and verbs in speech to their children (Choi, 2000; Hart & Risley, 1995; Tomasello, 2003). Among the earliest nouns hearing children produced, count nouns, animals, and foods were most prominent; however, body parts and words for other people (e.g., fireman) were rare (Smith, 2000). Even adults tended to remember some words better than others, recalling relatively concrete nouns more than abstract nouns (Paivio, Walsh, & Bons, 1994). Accordingly, children with cochlear implants may reveal strengths when tested on particular word classes and errors on others (e.g., adjectives). That children with cochlear implants make more errors on standardized vocabulary tests than hearing children do is evident in reports of persistent vocabulary delay (Connor et al., 2000; Fagan et al., 2007; Kirk et al., 2000); however, their errors patterns have not yet been explored. Whereas vocabulary performance is likely to reflect many aspects of language learning, including phonological memory (Gathercole & Baddeley, 1989), the underlying causes of vocabulary delay may be better addressed if children's error patterns are understood. A central question regarding vocabulary development in children with profound hearing loss and cochlear implants—whether children have selected difficulty acquiring certain word classes or whether they have more global difficulty acquiring words from all word classes—has not yet been addressed.

One step toward addressing questions about vocabulary performance in children with cochlear implants is to examine their errors on standardized measures of vocabulary comprehension for evidence that words from particular word classes are difficult for children with cochlear implants to learn. A second step toward addressing vocabulary performance is to reexamine children's overall scores in relation to their cochlear implant experience rather than their CA. Comparing traditionally calculated standard scores derived from CA with standard scores derived instead from hearing age (HA), or years of auditory language experience with a cochlear implant, will provide a clearer understanding of vocabulary acquisition after cochlear implantation. In memory research with deaf children, for example, Bebko and McKinnon (1990) found that spontaneous rehearsal emerged in connection with years of language experience (i.e., in the dominant modality) rather than CA. Together, these steps toward understanding vocabulary development in children with cochlear implants will clarify the effects of hearing experience on word learning, contribute to discussions regarding cochlear implantation, and advance preimplant and postimplant education and intervention practices.

The goals of this study were first to examine children's error patterns on a standardized test of vocabulary comprehension (i.e., *Peabody Picture Vocabulary Test, Third Edition* [*PPVT-III*]; Dunn & Dunn, 1997) for evidence of difficulty with specific lexical content areas, and second to examine their vocabulary scores in relation to HA rather than to CA. To the extent that the vocabulary knowledge of children with cochlear implants differs from normative expectations for hearing children, their error patterns and standard scores should also differ from those of the normative population. The purpose of this study was to identify factors underlying persistent receptive vocabulary delay in deaf children who use cochlear implants, with the long-term objective of improved intervention and access to opportunities requiring vocabulary knowledge routinely achieved by their hearing peers.

Method

Participants

Participants were 23 profoundly deaf children of hearing parents (15 male and 8 female children), ages 6–14 years (M = 9.1, SD = 2.4), who received a cochlear implant between 1.4 and 6.0 years (M = 2.5, SD = 1.3). Duration of cochlear implant use ranged from 3.7 to 11.8 years (M = 6.6 years, SD = 2.1). Twenty-one children were congenitally deaf; age of onset for the other 2 children was 6 months and 18 months, respectively. Parent responses to interview questions indicated that none of the participants had learning disabilities and that all used spoken English to communicate and functioned adequately in mainstream regular education programs. Before cochlear implantation, six children used Signed Exact English for some period of time between approximately 1.7 and 3.4 years of age (mean duration of sign use = 17.8 months, SD = 8.28), three with predominant emphasis on oral communication, and three with equal emphasis on oral and signed communication. However, none of the children relied on signed communication after cochlear implantation. Maternal education levels were reported as follows: high school, 26.1%; associate's degree, 8.7%; bachelor's degree, 43.4%; and graduate degree, 17.3%. One mother did not provide educational information.

All participants took part in an earlier study of language and motor development in children with cochlear implants (Fagan et al., 2007)[1] that found mean scores within the average range established for hearing children on standardized neuropsychological measures and selected tests of word reading and written sentence comprehension (i.e., *Developmental Neuropsychological Assessment*, Korkman, Kirk, & Kemp, 1998; *Peabody Individual Achievement Test-Revised*, Markwardt, 1998; *Woodcock Reading Mastery Tests-Revised*, Woodcock, 1998). Interview reports of adequate auditory functioning were validated by mean performance scores within the average range on measures of phoneme and syllable perception (i.e., *Lindamood Auditory Conceptualization Test-Third Edition*, Lindamood & Lindamood, 2004). Nevertheless, in this earlier study, mean receptive vocabulary scores (*PPVT-III*) were significantly below average. Therefore, *PPVT-III* scores and forms containing children's responses (Form A) were further examined to address questions regarding vocabulary delay for the present report.

