Published in final edited form as:
Cochlear Implants Int. 2014 July ; 15(4): 211–221. doi:10.1179/1754762813Y.0000000051.

The Effects of Audibility and Novel Word Learning Ability on Vocabulary Level in Children with Cochlear Implants

Lisa S. Davidson[1], **Ann E. Geers**[2], and **Johanna G. Nicholas**[1]

[1]Washington University in St. Louis

[2]University of Texas at Dallas

Abstract

Objectives—A Novel Word Learning (NWL) paradigm was used to explore underlying phonological and cognitive mechanisms responsible for delayed vocabulary level in children with cochlear implants (CIs).

Methods—101 children using CIs, 6–12 years old, were tested along with 47 children with normal hearing (NH). Tests of NWL, receptive vocabulary, and speech perception at 2 loudness levels were administered to children with CIs. Those with NH completed the NWL task and a receptive vocabulary test. CI participants with good audibility (GA) versus poor audibility (PA) were compared on all measures. Analysis of variance was used to compare performance across the children with NH and the two groups of children with CIs. Multiple regression analysis was employed to identify independent predictors of vocabulary outcomes.

Results—Children with CIs in the GA group scored higher in receptive vocabulary and NWL than children in the PA group, although they did not reach NH levels. CI-Aided PTA and performance on the NWL task predicted independent variance in vocabulary after accounting for other known predictors.

Discussion—Acquiring spoken vocabulary is facilitated by good audibility with a CI and phonological learning and memory skills. Children with CIs did not learn novel words at the same rate or achieve the same receptive vocabulary levels as their NH peers. Maximizing audibility for the perception of speech and direct instruction of new vocabulary may be necessary for children with CIs to reach levels seen in peers with NH.

Keywords

deafness; cochlear implant; pediatric; novel word learning; incidental learning; audibility; normal hearing vocabulary

Federal legislation in the United States requires that a child with a disability be educated in the least restrictive environment that is appropriate for his or her needs (Individuals with Disability Education Act (IDEA), 2004). This means that a child with a disability is given the opportunity to attend schools with non-disabled peers and have access to the general education curriculum, or any other program that peers are able to access. As a result of this legislation the vast majority of children with hearing loss are educated in general education settings (87% according to the U.S. Department of Education) as opposed to schools for the deaf (IDEAdata.org, 2009). The increased access to sound provided by a cochlear implant

(CI) to children who are learning to communicate via listening and spoken language has further contributed to this shift in educational placement. One recent study of 60 school-aged children using CIs and spoken language showed that they spent 85% of elementary grades in general education classrooms and 47% in classrooms with more than 20 children (Geers & Nicholas, 2013). Placement in a general education setting implies an expectation that children will often have to learn new vocabulary alongside their hearing peers 'incidentally', meaning without direct instruction and repeated exposures (Akhtar *et al*., 2001; Goodman, *et al*., 1998; Oshima-Takane, 1988; Oshima-Takane *et al*., 1999). These environments are in contrast to special education settings where children with severe to profound hearing loss often receive direct vocabulary instruction with repeated exposures and opportunities to hear and use new vocabulary. Incidental learning requires that children learn the meaning of new words by 'overhearing' speech in their everyday listening environments, speech that varies in level from soft to loud. Whether children who rely on CIs for hearing language input can rely on this type of 'incidental' learning of vocabulary is unclear, even for children with good measured speech perception ability. This study explores the word-learning abilities of children with CIs and how audibility influences this learning process.

Learning New Words through Overhearing

Incidental learning of new words depends upon at least two main processes. The first is to accurately *hear* or perceive the new word in its linguistic context (Ross, 1990). The second is a complex process that involves rapid encoding of phonological information into short-term memory, referring to existing linguistic knowledge, and making the link to new referents (Gathercole *et al*., 1997). The rapid acquisition of vocabulary has been well documented in children with normal hearing (NH) and is thought to result from this combination of sensory, perceptual and cognitive processes (Bloom, 2000, 2001). Some researchers propose that in addition to being taught some words directly by their parents or siblings, children learn most new words through overhearing, also referred to as "incidental learning" or "passive listening" (Akhtar *et al*., 2001; Goodman, *et al*., 1998; Oshima-Takane, 1988; Oshima-Takane *et al*., 1999). Notably, typically-developing children with NH sensitivity have vocabularies of 3–5,000 words by age 4–5 years (Conrad, 1979). Prior to the advent of CIs, children with severe to profound hearing loss who used conventional hearing aids (HAs) typically acquired spoken vocabulary at about half the rate of age-mates with NH (Blamey *et al*., 2001; Boothroyd *et al*., 1991). Incidental or casual language acquisition depends on the ability to overhear soft speech in addition to speech at normal-conversation level (Ross, 1990), thus one reason for the slower vocabulary growth documented in children with hearing loss may be the limited audibility of speech through HAs.

The audibility provided by CIs enables many children with severe-profound hearing loss to achieve high levels of speech perception (Davidson *et al*., 2011; Svirsky *et al*., 2004), and some children, particularly those receiving CIs at young ages, achieve spoken vocabulary levels approaching those of age-mates with NH (Geers *et al*., 2009; Svirsky *et al*., 2004). Better audibility, measured by CI-aided pure tone threshold average (PTA) was associated with higher language outcome scores in 60 children between 9 and 12 years old (Geers and Nicholas, 2013), suggesting that hearing softer speech sounds may contribute to more normal language development following cochlear implantation. However, many children remain delayed in vocabulary well into adolescence even with cochlear implantation during the preschool years (Geers and Sedey, 2011), perhaps because the process of learning new words requires more than just audibility. Building vocabulary is a complex process that involves encoding, remembering and mapping phonological information onto concepts or meanings. Attempts to mimic this complex process in a controlled laboratory setting led to the development of Novel Word Learning (NWL) paradigms (Carey, 1978; Rice *et al*., 1992; Rice *et al*., 1990; Rice and Woodsmall, 1988).

NWL and Vocabulary Development

Although the terminology and methodology vary across studies, NWL tasks include exposing a child to a novel (or nonsense) word and a target referent and assessing their ability to associate the word with the referent. It is suggested that the ability to learn the meaning of a novel word in a related context within the first few exposures reflects a child's capacity to quickly encode phonological information into long-term memory and make links to referents (Gathercole *et al*., 1997; Gilbertson and Kamhi, 1995; Houston *et al*., 2005). Vocabulary size, developmental level and word category (e.g. object, action, attribute) are among the variables that have been associated with NWL ability in typically- developing children (Oetting *et al*., 1995; Rice and Woodsmall, 1988).

