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Word learning in deaf children with cochlear implants: effects of early auditory experience

Derek M. Houston[1], **Jessica Stewart**[1], **Aaron Moberly**[1], **George Hollich**[2], and **Richard T. Miyamoto**[1]

[1]Department of Otolaryngology – Head & Neck Surgery, Indiana University, USA

[2]Department of Psychological Sciences, Purdue University, USA

Abstract

Word-learning skills were tested in normal-hearing 12- to 40-month-olds and in deaf 22- to 40-month-olds 12 to 18 months after cochlear implantation. Using the Intermodal Preferential Looking Paradigm (IPLP), children were tested for their ability to learn two novel-word/novel-object pairings. Normal-hearing children demonstrated learning on this task at approximately 18 months of age and older. For deaf children, performance on this task was significantly correlated with early auditory experience: Children whose cochlear implants were switched on by 14 months of age or who had relatively more hearing before implantation demonstrated learning in this task, but later implanted profoundly deaf children did not. Performance on this task also correlated with later measures of vocabulary size. Taken together, these findings suggest that early auditory experience facilitates word learning and that the IPLP may be useful for identifying children who may be at high risk for poor vocabulary development.

Introduction

A fundamental question in the study of human development is how language acquisition is affected by experience. One type of experience that affects language development is auditory experience. For most children access to auditory information begins before birth, and there is some evidence that such prenatal exposure affects speech perception development (see Houston, 2011, for a review). Being able to hear the sounds of the ambient language plays an important role in shaping infants' speech perception throughout the first year of life, putting them in position to learn the words and grammar of their language or languages throughout the rest of their development. Although access to auditory information is clearly important for spoken language development, we do not know if it is important for this access to happen during a particular time in development. For example, if children do not have access to auditory information for the first year of life and then gain access to auditory information, how will this affect their language development? Will it simply be delayed or will it be disordered in some way? Are there sensitive periods[1] in which auditory access needs to occur during particular stages of development for particular aspects of language acquisition to develop normally?

Address for correspondence: Derek M. Houston, Department of Otolaryngology – Head & Neck Surgery, Indiana University School of Medicine, Indianapolis, IN 46202, USA; dmhousto@indiana.edu.
Jessica Stewart is now at the University of North Carolina at Chapel Hill, Department of Medicine. Aaron Moberly is now at the Ohio State University, Department of Otolaryngology – Head & Neck Surgery.

[1] Knudsen (2004, p. 1412) defines sensitive periods as: `… periods in development during which certain capacities are readily shaped or altered by experience.…the experience must be of a particular kind and it must occur within a certain period if the behavior is to develop normally'.

Answering these questions is important for understanding the role of experience in language development. It is also important for making treatment decisions on interventions for deafness, such as cochlear implantation. Ideally, cochlear implantation would occur before important sensitive periods for language development close. The issue of auditory sensitive periods is important for this population, and this population can help us better understand auditory sensitive periods: By investigating the effects of age at implantation on aspects of language development we can better understand sensitive periods for auditory-based language development skills. For example, if congenitally deaf children who undergo cochlear implantation between 6 and 24 months of age were to show an effect of age at implantation on their ability to learn novel words it would suggest that a sensitive period for having access to sound in order to develop the ability to associate speech to referents starts to close during that period. If there were no effect of age at implantation during that period and children performed similar to normal-hearing peers, it would suggest that the sensitive period begins to close after that period. Finally, if there were no effect of age at implantation during that period and children performed worse than normal-hearing peers, it would suggest the very unlikely possibility that the sensitive period finishes closing before that period. The study reported here investigated these possibilities.

Effects of age at cochlear implantation on language outcomes

There have been a number of studies that have examined the effects of age at implantation on spoken language development. Most of these studies have used conventional language outcome measure tests, such as the Peadbody Picture Vocabulary Test (Dunn & Dunn, 2007) for vocabulary and the Preschool Language Scale (Zimmerman, Steiner & Pond, 2002) for receptive and expressive language. These assessment tools were designed to identify children who are not progressing in receptive and/or expressive language within standard distributions based on normative data. These tests assess language outcomes rather than specific language processes. Using such assessments, investigators have found that, across several different age ranges, children implanted at relatively younger ages achieve higher scores on measures of receptive and expressive language than children implanted at relatively older ages (Colletti, 2009; Kirk, Miyamoto, Ying, Perdew & Zuganelis, 2002; Geers, Nicholas & Moog, 2007; Nicholas & Geers, 2007; Miyamoto, Hay-McCutcheon, Kirk, Houston & Bergeson-Dana, 2008; Svirsky, Teoh & Neuburger, 2004). For example, Kirk *et al*. (2002) found that children implanted before 2 years of age showed faster gains in vocabulary and receptive language than children implanted between 2 and 4 years of age and children implanted after 5 years of age. Nicholas and Geers (2007) took language samples from 3.5- and 4.5- year-old children implanted between 12 and 38 months of age and found that earlier implanted children showed a greater number of root words, a greater mean length of utterance (MLU) and a greater number of bound morphemes than later implanted children.