Materials and Administration Procedures

The *PPVT-III* assesses word knowledge, requiring individuals to identify which of four stimulus pictures best represents the meaning of each word spoken by the examiner. *PPVT-III* raw scores yield standard scores based on normative data for hearing children and adults. Form A is comprised of 204 items from 20 different content areas compiled during *PPVT-III* development and standardization (e.g., actions, adjectives, and emotions; Williams & Wang, 1997). Table 1 lists the 20 content areas and the proportion of all 204 test items drawn from each of these content areas for Form A. (Table 1 also lists proportions of errors per content area for children in this study, to be discussed below.)

Note in Table 1 that some content areas of the *PPVT-III* are quite small, and words from such content areas may not be presented before children reach a performance ceiling. *PPVT-III* norms and procedures accommodate such routine variation. Furthermore, all *PPVT-III* stimulus words were validated

Table 1 Proportions of test items and errors by content area of the *Peabody Picture Vocabulary Test, Third Edition* Form III-A

Category	Items	Errors
Actions	.245	.258
Adjectives	.064	.061
Animals	.108	.062
Body parts	.034	.034
Books	.025	.027
Buildings	.059	.036
Clothing and accessories	.005	.008
Emotions	.034	.032
Foods	.010	.010
Fruits and vegetables	.015	.019
Geographical scenes	.049	.044
Household objects	.049	.069
Musical instruments	.020	.024
People	.044	.051
Plants	.034	.048
Shapes	.044	.020
Tools	.074	.107
Toys	.020	.024
Vehicles	.044	.050
Workers	.025	.015

during extensive standardization procedures to ensure that they reliably represented typical word knowledge at given ages (Williams & Wang, 1997). As a result, standardized testing begins at a place on the test where children of a given age are expected to achieve enough correct responses to establish a basal score.[2] Because words from the various content areas occur in places where, by and large, hearing children of a given age are expected to know the words and respond correctly (Williams & Wang, 1997), errors that occur where children are expected to be successful can impact their scores and identify the content areas represented in their errors. Although investigating *PPVT-III* errors is only one of many ways to assess vocabulary delay in children with cochlear implants, the method has many strengths, not the least of which are the wide use and acceptance of the *PPVT-III* in many fields of study, the fact that content words were carefully chosen and tested on normative populations and that the *PPVT-III* is standardized for use across a wide range of ages (Williams & Wang, 1997).

Consistent with standard *PPVT-III* administration procedures, study participants received unequal numbers of stimulus items, both overall and within content areas, due to differences in age and ability that determined the first word set presented and led some to obtain a performance ceiling sooner than others. As shown in the Appendix, which lists the number of participants tested with at least one to three items in a given content area, more than half of the study participants were presented with at least three items from 10 of the 20 content areas. Overall, the mean number of stimulus items presented to study participants per *PPVT-III* content area was 5.65 (SD = 6.30).

In compliance with standards for test administration and scoring, test items below the established basal set for each child (i.e., 12 words containing no more than one error) were credited as correct. After establishing a basal set, more than half of the children in the study (57%) made only one or two errors on the following word set, and more than two thirds (74%) made three or fewer. As typically expected during test administration, participants' errors tended to increase gradually from basal to ceiling. Thus, there was no evidence in children's test patterns to suggest that their responses were inconsistent or that items below the basal set should not be credited for this group of children with cochlear implants as they are for hearing children. Table 2 lists the total number of items credited below the basal for each participant as well as the total number of items directly administered.

Table 2 Number of *Peabody Picture Vocabulary Test, Third Edition* items credited below the basal and administered for each participant

Below basal	Administered
84	60
12	72
48	36
12	84
48	84
84	96
36	48
108	72
48	84
36	60
12	72
0	72
84	72
48	72
48	72
48	96
0	60
0	84
72	60
48	24
48	48
48	48
60	96
M = 44.87	M = 68.35
SD = 29.44	SD = 18.95

Note. N = 23.

Data Sets

For analyses relevant to the goals of this study, three new sets of data were calculated for each participant: (a) proportion of errors per content area, (b) HA, or duration of implant use, and (c) *PPVT-III* standard scores based on HA rather than CA.

Errors per content area. Utilizing the 20 content areas of the *PPVT-III* delineated in test standardization materials, for each participant, proportions of errors within each content area were calculated in relation to total errors (i.e., number of errors per content area/total errors). These calculations permitted an examination of children's error patterns for evidence that weakness in one or more content areas might disproportionately contribute to depressed vocabulary scores. For example, whereas only 6.4% of *PPVT-III* items are adjectives, 30% of a given child's errors (e.g., 3 of 10 errors) might occur on adjectives. For each participant, proportions of errors within each content area were also calculated in relation to content area items administered (i.e., errors per content area/content area items presented). These calculations permitted comparisons between content areas (discussed below).

Hearing age. A new age level was calculated for each participant—HA—which represented years of cochlear implant use at time of testing (i.e., CA − age at implantation). The term, hearing age, was chosen because it represents a discrete number of years of experience for each child, for use in calculating new standard scores (discussed below). An age-like term was also chosen to differentiate conceptually between discrete individual experience and continuous group data typically described as *duration of cochlear implant use*.[3] It is well established, for example, that performance on many measures tends to increase with duration of implant use; however, relations between duration of implant use at a given point in time and standardized scores based on duration of implant use typically are not calculated.