NWL paradigms are also used to examine word-learning skills in various clinical populations, most notably in children with specific language impairment (Oetting *et al*., 1995; Rice *et al*., 1992; Rice *et al*., 1990). Variables that are correlated with NWL performance in this population include existing vocabulary size, complex working memory and phonological processing skills (Ellis-Weismer and Hesketh, 1996; Montgomery, 2003; Weismer *et al*., 1999). There is growing interest in examining NWL in children with hearing loss following an early study by Gilbertson and Kamhi (1995). They found that approximately half of the children with mild to moderate hearing loss who wore HAs performed as well on a test of NWL as age-mates with hearing levels within normal limits. They also note that better NWL performance is associated with greater vocabulary size for children with hearing loss, but not for children with NH sensitivity. Subsequent studies generally report that NWL scores of children with hearing loss, using HAs, are on average lower than age-mates without hearing loss and that better NWL ability is correlated with larger receptive vocabulary size, better complex working memory and louder presentation level (Hansson *et al*., 2004; Pittman *et al*., 2005; Stelmachowicz *et al*., 2004).

There are relatively few studies that examine NWL in children with CIs. Houston and colleagues (Houston *et al*., 2005) tested 24 children with CIs aged 2–5 years and 24 age-matched peers with NH on a test of NWL. Children with CIs had worn their device for at least one year and were educated using an auditory-oral communication method (i.e. no sign language). On average, children with CIs performed more poorly than their NH age-mates and younger age at receipt of a CI was associated with better NWL performance. Willstedt-Svensson *et al*. (2004) studied 15 children with CIs ranging in test age from 5–11 years with both signing and spoken language experience. They examined scores on a NWL test in relation the child's receptive and expressive vocabulary, phonological processing, complex working memory and a number of audiologic/demographic factors (i.e. age at test, age at CI, and duration of CI). Correlation analyses revealed that NWL scores were related to expressive and receptive vocabulary, phonological processing, complex working memory span, and younger age at CI. A more recent study that included 98 preschoolers with moderate to profound hearing loss using HAs and/or CIs from both oral-only and oral/signing programs found that NWL ability was related to vocabulary size, but not age at test (Lederberg & Spencer, 2009).

Even those children who achieve excellent audibility and speech perception with a CI may not exhibit age-appropriate vocabulary unless these skills facilitate rapid learning of words within a limited number of exposures or opportunities to hear the new word. Unlike traditional tests of vocabulary and language, the NWL paradigm offers an assessment of the dynamic process that underlies lexical development. These tasks may be ideal for helping us to understand whether children who use CIs are able to learn new words incidentally, through overhearing, with the same ease and accuracy as their peers with NH. This information will, in turn, inform our expectations and goals for this population of children as they enter general educational settings in which their language-learning opportunities are less structured and direct. To that end, this study poses the following questions:

1. How do the NWL abilities (and receptive vocabulary scores) of children who receive CIs in preschool compare with those of their NH peers?
2. How is audibility for speech with a CI related to speech perception, vocabulary level and NWL ability?
3. What other demographic and audiological characteristics are associated with NWL and receptive vocabulary level?
4. Does performance on a NWL task provide additional information about receptive vocabulary scores once CI-audibility and other known predictors are accounted for?

METHOD

Participants

Test scores from two groups of children were analyzed for this study: a sample of 101 children from across North America (Canada and the United States) with severe-profound hearing loss using CIs and a group of 47 age-matched children with NH as a comparison group. Table 1 provides demographic details for the NH and CI groups of children. The groups were similar in average age (9 years), gender distribution and in their above-average maternal education level. Maternal education level was used as a socio-demographic variable and calculated in total years of education through college or beyond.

Protocol approvals for this study were provided by the Human Research Protection Office of Washington University in Saint Louis, Missouri (United States).

Children with CIs—Participants were recruited through schools and speech-language therapy centers in several cities and tested by the project staff's own trained examiners.

Audiological characteristics of the CI sample are summarized in Table 2. All 101 children received educational services via spoken language in either a general public education setting or an auditory-oral private school for the deaf. None of the children were reported to have any delays in cognitive development. All children had their hearing loss identified/confirmed by 36 months of age, were fit with HAs by 37 months and had received a CI by their 5th birthday. They received a first CI at an average age of 24 months and had used a CI for at least 2 years at the time of testing. Fifty-three children had received a second (bilateral) CI in the opposite ear and had used bilateral CIs on average for an average of 3 years. A “bilateral CI rating” was assigned to each participant based on duration of use of a second CI: 0 for no years (N= 48), 1 for < 3 years (N=25), and 2 for > 3 years (N = 28). In order to examine the effects of the generation of speech processor technology on word learning, processors were rank ordered by generation of technology for analysis, with higher rankings indicating newer technologies. All children used processors from one of two CI manufacturers. Processors from Cochlear Corporation were rated as follows: 1- Spectra, 2- ESPrit 22, 3- Sprint or ESPrit 3G, or 4-Freedom. Processors by Advanced Bionics were rated as follows: 2- PSP or BTE Platinum, 3- Auria BTE, or 4- Harmony BTE. Ten of the children used category 2 processors, 9 used category 3 and 82 used category 4 processors.

Children with NH sensitivity—The children in this group were recruited from general education schools in the Saint Louis, Missouri (USA) metropolitan area. A hearing screening was conducted on all children in this group to confirm that hearing threshold levels were within normal limits. This group served not only as a frame of reference for assessing CI scores on the NWL task, but also a more socio-economically relevant comparison reference for the vocabulary measures than the nationally stratified (USA) test norms provided by the Peabody Picture Vocabulary Test - Third Edition (PPVT-III; Dunn and Dunn, 1997). Dollaghan *et al*. (1999) documented a mean PPVT-III score of 110 for typically-developing children whose mothers completed college. Therefore both groups of children in this study, with mostly college-educated mothers, may be expected to achieve standard scores above the normative mean of 100. It is important to consider this factor when trying to determine whether a given clinical sample is on par with their “peers”.

Tests Administered

Audibility—Aided sound-field detection thresholds were obtained from the children with CIs using frequency-modulated tones at octave frequencies from 250–4000 Hz. The participants were seated approximately 1 to 1.5 m from the loudspeaker at 0° azimuth using their CI(s) as typically worn. A standard Hughson-Westlake procedure (Carhart and Jerger, 1959) was used to obtain thresholds in 5 dB increments. An aided PTA was calculated for speech frequencies (.5, 1 and 2 kHz) and for high frequencies (1, 2 and 4 kHz).