Age at implantation effects on language outcome measures have been found even when comparing children who received cochlear implants `early' (before 12 months) versus `later' (between 12 and 24 months), which is still considered to be young by most standards (Colletti, Mandalà, Zoccante, Shannon & Colletti, 2011; Dettman, Pinder, Briggs, Dowell & Leigh, 2007). For example, Dettman *et al*. (2007) found greater rates of expressive and receptive language growth in children implanted under 12 months of age than in children implanted between 12 and 24 months of age. These findings provide valuable information about the effects of early implantation on language outcomes. However, because they are general language assessments, they provide very little information about how early auditory deprivation affects specific language skills like the ability to segment words from fluent speech or the ability to associate words to their referents.

Findings that age at implantation affects language outcomes have led some to speculate that there may be sensitive periods of language development (e.g. Tomblin, Barker & Hubbs, 2007). However, language acquisition is a complex combination of skills and thus likely involves multiple sensitive periods (Houston & Miyamoto, 2010; Knudsen, 2004). In order to understand how auditory deprivation affects language development, we have to investigate how it affects specific aspects of language development.

One specific skill that has received a lot of attention in the field of hearing loss and cochlear implants is speech perception – specifically, the ability to hear and identify the sound patterns of words. Speech perception is typically assessed in children with cochlear implants by presenting the children with words or sentences – via either live voice or recorded materials – and asking them to repeat the words back. Measured in this way, studies have shown that children implanted before 3 years of age show better speech perception than children implanted at later ages (Zwolan, Ashbaugh, Alarfaj, Kileny, Arts, El-Kashlan & Telian, 2004). However, similar findings have not been found when comparing among children implanted under 3 years of age (Harrison, Gordon & Mount, 2005; Horn, Houston & Miyamoto, 2007; McConkey Robbins, Koch, Osberger, Zimmerman-Phillips & Kishon-Rabin, 2004; Tajudeen, Waltzman, Jethanamest & Svirsky, 2010). Tajudeen *et al*. (2010) concluded that the sensitive period for speech perception extends to at least 3 years of age.

The lack of age-at-implantation effects on speech perception among children implanted under 3 years of age contrasts with effects on general language measures among children implanted within that same age range. Taken together the findings suggest that effects of very early implantation on language outcomes is not likely due to sensitive periods for speech perception development. If it were, we would expect to see effects of age-atimplantation for speech perception among children implanted under 3 years of age just as we do for more general language measures. Thus, effects of implantation on general language measures among children implanted under 3 years of age are likely due to earlier sensitive periods of other language skills. This paper investigates the possibility that the ability to learn associations for the sound patterns of words and their references – i.e. early word learning – might be one of those language skills. If there are age-at-implantation effects on early word learning among children implanted under 3 years of age, it would suggest that age-at-implantation effects on general language outcomes may be partly explained by age-at-implantation effects on acquiring word-learning skills. It would also suggest a sensitive period for having access to sound to support early spoken word learning.

Word learning in children with CIs

As mentioned above, most work on language acquisition in children with CIs has focused on outcomes rather than processes. This is the case for lexical development. Several studies have shown that earlier implantation leads to larger vocabulary as measured by standardized tests (Colletti, 2009; Kirk *et al*., 2002; Nicholas & Geers, 2006; Svirsky *et al*., 2004) such as the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007) in which children are presented with words one at a time and after each word asked to point at the drawing (out of 4 possibilities) that corresponds to the word and by a diary study (Nott, Cowan, Brown & Wigglesworth, 2009). Only a handful of studies have investigated word-learning skills rather than vocabulary outcomes in the CI population. One study of 5- to 11-year-old children with CIs used a commonly used word-learning task (Gilbertson & Kamhi, 1995) in which children are first presented with some common objects and a novel word (e.g. *dax*) that is paired with a novel object. They are then asked to select that target item (*Please give me the dax*) from among common and other novel items and then later asked to name the target item. They found that word-learning skills were strongly correlated with age at implantation (Willstedt-Svensson, Löfqvist, Almqvist & Sahlén, 2004). Another study found that 2- to 6-