Hearing age has sometimes been used in educational settings to represent years of hearing aid use. At present, a mandatory prerequisite for cochlear implantation is that all candidates, including the children in this report, undergo a trial of hearing aid use and that they show no measureable benefit from the use of amplification. Therefore, hearing aid use was not a factor in calculations for HA as used in this study.

Standard scores based on HA. Using standard procedures for calculating *PPVT-III* standard scores, a new set of standard scores was calculated based on each child's HA rather than CA. These HA standard scores permitted new analyses of children's vocabulary performance in relation to years of experience using their cochlear implant. Additionally, this new set of standard scores permitted analyses comparing children's standard scores based on HA with those based on CA in order to provide information about vocabulary acquisition from both perspectives. To our knowledge, this study is the first to report standard scores for vocabulary development based on HA.

Results

Analyses focused on examining *PPVT-III* error patterns, new standard scores based on HA, and relations between scores based on HA and those based on CA. These analyses were conducted in order to identify elements of vocabulary knowledge underlying known delays in spoken vocabulary comprehension in deaf children with cochlear implants.

Error Patterns

Children's errors within *PPVT-III* content areas were examined for evidence that some content areas were disproportionately represented in children's total errors. Potentially challenging word content areas would be characterized by disproportionate numbers of errors in relation to test composition. Inspection of the columns in Table 1 shows that errors per content area were similar in proportion to test composition. That is, children's error patterns did not show evidence of disproportionate numbers of errors in any one or more content areas. For example, the largest proportion of errors per content area (i.e., .26) occurred for action words, the largest content area of the *PPVT-III* (i.e., .25). Furthermore, the intraclass correlation coefficient comparing proportions of errors per content area with those of items per content area was .95. Thus, within the limits of the *PPVT-III*, error patterns did not reveal particular areas of difficulty for children with cochlear implants.

Overall, children correctly identified words from every content area, including those with relatively concrete referents (e.g., foods and animals) and those that referred to more abstract or transient states or events (e.g., adjectives and actions). Inspection of responses showed that they comprehended more than half of all items presented; the mean proportion of correct responses per content area was .73 ($SD = 0.12$).

Due in part to the relatively large number of content areas (i.e., 20), many children did not receive multiple items in every content area. However, more than half (i.e., $n = 12$) of the children received three or more presentations in 10 content areas. Additional analyses of proportions of errors per content area (i.e., errors per content area/content area items presented) for these 10 content areas continued to show little, if any, content area-specific difficulty. That is, although results of a one-way analysis of variance with repeated measures indicated a significant difference in proportion of errors between content areas, $F(9, 162) = 2.50$, $p < .05$, planned contrasts comparing error proportions for each content area with the mean proportion for these 10 content areas (i.e., rather than total errors) indicated a significant difference only for "animals," $F(1, 18) = 8.75$, $p < .05$. Participants made significantly *fewer* errors on words in the animal content area ($M = 0.29$, $SD = 0.21$) as compared with mean errors for all 10 content areas ($M = 0.40$, $SD = 0.10$). Nevertheless, the relative strength for animal words evident in this analysis was not found in comparisons based on the full range of content areas in Table 1.

In sum, in this exploratory evaluation of *PPVT-III* errors, children with cochlear implants comprehended a wide variety of vocabulary items without strong evidence of disproportionate numbers of errors in any specific content area(s). Nevertheless, despite the absence of particular gaps in children's word knowledge, when compared with hearing peers, they understood fewer words overall, as indicated by their below-average standard scores.

Vocabulary Knowledge and HA

Given that children understood words from all content areas, additional analyses focused on why they might comprehend fewer words overall. Specifically, analyses asked about relations between vocabulary knowledge and hearing experience, represented by HA (i.e., years of implant use) and standard scores based on HA.

Hearing age. The mean CA of children in the study was 9.1 years; however, mean HA was 6.6 years ($SD = 2.1$). The mean difference between CA and HA, 2.5 years ($SD = 1.3$, range = 1.4–6.0), represents the average time between age at onset of deafness and age at cochlear implant surgery. A paired-samples t test indicated that this difference was significant, $t(22) = 8.99$, $p < .001$, $d = 1.1$.

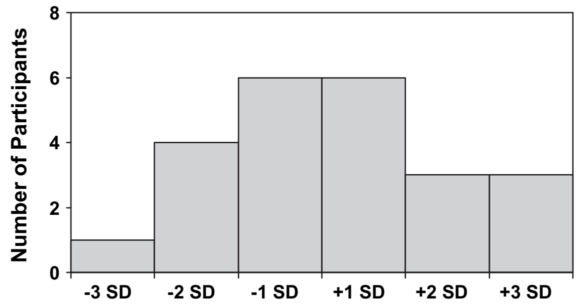

Figure 1 Distribution of *Peabody Picture Vocabulary Test, Third Edition* standard scores based on hearing age by standard deviation from the test mean.