Speech Perception—The Lexical Neighborhood Test (LNT) (Kirk *et al*., 1995) was used to assess open-set word recognition in CI users. Items were presented at a loud conversational level (70 dB SPL) in a quiet background and an alternate list was presented at a soft level (50 dB SPL) for each child. School-aged children with NH were found to score > 90% correct on the LNT at levels comparable to 50 dB SPL (Eisenberg *et al*., 2002). The child was instructed to repeat what s/he heard. A response was scored as correct if the child repeated the target word. The LNT was administered as a digitized presentation of recorded stimuli via a personal computer routed through a GSI 61 audiometer and sound field loudspeaker positioned at 0 degrees azimuth, approximately 3 feet away. Test stimuli were calibrated using a Type 2 sound-level meter placed at the level of the child's CI microphone.

Vocabulary—The PPVT-III was administered to children in both the CI and NH groups. This wide-ranging test of receptive vocabulary is normed on a large sample of NH individuals from age 2 years through adulthood. The test is individually administered face-to-face so that both auditory and lip-reading cues are available and the child selects the picture that best represents each spoken stimulus from four alternatives. A raw score corresponds to the number of items below a basal level plus the number of items correctly selected. This raw score may be converted to a standard score relative to the age-appropriate normative group, where the mean is set at 100 with a standard deviation of 15.

Novel Word Learning—A NWL task was administered to both CI and NH groups. A task was developed for this study based on the procedure used by Stelmachowicz and colleagues (Stelmachowicz et al., 2004; and an earlier version piloted by Gremp, 2006). The NWL task provided repeated exposures to a novel word (nonsense word) in the context of animated stories and assessed recognition after each story to estimate vocabulary-learning rate. The children were placed approximately 1 meter from a computer monitor and loudspeaker placed at 0° azimuth to the child. Stimuli were presented at 60 dB SPL in the sound field. Six different stories were created around a single character ("Teddy") and each story presented six novel words (e.g. Teddy wanted a *focosh* for his birthday). A 2–3 minute animated slide show was designed to accompany the auditory presentation of each story and each slide served to pair one of the novel words with a novel pictured object (see Appendix). A total of six different stories/slide shows were created in which the same six novel words were paired with the same six pictured objects. In this way the number of times the child heard, or was exposed to each novel word increased with each successive story (i.e. each novel word was presented 6 times by the end of the task). A recognition test/trial followed each story, using a response slide consisting of a 6-choice closed-set of the novel pictured objects. For this test, the child listened to each novel word and was instructed to point to the novel pictured object that had been associated with it.The number of correct responses (out of 6) for each test/trial following each story was recorded. The total number correct across all six stories (out of 36) was used to assess overall learning.

Statistical Analyses

Performance on speech perception, receptive vocabulary and NWL tests for the NH and the CI groups was compared using analysis of variance (ANOVA). Multiple regression analysis was employed to identify independent predictors of vocabulary outcomes.

RESULTS

Audibility and speech perception

Average aided thresholds did not differ significantly based on whether a speech frequency average (.5, 1, and 2 kHz) (mean = 21.6; SD = 6.3) or a high frequency average (1, 2 and 4 kHz) (mean = 23.3; SD = 6.4) was calculated. Correlations with PPVT-III receptive vocabulary scores were significant for both speech frequency and high frequency PTA thresholds (r = −.382 and −.375, respectively), so the more traditional PTA of the speech frequencies was used to estimate audibility. Two subgroups of CI participants were created based on a median split of aided PTA threshold at 20 dB HL to better understand the effects of audibility on outcomes (CI participants in the "good audibility" (GA) group (N=46) had thresholds that ranged from 8.3 dB HL to 20 dB HL and those in the "poor audibility" (PA) group (N=55) ranged from 21.7 to as high as 48.3 dB HL.

LNT word scores for GA and PA groups are summarized in Table 3. Children with GA scored significantly higher on the LNT than those with PA at both loud − 70 dB (F [1,99] = 5.7; p = .019) and soft − 50 dB (F[1,99] = 9.97; p = .002) levels, although the GA group advantage was greater for soft than for loud speech. Across audibility groups, there was a 21 percentage point mean decrease in LNT word recognition score associated with a 20 dB decrease in signal level, confirming the relative difficulty these CI children experienced hearing speech at soft conversational levels. Children with PA understood, on average, only about half of the LNT words at a soft conversational level. Correlation coefficients between LNT scores and possible predictor variables are included in Table 4. Significant correlations were found between aided PTA threshold and LNT scores at 50 dB and 70 dB. In addition, generation of speech processor technology was correlated with both PTA and speech perception at both 50 and 70 dB SPL, indicating that technology upgrades are associated with improved audibility and ultimately speech perception.

Receptive vocabulary and NWL

Box plots of PPVT-III standard scores from the 25th to the 75th percentiles are shown in Figure 1 for both CI groups (GA & PA) and the NH group. PPVT-III standard scores express performance in relation to the normative sample (Mean = 100, SD = 15). The mean standard score of 114 (SD = 11.7, range 85–150) for the NH comparison group was almost one standard deviation above the normative sample mean. As noted earlier, this elevated vocabulary level might be expected from any group of children with above-average parental education such as this one (Dollaghan *et al*., 1999). Children with GA obtained a mean standard score of 102 (SD=18.2, range 62–142); slightly above the normative average, while those with PA obtained a mean score of 89 (SD=18, range 44–135); almost one SD below the normative mean. Results from an ANOVA comparing PPVT-III scores for GA, PA and NH groups revealed a significant effect (F [2,145] = 30.0; p < .000). Post-hoc comparisons using a Bonferroni correction revealed that scores for the NH group were significantly better than the GA group (p < .002) and the PA group (p < .000). Additionally, the advantage for the GA group over the PA group was significant (p < .000). Although the CI children with GA achieved parity with NH children represented in the PPVT-III test norms, a vocabulary lag was evident when compared with peers from similarly advantaged families from the NH comparison group, which was matched for maternal education level.

Novel Word Learning

The mean overall percent-correct scores (out of 36 possible) on the NWL task for the three participant groups were 63% (SD=21.3, range 19–97) for the NH group, 47% (SD=20.6, range 14–92) for the GA group and 41% (SD= 20.7, range 0–97) for the PA group. ANOVA results revealed a significant effect for group (F [2,145] = 14.25, p < .000). Post-hoc comparisons across groups revealed that the mean score for the NH group was significantly higher than both the GA and PA groups (p < .001 and .000, respectively), although the difference between the GA and PA did not reach significance. NWL scores correlated significantly with age at implantation (r = -.26; p = .009), duration of CI use (r = .32; p = .001), age at test (r = .47; p < .001), LNT scores at both loud (r = .398; p < .001) and soft (r = .29; p = .003) levels, and aided PTA (r= .237, p = .017).