year-olds with CIs showed much poorer word-learning skills than NH age-matched peers (Houston, Carter, Pisoni, Kirk & Ying, 2005), using a task in which children were taught new names for stuffed animals (e.g. `red', `fuzzy') and then asked to demonstrate learning of the names both receptively, by pointing to the stuffed animals when they were named, and expressively, by naming the stuffed animals upon presentation. However, these studies did not investigate the effects of very early implantation (< 1 year) on word learning in young children.

In a study with younger children, Houston, Ying, Pisoni and Kirk (2003b) investigated the effects of age at implantation on deaf children's ability to learn associations between dynamic objects (e.g. a toy kangaroo hopping) and rhythmically coincident speech sounds (e.g. `hop hop hop...') using the intermodal preferential looking paradigm (IPLP) (Golinkoff, Hirsh-Pasek, Cauley & Gordon, 1987; Hirsh-Pasek & Golinkoff, 1996) in which two pairings of dynamic objects and corresponding speech sounds (e.g. a toy kangaroo bouncing and repetitions of `hop hop hop...') were presented one at a time and then speech sounds (e.g. `hop hop hop') were presented with both objects and children's looking time to the target (e.g. the toy kangaroo) versus a nontarget (a toy airplain moving across a table) were measured. Houston *et al*. (2003b) found that children whose CIs were switched on before 15 months of age showed learning within 2 to 6 months after initial CI stimulation, whereas children whose CIs were switched on after 16 months of age did not show learning in that task even after more than a year of CI experience.

While the Houston *et al*. (2003b) study demonstrated that sound–action association was facilitated by early implantation and validated the use of the IPLP with young children who use CIs, the investigation did not necessarily tap word-learning skills *per se* because the pairing of sound and objects was not arbitrary. Instead they shared rhythmic synchrony. Repetitions of the word `hop' occurred to synchronous bounces of the toy kangaroo. The purpose of the present study was to use the IPLP to investigate the effects of early auditory experience in a word-learning task that more closely resembles real life word learning in that the words were arbitrarily related to the objects. Our hypothesis is that if early auditory experience is important for word learning, then age at implantation and amount of residual hearing should predict performance on this word-learning task.

The word-learning task used was a variant of the IPLP originally developed by Golinkoff *et al*. (1987). While word-learning tasks have typically been conducted with a live experimenter (e.g. Mervis & Bertrand, 1994; Waxman & Booth, 2001), Schafer and Plunkett (1998) and others (e.g. Booth & Waxman, 2009; Hollich, 2006) have shown that it is not only possible to test word learning using a 2D video, but that such videos may be preferable because of the level of control afforded. Video allows for each participant to be presented with the same stimuli with the same timing and loudness. Video also allows for more complicated audio-visual manipulations (as in Houston *et al*., 2003b), which was itself a variant on a procedure by Spelke (1979). In the original version, two items are presented on different video monitors, while one of the items is requested. In the current version, first used by Hollich (2006), the stimuli are presented on a single screen, and there are both labeling and test phases. In either case, infants' looking toward the labeled object (specifically when requested) is taken as an indication that these infants understand the connection between word and referent.

To investigate whether early word-learning skills were predictive of later vocabulary and other speech and language outcome measures, we also compared their performance on the word-learning task to their performance on several other speech and language assessments 6 months to 1 year later.

Method

Participants

Children with cochlear implants—Twenty-five prelingually deaf children (8 female) who received a CI prior to 2 years of age were recruited through the Indiana University Medical Center's CI program. Four additional children were tested but not included because they failed to complete the experiment due to crying or excessive fussiness (2) or because of experimenter error (2). Additional demographic information is shown in Table 1.

Normal-hearing infants—Twenty-three 12-month-olds (10 female; mean age: 12.0 months; range: 11.1–13.0 months), 23 15-month-olds (12 female; mean age: 14.7 months; range: 13.8–15.5 months), 25 18-month-olds (19 female; mean age: 17.0 months; range: 17.2–18.6 months), and 28 21-month-olds (16 female; mean age: 21.1 months; range: 20.2–23.0 months) were recruited from the Indianapolis metropolitan area. Twenty-five (13 female) additional NH children were selected as age-matched controls (see right side of Table 1). For each CI child, there was a NH child tested who was a similar age (mean difference = 0.5 mos; range = 0.0 to 1.3 mos).