Standard scores and HA. Mean standard scores calculated from HA were also significantly different from standard scores calculated from CA, $t(22) = 9.1$, $p < .001$, $d = 1.0$. Whereas *PPVT-III* standard scores based on CA were >1 SD below the mean ($M = 78.96$), mean standard scores calculated from HA were within the average range ($M = 100.48$) for hearing children. In fact, the mean standard score based on HA ($M = 100.48$) was equivalent to the test mean for the normative hearing population (i.e., the test mean = 100). Thus, children's vocabulary comprehension abilities were within the average range established for the hearing population when based on their own hearing experience but markedly below average when based on their CA. A distribution of HA standard scores around the test mean is presented in Figure 1, and a full distribution of individual HA standard scores is shown in Figure 2.

Closer examination of individual scores presented in Table 3 revealed that standard scores calculated based on HA were higher than those based on CA, as would be predicted; however, HA standard scores did not increase by a constant value across participants. Instead, the standard score increase for each individual ranged widely, from 5 to 50 points ($M = 21.52$, $SD = 11.3$), from less than 1 SD in magnitude to more than 3 SDs. The larger increases occurred for children who had used their implants for relatively short periods of time relative to their CA (i.e., larger gaps between HA and CA). Additionally, the rank order of individual scores changed when the new standard scores were calculated. In comparison with CA scores, 26% of HA standard scores improved in rank order, but most (57%) decreased in rank. Therefore,

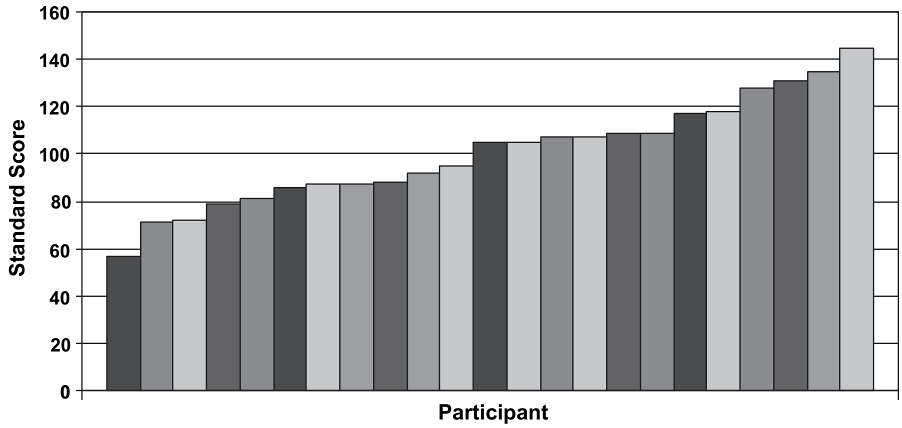

Figure 2 Distribution of individual *Peabody Picture Vocabulary Test, Third Edition* standard scores based on hearing age.

HA standard scores reflected new ways of assessing and thinking about vocabulary development.

A final set of analyses evaluated vocabulary scores for the small subgroup of children with preimplant experience using Signed Exact English ($n = 6$). For this subgroup, mean standard scores, whether based on HA ($M = 111.2$, $SD = 16.2$) or CA ($M = 80.3$, $SD = 23.5$), were higher than those of children who did not have experience with signed communication (i.e., $M = 96.7$, $SD = 23.3$ for HA; $M = 78.5$, $SD = 19.5$ for CA). However, the differences were not significant, $F(1, 21) = 1.94$, $p = .18$, for HA and $F(1, 21) = 0.04$, $p = .85$, for CA. Moreover, Pearson product–moment correlations (two-tailed) indicated that manual communication experience (in months) was not significantly correlated with HA or CA standard scores ($r = .21$, $p = .34$ and $r = -.04$, $p = .86$, respectively). Although differences in vocabulary performance were not significant for this subgroup, they may prove to be significant in a larger sample.

Table 3 *Peabody Picture Vocabulary Test, Third Edition* standard scores calculated from CA and HA for each participant

CA standard score	HA standard score
89	107
46	87
71	86
75	92
66	88
117	135
60	71
100	109
113	131
89	107
68	117
61	81
95	145
85	109
67	72
110	128
61	79
40	57
89	118
78	105
84	105
70	87
82	95

Note. $N = 23$. CA, chronological age; HA, hearing age.

Table 4 summarizes mean standard scores and standard deviations by age type. Pearson product–moment correlations (two-tailed) indicated that neither set of standard scores (i.e., HA or CA) was correlated with maternal education ($r = .18$, $p = .43$ and $r = .13$, $p = .56$, respectively). Furthermore, age at implantation and duration of implant use were not significantly correlated ($r = -.11$, $p = .63$) as both varied individually. It is remarkable, therefore, given independent relations between these two important variables that mean vocabulary scores, regardless of age at implantation, reliably reflected hearing experience.