Improvement in novel word recognition scores with repetition (i.e., learning) was evaluated by calculating the percent correct (out of 6) following each of the successive stories (i.e. trials). A group x trials ANOVA indicated a significant effect for both group (F[2, 145] = 13.8; p < .001) and trials (F[4.1, 600] = 68.7; p < .001) and a significant interaction (F[8.3, 600] = 2.74, p < .005), indicating that the scores for the NH group increased at a greater rate than the CI groups. Means for the three groups for each of the 6 trials are depicted in Figure 2. Note that all groups have scores that are only slightly above chance level (chance = 16%) at Trial 1. However, at Trial 6 the NH group achieved an average score of 81% (SD = 26.4) while the GA and PA groups achieved average scores of 65% (SD=27) and 52% (SD=31.6) respectively.

Predictors of Receptive Vocabulary

Correlations between PPVT-III standard scores and predictor variables are also included in Table 4. Receptive vocabulary level was not associated with age at test, duration of CI use or bilateral CI use. Vocabulary levels were higher for children implanted at the youngest ages and those with higher maternal education level. Higher vocabulary levels were also associated with better speech perception scores at both loud and soft levels and with use of more recent CI speech processor technology. Finally, vocabulary level was highly associated with performance on the NWL task ($r = .470$, $p < .000$).

Multiple regression analysis was used to determine the independent contributions of these predictors to vocabulary level. Since aided PTA, LNT, and CI processor are all highly correlated, aided PTA was used to represent audibility in the analysis. Results are summarized in Table 5. Maternal education, aided PTA and NWL scores each predicted significant independent variance, together, accounting for 37% of the total variance in PPVT-III standard scores ($F(4,94) = 13.62$, $p < .001$). Age at CI was not a significant predictor when entered with maternal education.

DISCUSSION AND CONCLUSIONS

This study compared speech perception, NWL and receptive vocabulary scores for 6–12 year olds with aided PTA thresholds above and below 20dB HL (.5, 1, 2 KHz) using a CI. The objective was to determine how audibility for speech and incidental word learning ability interact to facilitate vocabulary development. We hypothesized that these variables operate independently and that good audibility combined with good NWL ability may allow children with CIs to develop receptive vocabulary commensurate with age mates with NH sensitivity. Test results from 101 children with CIs and 47 children with NH sensitivity were analyzed to address the following questions:

1. How do the NWL abilities (and receptive vocabulary scores) of children who receive CIs in preschool compare with those of their NH peers?

Children with CIs remained significantly below their age mates from the NH group on the NWL task in both overall number of novel words learned and improvement with repeated exposures. The NWL results reported here and in other studies (Gilbertson and Kamhi, 1995; Houston *et al*., 2005; Lederberg and Spencer, 2009; Pittman *et al*., 2005; Stelmachowicz *et al*., 2004) seem to suggest that many children with hearing loss, wearing HAs or CIs, do not learn novel words at the level of NH age mates.

The mean PPVT-III score of the CI group (95) did not reach the normative mean score of 100. When results were considered separately for the GA and PA groups, a mean standard score of 102 for the GA group suggests that they had achieved parity with typical NH children such as those represented in the PPVT-III test norms. However, a significant vocabulary lag was found when compared with a NH comparison group of peers with similar levels of maternal education, whose average standard score was 114, almost one SD above the mean for the PPVT-III normative sample. This result highlights the importance of considering children's performance in the context of their socio-economic peers as well as their age-peers. Age-appropriate standard scores in relation to test norms may not reflect language skills that are sufficient to meet academic expectations within a socio-economically advantaged school environment.

2. How is audibility for speech with a CI related to speech perception, vocabulary level and NWL ability?

Children with a PTA threshold of 20 dB or better (GA group) scored significantly higher on the LNT speech perception task at both loud and soft presentation levels. The advantage of GA was greater for soft speech. Aided thresholds across the frequency range from .25 to 6 kHz which approximate 20 dB HL may provide the best opportunity to hear the acoustic cues of soft speech (Humes *et al*., 1986; Mueller and Killion, 1990; Pavlovic, 1984; Pavlovic *et al*., 1986). Notably, children in the GA group exhibited NWL and receptive vocabulary levels (standard scores) that were better than those in the PA group, however they still lagged behind their NH age-mates. The goal of achieving maximum audibility for the perception of speech is important because it may facilitate the acquisition of language by enabling children to learn language incidentally as well as by direct instruction. These results contrast with those from studies of children with mild to severe hearing loss using HAs that found that neither speech perception nor audibility index (computed using HA output and gain for speech) were associated with scores on a NWL test (Stelmachowicz *et al*., 2004). Perhaps the roles of audibility and speech perception ability are more critical for NWL in children who need a CI.

3. What other demographic and audiological characteristics are associated with NWL and receptive vocabulary level?

NIH-PA Author Manuscript

NIH-PA Author Manuscript

For this group of pediatric CI recipients, we found that younger age at CI was related to better NWL scores and ultimately better vocabulary scores. On the other hand, duration of CI use did not predict vocabulary scores, so it appears that receiving a CI at a young age provided a lasting advantage for vocabulary development. Finding positive effects of early implantation on vocabulary is consistent with results reported elsewhere (Nicholas and Geers, 2006, 2007, 2013; Geers and Nicholas, 2013). In addition, use of the most recent speech processor technology had a positive effect on aided PTA threshold, speech perception, and ultimately vocabulary level achieved. Bilateral implantation did not significantly affect either NWL or receptive vocabulary level.

4. Does performance on a NWL task provide additional information about receptive vocabulary scores once CI-audibility and other known predictors are accounted for?

In the CI group, vocabulary scores were positively correlated with NWL scores, indicating a relation between the ease of learning new words and vocabulary size. We examined whether the relation between NWL performance and vocabulary level remained after audibility was statistically controlled. We hypothesized that NWL scores reflect a dynamic process of phoneme processing and memory that complements audibility of the speech signal in facilitating vocabulary acquisition. Results from the multiple regression analysis revealed that NWL predicted independent variance after accounting for audibility, and all variables together accounted for 37% of the variance in receptive vocabulary scores. As predicted, the NWL task provided an estimate of cognitive and processing skills beyond sensory processing related to audibility and speech perception.

Conclusions

In summary, we found that children with CIs had receptive vocabulary levels that were significantly below their NH age mates with similar maternal education, and this was also reflected in their ability to learn novel words. Early access to sound and good audibility of speech were related to NWL ability and ultimately vocabulary level, although even children using Cis with good audibility lagged behind their NH age mates with similar maternal education level.

Estimates of vocabulary development were based only on a measure of single-word receptive vocabulary, and did not encompass other types of vocabulary knowledge as may be measured by tests requiring expressive labeling, definitions, or word recognition in a sentence context. Nevertheless, these results suggest that children with CIs may not be able to capitalize on “overhearing” for learning vocabulary, at least to the extent that their NH peers are able to. Novel-word-learning paradigms may be used to explore underlying phonological and cognitive mechanisms responsible for delayed receptive vocabulary in children with CIs.