Twenty-eight children were tested but did not complete the procedure due to crying (22), experimenter error (3), side bias (3), parental interference (1), and falling asleep (1).

Apparatus

The testing was conducted in a custom-designed double-walled IAC sound booth. Children sat on their caregiver's lap in front of a large 55″ wide-aspect TV monitor. The visual stimuli were displayed as left and right picture-in-picture (PIP) displays on the TV monitor at approximately eye level to the infant, and the auditory stimuli were presented through both the left and right loudspeakers of the TV monitor. The experimenter observed the infant from a separate room via a hidden closed-circuit TV camera and controlled the experiment using Habit (Cohen, Atkinson & Chaput, 2004) running on a Macintosh G4 desktop computer.

Materials

Speech stimuli for word-learning task—All of the speech stimuli were recorded by a female talker who was instructed to produce the stimuli as if she were speaking to an infant or toddler. The passages recorded for each phase of the experiment are displayed in Figure 1. Two nonwords – *blick* and *modi* – were selected as the novel words to be learned in the experiment. The nonwords did not contain any of the same phonemes and differed in number of syllables, making them easily discriminable, even for children with a year of CI experience.

Visual stimuli for word-learning task—The novel objects, designed and rendered using Macromedia's Extreme 3D, are shown in Figure 1. A video of an infant laughing was used as the *attention getter*. For the training phase, the novel objects were animated using Macromedia Director Software Package to move in various ways (although not in synchrony with the occurrence of the target words). The duration of the video was 24 seconds. In all other phases, the objects were static and the duration of the trials was 7 seconds.

Speech perception and vocabulary outcome measures—All outcome measure tests were administered in the communication mode of the child (see Table 1) by a certified speech-language pathologist. Speech perception of children with CIs was assessed in two ways. The first was by using two closed-set word recognition tasks – the Grammatical Analysis of Elicited Language - Pre-Sentence Level (GAEL-P) (Moog, Kozak & Geers,

1983) and the Pediatric Speech Intelligibility Test (PSI) (Jerger & Jerger, 1984). In these tests, the examiner presented children with four objects (GAEL-P) or six pictures (PSI) at a time, and the child was asked to point at the object or picture that corresponded to the word that the examiner spoke. The second way in which speech perception was assessed was by using an open-set word recognition task – the Lexical Neighborhood Test (LNT; Kirk, Pisoni & Osberger, 1995). This test was administered by a speech-language pathologist who was highly familiar with the child's communication skills after having tested the child in several previous sessions. Recorded words were presented one at a time in a sound booth, and the child was instructed to repeat the word he or she heard. If the child's speech was unintelligible, the examiner prompted the child to communicate through manual means (i.e. signs or gestures) or to repeat his or her response. A word was scored as correct only if the examiner was certain that the child attempted to communicate the correct word, taking into consideration the child's articulation errors and general communication abilities.

Vocabulary was assessed in children with CIs using the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007). In this test, children are presented with cards, one at a time, which contain four drawings. The examiner speaks the word corresponding to one of the drawings and the child is asked to point to it on the card. The vocabulary items increase with difficulty with each subsequent group of cards, and normative data allow the clinician to know where the child falls with respect to age-matched peers. Vocabulary was assessed in age-matched children with NH using the MacArthur-Bates Communicative Developmental Index (MCDI; Fenson, Marchman, Thal, Dale, Reznick & Bates, 2005). The MCDI includes two parental questionnaires: One is devised for infants ages 8–18 months and the other is for toddlers ages 16–30 months. We used the toddler form. The toddler form assesses productive vocabulary knowledge of 100 items and poses an additional question regarding whether the child can combine words.

The GAEL-P and PSI were administered two years after initial CI stimulation – when the children were between 2.5 and 4 years of age. The LNT was administered four years after initial CI stimulation – when the children were between 4.5 and 6 years of age. The PPVTIV was administered at both post-CI intervals. The MCDI was administered to NH children at the time of testing in the word-learning experiment. Table 1 shows what tests were administered to which children. Missing data were due to a variety of factors, including moving, dropping out of the research program, the child not being able to complete all of the testing at a given interval, and not having reached the two- or four-year post-CI interval at time of analyses.