In summary, these data show that deaf children with cochlear implants understood words from all content areas of the *PPVT-III* without evidence of particular difficulty with any content areas. Their comprehension vocabulary size was commensurate with HA, or years of experience using their cochlear

Table 4 Mean age and *Peabody Picture Vocabulary Test, Third Edition* standard score by age type

	Age type	
Measure	Chronological age	Hearing age
Mean age (*SD*)	9.13 (2.40)	6.63 (2.14)
Range	6.08–14.0	3.67–11.83
Mean standard score (*SD*)	78.96 (20.05)	100.48 (22.32)
Range	40–117	57–145

implant, rather than CA. Thus, on average, children's vocabulary acquisition kept pace with expectations for younger hearing children with equivalent years of spoken language experience but not with hearing children their own age.

Discussion

The goals of this study investigating vocabulary comprehension in deaf children with cochlear implants were to examine children's errors in lexical content areas and to evaluate vocabulary standard scores in relation to hearing experience rather than CA. Error analyses revealed that children with cochlear implants understood words from all content areas of the *PPVT-III* without clear evidence of marked difficulty comprehending words from any 1 or more of the 20 content areas. Although these analyses did not find evidence of difficulties with specific content areas, children's overall standard scores calculated from CA were below average. However, when standard scores were calculated with HA, or years of experience with their cochlear implants, rather than CA, the receptive vocabulary scores of children with cochlear implants were within the average range for hearing children. Thus, children's receptive vocabulary development was appropriate for their HA (i.e., $M = 6.6$ years) but below average for their CA (i.e., $M = 9.1$ years).

Thal et al. (2007) found a similar relationship between hearing experience and *production* vocabulary in children with cochlear implants using a parent report measure of language development (i.e., *MacArthur-Bates Communicative Development Inventories*, Fenson et al., 1993). After 22.8 months of cochlear implant use, 4.7-year-old children with cochlear implants scored below the median for 27-month-old hearing children on number of words produced. Therefore, participants in the study by Thal et al. achieved a level of vocabulary production more closely related to months of experience with their cochlear implants (i.e., 22.8 months) than to their CA (i.e., 4.7 years). In other words, their production vocabulary was similar in size to that of younger hearing children who had auditory experience with spoken language from birth.

For hearing children, vocabulary knowledge is tightly linked with the quality and quantity of language they hear in their environment (Hart, 1991; Hart & Risley, 1995; Huttenlocher et al., 1991; Weizman & Snow, 2001). During early word learning (i.e., from 11 to 17 months), children's spoken words tend to be words frequently spoken to them by their parents (Hart, 1991). Thereafter, children continue to depend on input frequency for learning increasing numbers of words. In fact, Weizman and Snow found a significant correlation between mothers' use of low-frequency words and kindergarten children's vocabulary size. Moreover, Huttenlocher et al. found a close relationship between the amount of speech parents addressed to their children and children's rate of vocabulary growth. Parents' speech influenced children's vocabulary growth in two ways. The overall amount of parents' speech to their children was related to individual differences in children's vocabulary size, and frequency of parents' specific word use influenced the age when words were acquired. Accordingly, Hart and Risley found that substantially increasing language exposure through intensive intervention resolved significant deficits in word knowledge identified in impoverished children. Therefore, substantially increasing word-learning opportunities for children with cochlear implants may have similar effects.

Profound hearing loss, by its very nature, severely limits early exposure to auditory word–learning opportunities. Therefore, children who receive cochlear implants at earlier ages generally show more favorable rates of lexical growth than do children who receive implants at later ages (Blamey et al., 2001; Connor et al., 2000; Kirk et al., 2000). However, regardless of age at implantation, rates of growth in spoken vocabulary acquisition rarely reach or exceed 1.0, a 1-year increase in vocabulary per year. Therefore, most studies of vocabulary development have found that children with cochlear implants do not catch up with their hearing peers (Blamey et al., 2001; Connor et al., 2000; El-Hakim et al., 2001).

If deaf children who use cochlear implants depend on auditory language exposure for word learning to the extent that hearing children do, years of cochlear implant use is likely to represent children's language experience and word-learning opportunities more closely than does their CA. The results of this study provide evidence to suggest that amount of language experience is as critical for spoken word learning in deaf children with cochlear implants as it is in hearing children. Moreover, whereas hearing children have considerable early experience with speech perception and language processing even before word comprehension begins to emerge (e.g., Mandel, Jusczyk, & Pisoni, 1995; Saffran, Aslin, & Newport, 1996), deaf children have little if any auditory experience with spoken language before cochlear implantation. Thus, although central auditory pathways begin to function soon after cochlear implantation (Sharma et al., 2002), substantial experience listening to language is likely to be required before children with cochlear implants begin to understand spoken language. Acquiring basic experience and familiarity with spoken language potentially contributes to further delays in spoken word learning immediately after cochlear implantation. Moreover, because many deaf children of hearing parents receive little exposure to sign language before they receive cochlear implants, limited experience with symbolic representation and communication may further impact word-learning and vocabulary development.