Acknowledgments

Special thanks to Christine Brenner for help with data analysis and to Michelle Gremp for help with development and pilot testing of earlier versions of the Novel Word Learning task. Thanks also to the children and families who volunteered to participate as well as the schools and audiologists whose contributions made this research possible.

This work was funded by grants R01DC004168 and K23DC008294 from the National Institute on Deafness and Other Communication Disorders.

REFERENCES

Akhtar N, Jipson J, Callanan MA. Learning words through overhearing. Child Development. 2001; 72:416–430. [PubMed: 11333075]

Blamey PJ, Sarant JZ, Paatsch LE, Barry JG, Bow CP, Wales RJ, et al. Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. Journal of Speech, Language, and Hearing Research. 2001; 44:264–285.

Bloom, P. How children learn the meanings of words. Cambridge, MA: MIT Press; 2000. p. 1-23.

Bloom P. Precis of 'How children learn the meanings of words'. Behavioral and Brain Sciences. 2001; 24:1095–1103. [PubMed: 12412326]

Boothroyd A, Geers AE, Moog JS. Practical implications of cochlear implants in children. Ear & Hearing. 1991; 12:81S–89S. [PubMed: 1955093]

Carey, S. The child as word learner. Cambridge, MA: MIT Press; 1978.

Carhart R, Jerger J. Preferred method for clinical determination of pure-tone thresholds. Journal of Speech and Hearing Disorders. 1959; 24:330–345.

Conrad, R. The deaf schoolchild. London, UK: Harper and Row; 1979.

Davidson L, Geers A, Blamey P, Tobey E. Factors contributing to speech perception scores in long-term pediatric CI users. Ear and Hearing. 2011; 32:19–26.

Dollaghan CA, Campbell TF, Paradise JL, Feldman HM, Janosky JE, Pitcairn DN, Kurs-Lasky M. Maternal education and measures of early speech and language. Journal of Speech, Language, and Hearing Research. 1999; 42:1432–1443.

Dunn, LM.; Dunn, LM. Peabody Picture Vocabulary Test. 3rd Ed.. Circle Pines, MN: American Guidance Service; 1997.

Eisenberg LS, Martinez AS, Holowecky SR, Pogorelsky S. Recognition of lexically controlled words and sentences by children with normal hearing and children with cochlear implants. Ear & Hearing. 2002; 23:450–462. [PubMed: 12411778]

Ellis, Weismer S.; Hesketh, LJ. Lexical learning by children with specific learning impairment: ffects of linguistic input presented at varying speaking rates. Journal of Speech, Language, and Hearing Research. 1996; 39:177–190.

Gathercole SE, Hitch GJ, Service E, Martin AJ. Phonologial short-term memory and new word learning in children. Developmental Psychology. 1997; 33:966–979. [PubMed: 9383619]

Geers AE, Moog JS, Biedenstein J, Brenner C, Hayes H. Spoken language scores of chidlren using cochlear implants compared to hearing age-mates at school entry. Journal of Deaf Studies and Deaf Education. 2009; 14:371–385. [PubMed: 19155289]

Geers AE, Nicholas JG. Enduring advantages of early cochlear implantation for spoken language development. Journal of Speech, Language, and Hearing Research. 2013; 56 *(pp not available yet)*. doi:10.1044/1092-4388(2012/11-0347).

Geers AE, Sedey AL. Language and verbal reasoning skills in adolescents with 10 or more years of cochlear implant experience. Ear & Hearing. 2011; 32(Supp):39S–48S. [PubMed: 21832889]

Gilbertson M, Kamhi AG. Novel word learning in children with hearing impairment. Journal of Speech and Hearing Research. 1995; 38:630–642. [PubMed: 7674656]

Goodman JC, McDonough L, Brown NB. The role of semantic context and memory in the acquisition of novel nouns. Child Development. 1998; 69:1330–1344. [PubMed: 9839419]

Gremp, M. Independent Studies and Capstones: Paper 565. Program in Audiology and Communication Sciences. Washington University School of Medicine; 2006. Novel word-learning for normal-hearing and hearing-impaired children. http://digitalcommons.wustl.edu/pacs_capstones/565

Hansson K, Forsberg J, Lofqvist A, Maki-Torkko E, Sahlen B. Working memory and novel word learning in children with hearing impairment and children with specific language impairment. International Journal of Language and Communication Disorders. 2004; 39:401–422. [PubMed: 15204448]

Houston DM, Carter AK, Pisoni DB, Kirk KI, Ying EA. Word learning in children following cochlear implantation. Volta Review. 2005; 105:41–72. [PubMed: 21528108]

Humes LE, Dirk DD, Bell TS, Ahlstrom C, Kincaid GE. Applications of the Articulation Index and the Speech Transmission Index to the recognition of speech by normal hearing and hearing-impaired listeners. Journal of Speech and Hearing Research. 1986; 29:447–462. [PubMed: 3795887]

IDEA. Individuals with Disabilities Education Improvement Act of 2004, Pub L No. 108–446. 2004 118 Stat 2647.

IDEAdata.org. [Accessed 4/11/13] Individuals with Disabilities Education Act (IDEA) data Part B Educational Environments. 2009. www.ideadata.org/PartBenvironments.asp

Kirk KI, Pisoni DB, Osberger MJ. Lexical effects on spoken word recognition by pediatric cochlear implant users. Ear & Hearing. 1995; 16:470–481. [PubMed: 8654902]

Lederberg AR, Spencer PE. Word-learning abilities in deaf and hard-of-hearing preschoolers: Effect of lexicon size and language modality. Journal of Deaf Studies and Deaf Education. 2009; 14:44–62. [PubMed: 18495655]

Montogomery JW. Working memory and comprehension in children with specific language impairment: What we know so far. Journal of Communication Disorders. 2003; 36:221–231. [PubMed: 12742669]

Mueller JG, Killion MC. An easy method for calculating the articulation index. Hearing Journal. 1990; 43:14–17.

Nicholas JG, Geers AE. Effects of early auditory experience on the spoken language of deaf children at 3 years of age. Ear & Hearing. 2006; 27:286–298. [PubMed: 16672797]

Nicholas JG, Geers AE. Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. Journal of Speech, Language, and Hearing Research. 2007; 50:1048–1062.