Procedure

Word-learning testing—Word learning was tested using a modified version of the IPLP at either 12 ($n = 13$) or 18 ($n = 12$) months after initial stimulation (+ 2 months). Thus, their experience with a CI (or their `hearing age') ranged from 10.3 to 20.1 months. A schematic of the experimental design is displayed in Figure 1. As shown in the figure, after children were presented with training movies where they could learn two novel-object/novel-word associations, they were presented with four blocks of test trials. Each block consisted of four trials – two in which the child heard *blick* in carrier sentences and two in which the child heard *modi* in carrier sentences. Between each block of test trials, children were presented with two reminder trials in which each novel-word/novel-object pair was reintroduced. Prior to testing, parents were encouraged to set their child's CIs to the settings that they felt would be best for enabling their child to hear speech.

Data collection—A digital video camera was used to record the children during testing. The digital video recordings were used for frame-by-frame analyses of their looking behavior. We predicted that if children were able to learn the associations between the visual displays and the speech sounds during the training, then they would, on average, show longer looks to the target than to the nontarget on the test trials.[2]

Outcome measures—Vocabulary and closed-set word recognition tests were administered to the CI children two years after implantation (six to twelve months after testing on the word-learning task). At four years after implantation, vocabulary and open-set word recognition tests were administered (see Table 1). For age-matched NH children, vocabulary measures were administered at time of testing.

Results

Word-learning assessment

NH groups—Mean longest look to the target and nontarget during each test block is displayed in Figure 2, separated by age group. The data from each age group were analyzed using a repeated-measures ANOVA with Stimulus Type (target, nontarget) and Test Block (1, 2, 3, 4) as within-subject variables. Twelve- and 15-month-olds did not look significantly longer to the target versus the nontarget. Looking time preference for the target approached statistical significance in the 18-month-olds ($F(1, 24) = 3.06$, $p = .08$, $\eta_p^2 = .11$) and was significant in the 21-month-olds ($F(1, 27) = 7.05$, $p = .01$, $\eta_p^2 = .21$). There were no other significant main effects or interactions for any of the groups. It is worth noting that the NH infants who did not demonstrate word learning (12- and 15-month-olds) were younger in chronological age than the children with CIs but similar to the lower end of their hearing age range. The NH infants who did demonstrate word learning (18- and 21-month-olds) were also younger in mean chronological age than the children with CIs but similar to the upper end of their hearing age range. Thus, these groups of NH children serve as good comparisons for how the children with CIs perform relative to NH infants with similar hearing ages.

CI children and NH age-matched controls—The primary objective of the study was to investigate the effects of early auditory experience (i.e. during the first two years of life) on children's word-learning skills after cochlear implantation. Using multiple linear regression analyses, we tested for the effects of age at cochlear implantation (Age at CI), aided hearing levels before implantation (Aided PTA), and amount of CI experience (Hearing Age) on performance on the word-learning task. Because there were no effects of test block for the CI children, mean longest look differences were used as the dependent variable. As shown on the top half of Table 2, the regression analyses revealed a significant effect of pre-CI hearing levels on performance, suggesting that having some degree of hearing before implantation facilitates word learning. A scatterplot of pre-CI hearing levels and word-learning performance is displayed in Figure 3a.

Visual inspection of the data (see Table 1 and Figure 3a) revealed very little variance in pre-CI aided hearing thresholds except for a handful of children who had better pre-CI hearing than the rest of the group. This raises the possibility that the effect of pre-CI hearing on performance was due to a small number of CI children with better hearing than most of the other children. To explore this possibility, we calculated the mean and standard deviation of pre-CI aided thresholds. No children had hearing thresholds more than one standard deviation above the mean, but five children had pre-CI aided thresholds more than one standard deviation below the mean – i.e. better hearing. Those better-hearing children had a

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[2] Longest look was used as the dependent measure because it has been found to be a more sensitive measure of word learning than overall looking time (Schafer & Plunkett, 1998).

mean looking time difference of 1.07 s whereas the rest of the group showed a mean looking time difference of 0.28 s. Moreover, the three largest looking time differences among all children came from these five better-hearing subjects.