Together, early limitations in auditory experience, language learning, and symbolic communication may affect children's ability to acquire vocabulary knowledge quickly enough to close the gap that separates them from their hearing peers. However, because intensive intervention has resolved vocabulary delays in impoverished hearing children (Hart & Risley, 1995), new interventions may help to resolve vocabulary delays in children with cochlear implants as well. Additional research is necessary to investigate efficacious programs of intervention and word learning. The *PPVT-III*, although not designed to assess error patterns specifically, was recruited in this study to provide preliminary data regarding children's word learning and error patterns that should be tested using additional methods.

An early experimental study of novel nonsense word learning in children with mild to moderate hearing loss found that many children learned novel words as well as hearing children did. That is, they quickly mapped nonsense words to novel objects and used these newly formed associations to identify objects during comprehension testing (Gilbertson & Kamhi, 1995). In fact, children acquired and used rapid word-learning strategies both when novel referents were explicitly named and when tasks required that they infer the referents for novel words (Gilbertson & Kamhi, 1995; Houston, Carter, Pisoni, Kirk, & Ying, 2005; Lederberg, Prezbindowski, & Spencer, 2000). Children with profound hearing loss with cochlear implants tended to form fewer word-referent associations than hearing children did, but they later remembered the novel associations they had learned just as well as hearing children did (Houston et al., 2005). Together, this experimental research is consistent with our results showing that children with cochlear implants do learn and recall words, albeit in smaller numbers than their age-matched hearing peers.

Despite evidence of a capacity for novel word learning and recall, children with cochlear implants often receive below-average scores on measures of short-term memory (e.g., nonword repetition and digit span tests, Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003). Thus, because phonological memory in nonword repetition tasks is important for vocabulary development in hearing children (Gathercole & Baddeley, 1989), short-term memory problems may adversely impact vocabulary learning in children with cochlear implants. Nonetheless, participants in our study demonstrated the capacity to acquire vocabulary knowledge consistent with their hearing experience. Thus, their phonological memory was sufficient for word learning equivalent to that of their younger hearing peers. Results from this and other studies suggest that only an accelerated rate of word learning will close the vocabulary gap for children with cochlear implants.

In general, hearing children's short-term memory performance is improved by spontaneous rehearsal (i.e., serial recall tasks). However, deaf children showed delayed emergence of spontaneous rehearsal in comparison to hearing children (Bebko & McKinnon, 1990). Whereas hearing children began to engage in spontaneous rehearsal at 7 or 8 years of age, deaf children did not use spontaneous rehearsal until they were 10–13 years old. Nevertheless, when hearing and deaf children were matched on language experience (rather than age), their serial recall scores were equivalent. Thus, these results are compatible with our research in highlighting the importance of language experience for memory and word learning. Consider, however, that early vocabulary learning is unlikely to depend on spontaneous rehearsal alone, as hearing children typically learn many thousands of words (Anglin, 1993) before the age of 7 years when spontaneous rehearsal begins to emerge.

Assessing vocabulary development in growing numbers of children receiving cochlear implants at 12 months and younger will contribute important additional information about the effects of early auditory and linguistic experience on word learning. In projecting future vocabulary outcomes, Connor et al. (2006) estimated that receptive vocabulary scores would approximate average rates of growth for hearing children only when children receive cochlear implants between 12 and 30 months ($M = 21$ months). However, average predicted raw scores even for children who receive cochlear implants at a mean age of 21 months were below average (Connor et al., 2006). Predicted growth curves showed that, with the exception of children with favorable preimplant aided thresholds (Nicholas & Geers, 2008), children's projected vocabulary scores did not catch up with those of hearing children over time (Connor et al., 2006).

Together with the literature on vocabulary development in children with cochlear implants reviewed here, this study highlights the need for early identification of hearing loss, early amplification or cochlear implantation, and an accessible system of language for early word learning. Overall, the results of this study investigating delayed spoken vocabulary comprehension in children with cochlear implants are consistent with evidence from research with hearing children showing that vocabulary development is closely bound to language experience. Exploring vocabulary scores based on HA provided information not only about children's performance in relation to their hearing peers but also in relation to their cochlear implant experience. Delays in vocabulary comprehension commensurate with the gap between CA and age at implantation underscore the importance of auditory experience in spoken word learning and contribute to a growing body of evidence showing better outcomes in language achievement the earlier the age at cochlear implantation. In future research, examining vocabulary standard scores using both CA and HA will provide useful clinical and educational data about vocabulary development and intervention efficacy.

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Appendix

Table A1 Number of participants by minimum number of *Peabody Picture Vocabulary Test* items presented per content area

	Minimum number of items presented		
Content area	1	2	3
Actions	23	23	21
Adjectives	22	17	15
Animals	23	21	21
Body parts	22	18	8
Books	20	19	7
Buildings	17	12	10
Clothing and accessories	11	0	0
Emotions	20	14	12
Foods	12	0	0
Fruits and vegetables	22	17	6
Geographical scenes	23	21	16
Household objects	23	22	21
Musical instruments	20	19	2
People	23	20	11
Plants	21	18	14
Shapes	23	21	13
Tools	23	22	21
Toys	23	17	11
Vehicles	23	22	19
Workers	17	2	2

Note. Clothing and accessories contains only one stimulus item and foods contains only two.