Nicholas JG, Geers AE. Spoken language benefits of extending cochlear implant candidacy below 12 months of age. Otology & Neurotology. 2013; 34:532–538. [PubMed: 23478647]

Oetting JB, Rice ML, Swank LK. Quick Incidental Learning (QUIL) of words by school-age children with and without SLI. Journal of Speech and Hearing Research. 1995; 38:434–445. [PubMed: 7596109]

Oshima-Takane Y. Children learn from speech not adddressed to them: The case of personal pronouns. Journal of Child Language. 1988; 15:95–108. [PubMed: 3350879]

Oshima-Takane Y, Takane Y, Shultz TR. The learning of first and second person pronouns in English: Network models and analysis. Journal of Child Language. 1999; 26:545–575. [PubMed: 10603696]

Pavlovic CV. Use of the articulation index for assessing residual auditory function in listeners with sensorineural hearing impairment. The Journal of the Acoustical Society of America. 1984; 75:1253–1258. [PubMed: 6725776]

Pavlovic CV, Studebaker GA, Sherbecoe RL. An articulation index based procdure for predicting the speech recognition performance of hearing-impaired individuals. The Journal of the Acoustical Society of America. 1986; 80:50–57. [PubMed: 3745665]

Pittman AL, Lewis DE, Hoover BM, Stelmachowicz PG. Rapid word-learning in normal-hearing and hearing-impaired children: Effects of age, receptive vocabulary, and high-frequency amplification. Ear & Hearing. 2005; 26:619–629. [PubMed: 16377997]

Rice ML, Buhr J, Oetting JB. Specific-language-impaired children's quick incidental learning of words: The effect of a pause. Journal of Speech and Hearing Research. 1992; 35:1040–1048. [PubMed: 1447916]

Rice ML, Buhr JC, Nemeth M. Fast mapping word-learning abilities of language-delayed preschoolers. Journal of Speech and Hearing Disorders. 1990; 55:33–42. [PubMed: 2299838]

Rice ML, Woodsmall L. Lessons from television: Children's word learning when viewing. Child Development. 1988; 59:420–429. [PubMed: 3359862]

Ross M. Implications of delay in detection and management of deafness. Volta Review. 1990; 92:69–79.

Stelmachowicz PG, Pittman AL, Hoover BM, Lewis DE. Novel-word learning in children with normal hearing and hearing loss. Ear & Hearing. 2004; 25:47–56. [PubMed: 14770017]

Svirsky MA, Teoh SW, Neuburger H. Development of language and speech percetion in congenitally, profoundingly deaf children as a function of age at cochlear implantation. Audiology and Neuro-Otology. 2004; 9:2 24–233. [PubMed: 14676470]

Weismer SE, Evans J, Hesketh LJ. An examination of verbal working memory capacity in chidlren with specific language impairment. Journal of Speech, Language, and Hearing Research. 1999; 42:1249–1260.

Willstedt-Svensson U, Lofqvist B, Almqvist B, Sahlen B. Is age at implant the only factor that counts? The influence of working memory on lexical and grammatical development in children with cochlear implants. International Journal of Audiology. 2004; 43:506–515. [PubMed: 15726841]

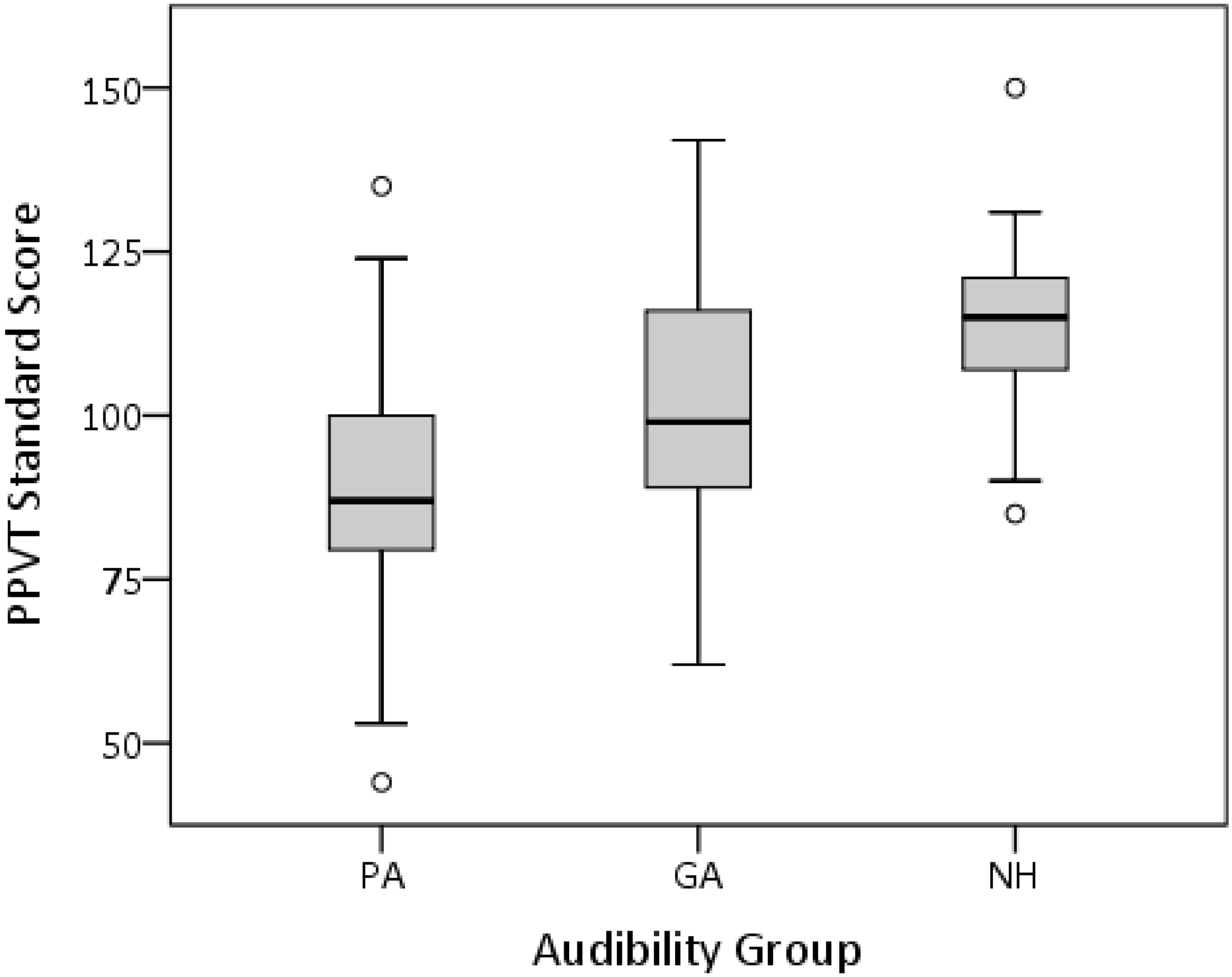


Figure 1.
Box plots of receptive vocabulary standard scores on the PPVT-III for children using CIs with good audibility (GA) vs poor audibility (PA) and normally-hearing (NH) peers. The shaded portion represents the 25th and 75th percentiles; the whiskers represent the minimum and maximum scores, excluding outliers. The median score is indicated within each box and outliers are represented by circles.