The regression analyses were rerun on the data without the better-hearing subjects; the results are displayed on the bottom half of Table 2. In this set of analyses, amount of pre-CI hearing did not contribute significantly to the variability in word-learning performance. However, age at implantation did account for a significant amount of the variance in these analyses. A scatterplot of age at implantation and word-learning performance is displayed in Figure 3b.

Taken together, the results suggest that when children's pre-CI hearing thresholds are in the typical range for CI candidates, earlier cochlear implantation is related to better performance on the word-learning task. However, relatively better hearing before implantation predicts better performance regardless of age at implantation. Hearing age, which ranged from 10.3 to 20.1 months, did not contribute to the variability in word-learning performance.

Early vs. late implanted children—Although there was an age-at-implantation effect, it is possible that the age-at-implantation effect was really just an age effect. The two effects are confounded in this study because children were tested at the same intervals (12 or 18 months) rather than at the same age. Thus, the later implanted children were necessarily older than the earlier implanted children at time of test. It is possible that the later implanted children failed at the task not because they were implanted later but because the stimuli and/or testing procedures may not have been sufficiently engaging at this age. To explore this possibility, the twenty children with similar degrees of hearing loss were divided based on their age at initial stimulation and compared to age-matched NH children. Because there was no *a priori* rationale for how to divide the subjects into `early' and `late' implanted groups, we used a K-means clustering method (PASW Statistics 18).[3] This method assigns cases to groups such that the differences in values within each group are minimized and the differences in values between each group are maximized. The results produced an early implanted group of 12 children who were between 7.6 and 13.6 months old when their CIs were switched on and a late implanted group of eight children who were between 16.0 and 21.4 months old when their CIs were switched on. The five children who were removed from these analyses were 12.8, 13.9, 16.9, 17.3, and 21.5 months old at initial stimulation.

Mean longest looks for the early and late implanted groups are displayed on the left side of Figure 4. There was a main effect of Stimulus Type ($F(1, 18) = 6.37$, $p = .02$, $\eta_p^2 = .26$) and a Stimulus Type × Implant Group interaction ($F(1, 18) = 10.39$, $p = .002$, $\eta_p^2 = .43$). There was no main effect of Block and no significant interaction between block and the other variables. The results suggest that the early implanted group performed significantly better on the word-learning task than late implanted group.

CI vs. age-matched NH children—For the early implanted group and their NH age-matched peers, there was a main effect of Stimulus Type ($F(1, 22) = 15.06$, $p = .001$, $\eta_p^2 = .41$) and no other significant main effects or interactions (see Figure 4). For the late implanted group and their NH age-matched peers, there was a main effect of Stimulus Type ($F(1, 14) = 6.14$, $p = .03$, $\eta_p^2 = .31$) and a significant Stimulus Type × Hearing Group interaction ($F(1, 14) = 9.95$, $p = .007$, $\eta_p^2 = .42$). A main effect of block approached statistical significance ($F(3, 42) = 2.60$, $p = .07$, $\eta_p^2 = .16$), reflecting a generally downward

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[3] The analyses reported below were also conducted with subjects split into equal halves (10 early; 10 late). The pattern of results was identical in both sets of analyses.

trend in looking times across blocks in both groups and possibly due to boredom with the task toward the end of the experiment.

Paired *t*-tests revealed that the mean looking time differences between the target and nontarget was statistically significant for the early implanted group ($t(11) = 4.85$, $p = .001$, Cohen's $d = 1.41$), their normal-hearing peers ($t(11) = 2.32$, $p = .04$, Cohen's $d = .68$), and the normal-hearing peers of the late implanted group ($t(7) = 3.14$, Cohen's $d = 1.17$), but not for the late implanted group ($t(7) < 1$). Taken together, this pattern of results suggests that the early implanted children and their normal-hearing peers demonstrated word learning and did not differ from each other significantly, whereas the late implanted children did not demonstrate word learning unlike their age-matched peers who did demonstrate word learning.

Outcome measures

A secondary goal of this project was to determine the relationship between performance on the word-learning task and outcome measures of speech and language. If performance on the word-learning task predicts speech and language outcomes, then it could potentially be useful for early (i.e. within the first 3 years of life) identification of children who are at risk for poor speech and language outcomes after cochlear implantation. To determine the relationship between performance on the word-learning task and speech perception and language outcomes, correlations were calculated between looking time differences – at each block of trials and overall – and scores on the tests described above at two and four years after cochlear implant switch on. Vocabulary scores were converted into age-adjusted percentile scores, and then all of the scores were converted to z-scores to make the scales homogeneous.