Notes

1. Three additional children included in the larger study were omitted from this study, one with onset of hearing loss at 3.5 years and two for whom age at implantation was unreported.

2. "A starting set of items has an average Rasch item difficulty approximately 1 to 2 logits below the mean ability for that age. Therefore, by these generous start points, only a small percentage of examinees tested will have to be administered a lower item set to establish a basal set" (Williams & Wang, 1997, p. 17).

3. In many studies, age at implantation and duration of implant use are not correlated. For example, two participants who receive their implants at 2.0 might be 4 and 7 years old at the time of testing. Therefore, length of implant use differs by 3 years, even though age at implantation was the same. Similarly, duration of implant use can be equivalent for two children implanted at very different ages. Study outcomes are often complicated by these differences that are frequently unavoidable, as children vary widely in age at time of implantation and time of testing.

References

Anglin, J. M. (1993). Vocabulary development: A morphological analysis. *Monographs of the Society for Research in Child Development, 58*. (10, Serial No. 238).

Bebko, J. M., & McKinnon, E. E. (1990). The language experience of deaf children: Its relation to spontaneous rehearsal in a memory task. *Child Development, 61,* 1744–1752.

Blamey, P. J., Sarant, J. Z., Paatsch, L. E., Barry, J. G., Bow, C. P., Wales, et al. (2001). Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. *Journal of Speech, Language, and Hearing Research, 44,* 264–285.

Burkholder, R. A., & Pisoni, D. B. (2003). Speech timing and working memory in profoundly deaf children after cochlear implantation. *Journal of Experimental Child Psychology, 85,* 63–88.

Choi, S. (2000). Caregiver input in English and Korean: Use of nouns and verbs in book-reading and toy-play contexts. *Journal of Child Language, 27,* 69–96.

Connor, C. M., Craig, H. K., Raudenbush, S. W., Heavner, K., & Zwolan, T. A. (2006). The age at which young children receive cochlear implants and their vocabulary and speech-production growth: Is there an added value for early implantation? *Ear and Hearing, 27,* 628–644.

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.

Connor, C. M., & Zwolan, T. A. (2004). Examining multiple sources of influence on the reading comprehension skills of children who use cochlear implants. *Journal of Speech, Language, and Hearing Research, 47,* 509–526.

Dawson, P. W., Blamey, P. J., Dettman, S. J., Barker, E. J., & Clark, G. M. (1995). A clinical report on receptive vocabulary skills in cochlear implant users. *Ear and Hearing, 16,* 287–294.

Dawson, P. W., Busby, P. A., McKay, C. M., & Clark, G. M. (2002). Short-term memory in children using cochlear implants and its relevance to receptive language. *Journal of Speech, Language, and Hearing Research, 45,* 789–801.

Dunn, L. M., & Dunn, L. M. (1997). *Peabody picture vocabulary test* (3rd ed). Circle Pines, MN: American Guidance Service.

Eisenberg, L. S., Kirk, K. I., Martinez, A. S., Ying, E. A., & Miyamoto, R. T. (2004). Communication abilities of children with aided residual hearing. *Archives of Otolaryngology—Head & Neck Surgery, 130,* 563–569.

El-Hakim, H., Levasseur, J., Papsin, B. C., Panesar, J., Mount, R. J., Stevens, D., et al. (2001). Assessment of vocabulary development in children after cochlear implantation. *Archives of Otolaryngology—Head & Neck Surgery, 127,* 1053–1059.

Fagan, M. K., Pisoni, D. B., Horn, D. L., & Dillon, C. M. (2007). Neuropsychological correlates of vocabulary, reading, and working memory in deaf children with cochlear implants. *Journal of Deaf Studies and Deaf Education, 12,* 461–471.

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., et al. (1993). *The MacArthur-Bates Communicative Development Inventories: User's guide and technical manual*. Baltimore: Brookes.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28,* 200–213.

Geers, A. E. (2003). Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing, 24,* 59S–68S.

Geers, A. E., Nicholas, J. G., & Sedey, A. L. (2003). Language skills of children with early cochlear implantation. *Ear and Hearing, 24,* 46S–58S.

Gilbertson, M., & Kamhi, A. G. (1995). Novel word learning in children with hearing impairment. *Journal of Speech and Hearing Research, 38,* 630–642.

Hart, B. (1991). Input frequency and children's first words. *First Language, 11,* 289–300.

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore: Brookes.

Houston, D. M., Carter, A. K., Pisoni, D. B., Kirk, K. I., & Ying, E. A. (2005). Word learning in children following cochlear implantation. *Volta Review, 105,* 41–72.