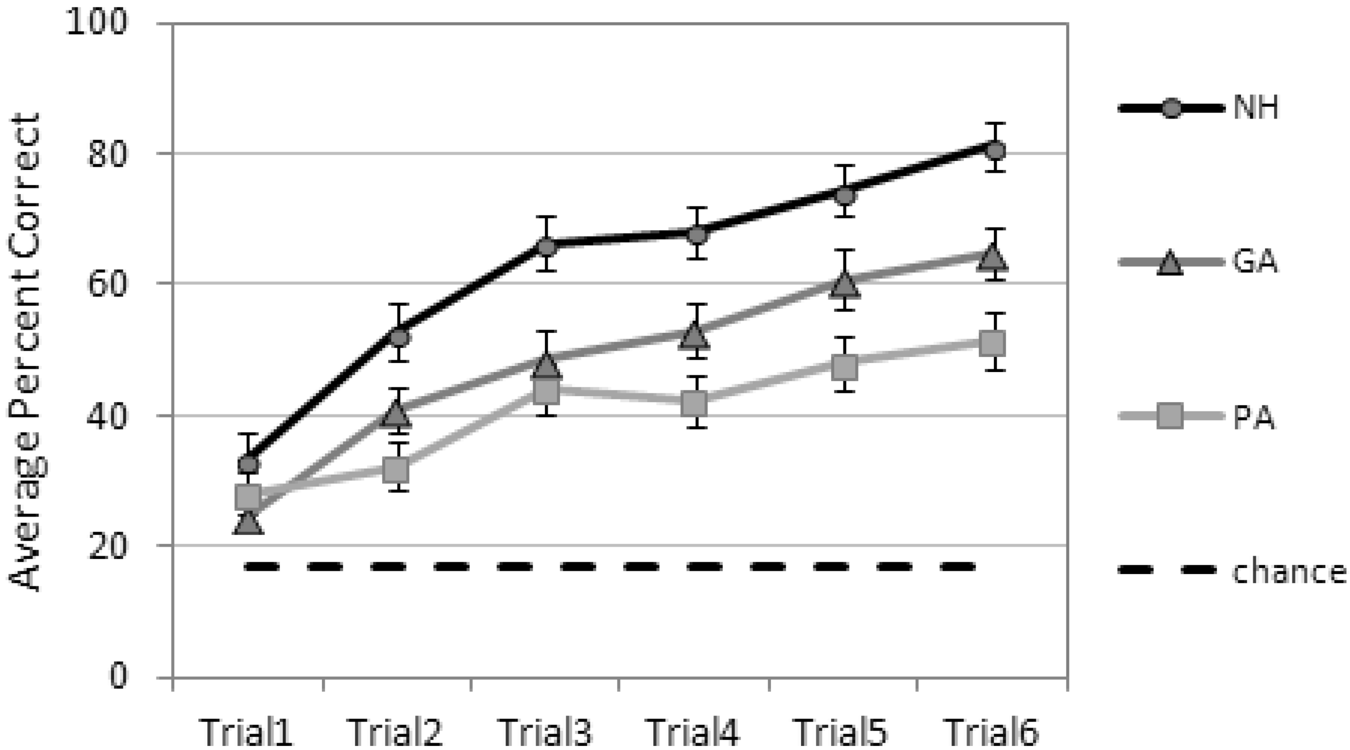
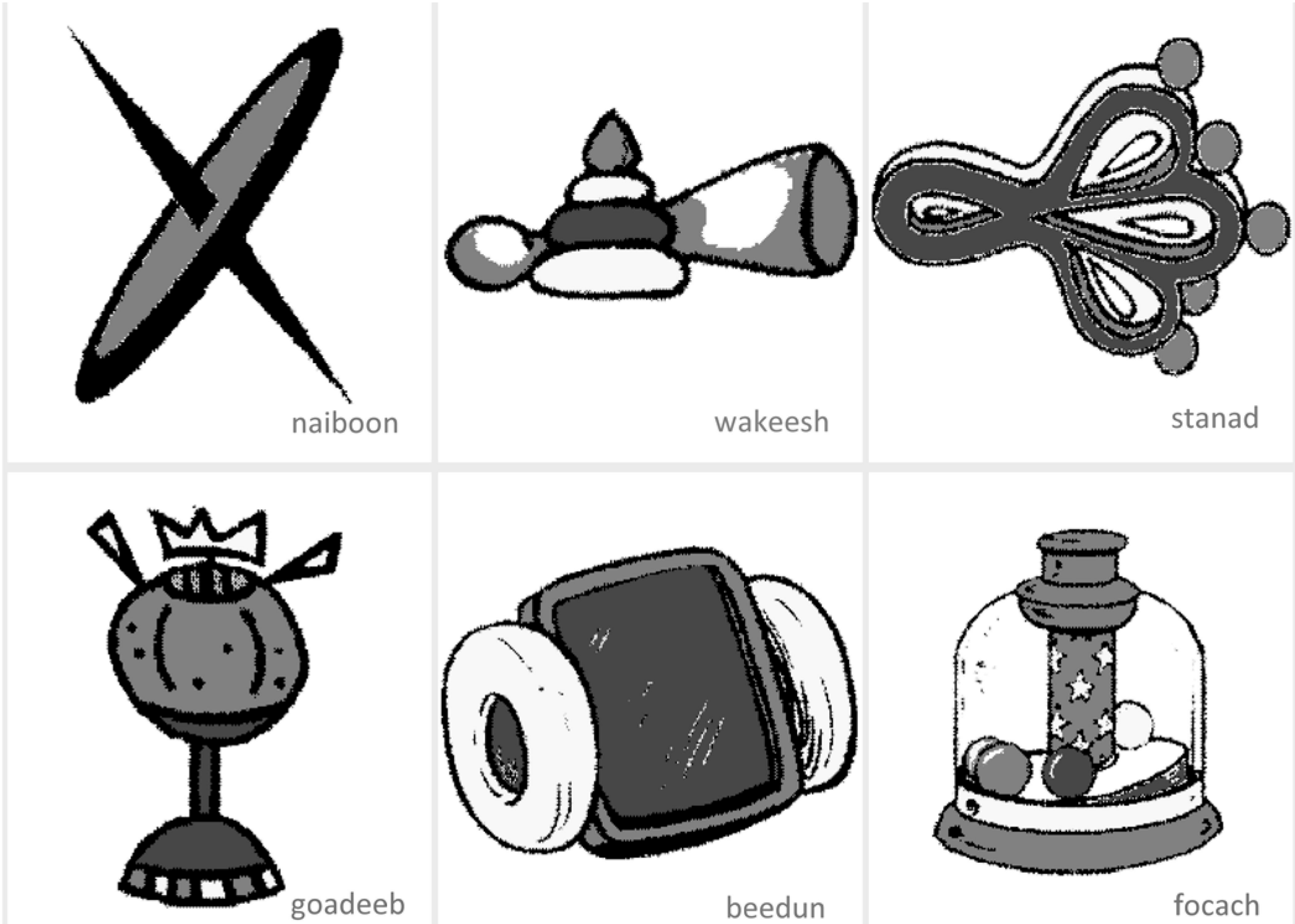


Figure 2.