NH age-matched controls—Raw scores on the MCDI administered at time of testing were compared to the mean difference in children's longest looks to the target and nontarget stimuli.[4] Partial correlations, controlling for age, revealed that performance on the word-learning task correlated significantly with word production ($r = .77$, $p < .05$) and irregular word production ($r = .46$, $p < .05$). The correlation between performance and sentence complexity approached statistical significance ($r = .41$, $p = .06$), and there was no correlation between performance and sentence length ($r = .07$). The results suggest that performance on this word-learning task is related to children's vocabulary but not necessarily with – or not as strongly with – measures of more general language skills. It should be noted that because the vocabulary and language measures for the age-matched controls were different and administered at time of testing rather than at later times, the correlational analyses conducted for the children with CIs should not be compared to those conducted for the age-matched controls.

CI children—Correlation values of word-learning performance and language outcome measures at two and four years after cochlear implantation are displayed on the left-most column of Table 3. Word-learning performance correlated significantly with the measure of vocabulary size (PPVT) at two years post-CI. The correlation between word-learning performance and vocabulary at four years post-CI approached statistical significance. The correlations with the measures of speech perception were all in the positive direction but did not approach statistical significance, possibly because the statistical analyses lacked power due to small sample sizes. For example, we had only nine subjects complete the GAEL-P and LNT. Power analyses reveal that in order to achieve a 70% probability of detecting a

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[4] Age-normed percentile scores can be computed for the MCDI up to 30 months old. However, several of our subjects were older than 30 months, so we used the raw scores and controlled for age using partial correlations.

statistically significant correlation with only nine subjects, the effect size (*r*) would need to be .69 or greater. In order to achieve a 70% probability of detecting a moderate correlation of .4 or greater, the sample size would need to be 35. Thus, these correlational analyses should be interpreted with caution.

The fact that word-learning performance correlated so strongly with vocabulary at two years post-CI but did not correlate significantly with speech perception was somewhat surprising because the various components of language are typically highly correlated with each other. Although we expected that word-learning performance may correlate most strongly with vocabulary, we thought it would correlate with speech perception as well. It is possible that for our particular group of children, scores among the various speech perception and language measures are atypically independent. To assess this possibility, we computed correlations among the outcome measures. Correlation values among the outcome measures at two years post-CI are displayed in Table 3. As can be seen, correlations among the outcome measures were all in the positive direction with some of them reaching statistical significance even with small sample sizes. These results suggest that, consistent with other findings (e.g. Blamey, Sarant, Paatsch, Barry, Bow, Wales, Wright, Psarros, Rattigan & Tooher, 2001; Geers, Brenner & Davidson, 2003), various language abilities are highly interrelated in children with cochlear implants.

Discussion

The experiment reported here used an intermodal preferential looking paradigm (IPLP) to investigate word learning in deaf children with cochlear implants in comparison with normal-hearing children. Children's performance on the word-learning task was relatively stable: No groups of children showed any significant decrements or improvements in performance across test blocks. This is somewhat surprising because the reminder trials between each test block provided children with additional opportunity to learn. It is possible that children's attention decreased over the course of the experiment, limiting any potential learning opportunity from the reminder trials. Indeed, later implanted children and their normal-hearing peers showed a decrease in looking times that approached statistical significance. This suggests that this version of the IPLP may be a block or two longer than necessary, especially for older children. Nevertheless, there was no significant effect of block on performance and so the remaining findings will be discussed based on children's overall performance.

The pattern of results suggests that deaf children's performance on a novel word-learning task 10 to 20 months after cochlear implantation depended on the nature of their early auditory experience. Children with relatively more hearing before cochlear implantation performed better on the word-learning task than children with relatively less hearing before implantation. Among the children with relatively less hearing before implantation, children implanted by 1 year of age performed similarly to their NH chronologically age-matched peers whereas children implanted between 14 and 21 months of age did not look longer to the target than to the nontarget during the test phases. These results parallel the earlier findings of Houston *et al.* (2003b) who found that CI stimulation by about 15 months of age facilitated the learning associations between dynamic objects and rhythmically congruent speech sounds.