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology, 27,* 236–248.

Huttenlocher, J., & Smiley, P. (1987). Early word meanings: The case of object names. *Cognitive Psychology, 19,* 63–89.

Kirk, K. I., Miyamoto, R. T., Ying, E. A., Perdew, A. E., & Zuganelis, H. (2000). Cochlear implantation in young children: Effects of age at implantation and communication mode. *Volta Review, 102,* 127–144.

Korkman, M., Kirk, U., & Kemp, S. (1998). *A developmental neuropsychological assessment*. San Antonio, TX: The Psychological Corporation.

Lederberg, A. R., Prezbindowski, A. K., & Spencer, P. E. (2000). Word-learning skills of deaf preschoolers: The development of novel mapping and rapid word-learning strategies. *Child Development, 71,* 1571–1585.

Lindamood, P. C., & Lindamood, P. (2004). *Lindamood auditory conceptualization test* (3rd ed). Austin, TX: Pro-Ed.

Mandel, D. R., Jusczyk, P. W., & Pisoni, D. B. (1995). Infants' recognition of the sound patterns of their own names. *Psychological Science, 6,* 314–317.

Markwardt, F. C. (1998). *Peabody individual achievement test-revised*. Circle Pines, MN: American Guidance Service.

Nicholas, J. G., & Geers, A. E. (2008). Expected test scores for preschoolers with a cochlear implant who use spoken language. *American Journal of Speech-Language Pathology, 17,* 121–138.

Ouellette, G. P. (2006). What's meaning got to do with it: The role of vocabulary in word reading and reading comprehension. *Journal of Educational Psychology, 98,* 554–566.

Paatsch, L. E., Blamey, P. J., Sarant, J. Z., & Bow, C. P. (2006). The effects of speech production and vocabulary training on different components of spoken language performance. *Journal of Deaf Studies and Deaf Education, 11,* 39–55.

Paivio, A., Walsh, M., & Bons, T. (1994). Concreteness effects on memory: When and why? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1196–1204.

Pisoni, D. B., & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. *Ear and Hearing, 24,* 106S–120S.

Robbins, A. M., Koch, D. B., Osberger, M. J., Zimmerman--Phillips, S., & Kishon-Rabin, L. (2004). Effect of age at cochlear implantation on auditory skill development in infants and toddlers. *Archives of Otolaryngology—Head & Neck Surgery, 130,* 570–574.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274,* 1926–1928.

Sharma, A., Dorman, M. F., & Spahr, A. J. (2002). Rapid development of cortical auditory evoked potentials after early cochlear implantation. *NeuroReport, 13,* 1365–1368.

Smith, L. B. (2000). Learning how to learn words: An associative crane. In R. M. Golinkoff, K. Hirsh-Pasek, L. Bloom, L. B. Smith, A. L. Woodward, N. Akhtar, M. Tomasello, & G. Hollich (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 51–80). New York: Oxford University Press.

Spencer, L. J., Barker, B. A., & Tomblin, J. B. (2003). Exploring the language and literacy outcomes of pediatric cochlear implant users. *Ear and Hearing, 24,* 236–247.

Svirsky, M. A., Robbins, A. M., Kirk, K. I., Pisoni, D. B., & Miyamoto, R. T. (2000). Language development in profoundly deaf children with cochlear implants. *Psychological Science, 11,* 153–157.

Tardif, T., Gelman, S. A., & Xu, F. (1999). Putting the "noun bias" in context: A comparison of English and Mandarin. *Child Development, 70,* 620–635.

Thal, D., DesJardin, J. L., & Eisenberg, L. S. (2007). Validity of the MacArthur-Bates Communicative Development inventories for measuring language abilities in children with cochlear implants. *American Journal of Speech-Language Pathology, 16,* 54–64.

Tomasello, M. (2003). *Constructing a language*. Cambridge, MA: Harvard University Press.

Weizman, Z. O., & Snow, C. E. (2001). Lexical input as related to children's vocabulary acquisition: Effects of sophisticated exposure and support for meaning. *Developmental Psychology, 37,* 265–279.

Williams, K. T., & Wang, J. (1997). *Technical references to the Peabody Picture Vocabulary Test* (3rd ed). Circle Pines, MN: American Guidance Service.

Wise, J. C., Sevcik, R. A., Morris, R. D., Lovett, M. W., & Wolf, M. (2007). The relationship among receptive and expressive vocabulary, listening comprehension, pre-reading skills, word identification skills, and reading comprehension by children with reading disabilities. *Journal of Speech, Language, and Hearing Research, 50,* 1093–1109.

Woodcock, R. W. (1998). *Woodcock reading mastery tests-revised*. Allen, TX: DLM Teaching Resources.

Woodward, A. L., & Markman, E. M. (1998). Early word learning. In W. Damon, (Series Ed.), D. Kuhn, & R. S. Siegler (Eds.), Handbook of child psychology: Cognition, perception, and language (5th ed., Vol. 2., pp. 371–420). Hoboken, NJ: Wiley.

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