Group mean and standard error for NWL scores of children using CIs with good audibility (GA) vs poor audibility (PA) and normally-hearing (NH) peers, at each of 6 successive trials. Chance performance is indicated by dashed line at 16.66%.



Appendix.

Table 1

Demographic Characteristics of the Children with Cochlear Implants and Children with Normal Hearing Sensitivity

Variable	**Group**	**N**	**Mean**	**SD**	**Range**
Age	CI	101	8.96	1.97	5.8 – 12.8
	NH	47	9.16	1.80	6.1 – 12.1
Gender	CI	101			46 F; 55 M
	NH	47			25 F; 22 M
Mother’s Education Level	CI	99	15.2	2.32	11 – 20
	NH	45	16.9	2.18	12 – 20

CI = cochlear implant, NH = normally-hearing, F = female, M = male

Table 2

Audiological Characteristics of the Sample of Children Using Cochlear Implants

Variable	Mean	SD	Range
Age at Diagnosis (months)	8.3	8.4	0 – 36
Age at First Hearing Aid Fit (months)	12.2	8.2	1 – 37
Age at Cochlear Implant (months)	24.6	10.9	10 – 60
Duration of Implant Use (years)	6.91	2.28	2.0 – 11.2

Table 3

Level of Aided Hearing and Scores on Lexical Neighborhood Test, for Children Using Cochlear Implants (N=101)

Variable	Mean	SD	Range
Aided PTA in dB HL	21.6	6.3	8.3 – 48.3
Good Audibility Group	16.7	3.4	8.3 – 20.0
Poor Audibility Group	25.8	5.1	21.7 – 48.3
LNT word score at 50 dB SPL	56.4%	24.2	0 – 94
Good Audibility Group	64.4%	17.4	18 – 94
Poor Audibility Group	49.7%	27.1	0 – 92
LNT word score at 70 dB SPL	77.3%	18.2	0 – 96
Good Audibility Group	81.9%	11.2	50 – 94
Poor Audibility Group	73.5%	21.8	0 – 96

All LNT scores are a percent-correct score; LNT = Lexical Neighborhood Test; PTA = Pure Tone Average; dB HL = decibels hearing level; dB SPL = decibels sound pressure level

Table 4

Correlation Matrix with all Predictor and Outcome Variables for all CI Participants (N=101)

		PPVT-III Standard Score	Age	Age at CI	Duration CI	Duration Second CI Group	NWL percent correct	Aided PTA	LNT @ 50 dB SPL	LNT @ 70 dB SPL	Mother's Education Level	CI processor
PPVT-III[1] Standard Score	Pearson Correlation	1										
	Sig. (2-tailed)											
	N	101										
Age	Pearson Correlation	.030	1									
	Sig. (2-tailed)	.766										
	N	101	101									
Age at CI[2]	Pearson Correlation	−.267	−.134	1								
	Sig. (2-tailed)	.007	.180									
	N	101	101	101								
Duration CI	Pearson Correlation	.133	.918	−.516	1							
	Sig. (2-tailed)	.185	.000	.000								
	N	101	101	101	101							
Duration Second CI Group	Spearman Correlation	.155	−.143	−.230	−.012	1						
	Sig. (2-tailed)	.122	.153	.021	.905							
	N	101	101	101	101	101						
NWL[3] percent correct	Pearson Correlation	.470	.250	−.259	.320	.006	1					
	Sig. (2-tailed)	.000	.012	.009	.001	.951						
	N	101	101	101	101	101	101					
Aided PTA[4]	Pearson Correlation	− 382	−.003	−.022	.006	.026	−.237	1				
	Sig. (2-tailed)	.000	.978	.825	.952	.795	.017					
	N	101	101	101	101	101	101	101				
LNT @ 50 dB SPL[5]	Pearson Correlation	.360	−.205	−.039	−.161	.252	.289	−.542	1			
	Sig. (2-tailed)	.000	.040	.701	.108	.011	.003	.000				
	N	101	101	101	101	101	101	101	101			

		PPVT-III Standard Score	Age	Age at CI	Duration CI	Duration Second CI Group	NWL percent correct	Aided PTA	LNT @ 50 dB SPL	LNT @ 70 dB SPL	Mother's Education Level	CI processor
LNT @ 70 dB SPL[6]	Pearson Correlation	.404	−.055	−.131	.005	.256	.398	−.446	.735	1		
	Sig. (2-tailed)	.000	.583	.192	.962	.010	.000	.000	.000			
	N	101	101	101	101	101	101	101	101	101		
Mother's Education Level	Pearson Correlation	.206	.037	−.162	.098	.076	−.079	−.102	−.047	−.090	1	
	Sig. (2-tailed)	.041	.719	.109	.334	.454	.436	.316	.643	.377		
	N	99	99	99	99	99	99	99	99	99	99	
CI processor	Spearman Correlation	.273	−.380	−.096	−.247	.380	.077	−.247	.351	.315	− .065	1
	Sig. (2-tailed)	.006	.000	.342	.013	.000	.447	.013	.000	.001	.520	
	N	101	101	101	101	101	101	101	101	101	99	101

[1]PPVT-III = Pea body Picture Vocabulary Test, 3rd edition

[2]CI = Cochlear Implant

[3]NWL = Novel Word Learning

[4]PTA= Pure Tone Average

[5]LNT= Lexical Neighborhood Test

[6]dB SPL = deciBels in Sound Pressure Level. Note: Duration second CI groups are: No second CI Less than 3 years (n=25), 3 years or more (n=28).

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 5

Results of Multiple Regression Analysis of Predictors for PPVT-III Standard Score

Predictor	β	p	R^2 for model
Age at CI	−0.16	.063	
Mother's Education	0.18	**.039**	
Aided PTA	−0.30	**.001**	
NWL	0.36	**.0001**	
Total Explained Variance			0.37

CI = cochlear implant; PTA = Pure Tone Average; NWL = Novel Word Learning, percent correct score