The performance of the earlier implanted children is especially impressive when compared to 12- to 21-month-old NH infants. Only the 18- and 21-month-olds showed evidence of word learning. The hearing age of the children with CIs was a similar range (10.3 to 20.1 months), but hearing age did not contribute to the variability in performance. It is possible that children who receive their CIs by 1 year of age may have superior word-learning skills compared to their NH hearing age-matched peers at 12 months after their CIs are switched on. However, additional children would need to be tested at 12 months after CI initial stimulation before that possibility could be tested because only about half of our subjects were tested at that post-CI interval.

Previous work with CI children has shown that implantation under 1 year of age leads to better language outcomes than implantation after 1 year (Colletti *et al.*, 2011; Dettman *et al.*, 2007). The present study contributes to our understanding of why very early implantation may lead to better language outcomes. It is possible that better language outcomes with very early implantation are in part due to better word-learning skills developed within the first 2 years of life. The findings that very early implantation facilitates the development of word-learning skills contrasts with findings that differences in age at implantation during the first 2 years of life do not have significant effects on speech perception skills (Harrison *et al.*, 2005; Horn *et al.*, 2007; McConkey Robbins *et al.*, 2004). Taken together, the findings suggest that the effects of very early implantation on language outcomes may more likely be mediated by better word-learning skills than better speech perception skills. However, further work is needed before drawing that conclusion.

The present study also extends the findings of previous studies that have found age-at-implantation effects on word-learning skills. Both Wilstedt-Svensson *et al.* (2004) and Houston *et al.* (2005) found that earlier implantation led to better word-learning skills. The ages of implantation for those studies were 24-to-73 months and 10-to-55 months, respectively. Thus, they did not evaluate the possibility that differences in age at implantation within the first 2 years of life had an effect on the development of word-learning skills. Taken together, the findings are consistent with the possibility that a sensitive period for access to sound in order to develop the ability to associate spoken words to their referents begins to close during the first 2 years of life but that this sensitive period does not finish closing until at least after 5 years of age.

There are several possible reasons why having earlier access to auditory input could lead to developing better word-learning skills. One possibility is that speech perception skills may be better when access to auditory information occurs earlier in life. If children have difficulty discriminating the sound patterns of words, then word learning will be difficult even if the mechanisms for associative learning are intact. While we cannot dismiss this possibility altogether, it is unlikely for at least three reasons. First, several studies now have found no effects of age-at-implantation on speech perception skills among children implanted before 2 years of age (Harrison *et al.*, 2005; Horn *et al.*, 2007; McConkey Robbins *et al.*, 2004). Second, the words used were highly dissimilar to each other in terms of both the segmental and suprasegmental characteristics – i.e. one word was monosyllabic; the other was bisyllabic. Previous investigations have found that by six months after implantation, children with CIs can discriminate sound patterns (e.g. `hop hop hop' vs. `ahhhh') and nonsense words (`seepug' vs. `boodup') (Horn *et al.*, 2007; Houston, Pisoni, Kirk, Ying & Miyamoto, 2003a). With at least one year of CI experience, it is unlikely that any of the children would have difficulty discriminating `blick' and `modi'. Third, if their basic discrimination played a significant role in their word-learning performance, then we would expect their performance to correlate with their speech perception abilities, but it did not.

It is more likely that differences in performance were due to differences in cognitive mechanisms (e.g. sensory integration, working memory) rather than differences in perceptual discrimination. Early implanted children's earlier access to sound may have allowed them to more fully develop some basic cognitive mechanisms important for word learning, such as sensory integration. Indeed, recent work has shown that sensory integration is significantly affected by early sensory experience in both animal models (Carriere, Royal, Perrault, Morrison, Vaughan, Stein & Wallace, 2007; Wallace & Stein, 2007) and in humans (Putzar, Goerendt, Lange, Ro̧sler & Rȯ̧der, 2007). Other recent work suggests that sensory integration plays an important role in word learning (Gogate & Bahrick, 1998; Gogate, Bolzani & Betancourt, 2006). Taken together, it is possible that early auditory-visual experience allows infants to develop necessary domain-general sensory integration skills necessary for word learning; lack of early experience with one of the senses may impair sensory integration and make word learning more difficult.

Another cognitive skill that is important for language and that might be affected by early auditory experience is working memory. Phonological working memory has been linked to vocabulary acquisition, especially during the early stages of vocabulary development (Baddeley, Gathercole & Papagno, 1998; Gathercole, 2006; Gupta & MacWhinney, 1997). Investigations of working memory in children with CIs have revealed similar findings. Performance on two types of working-memory measures – the Wechsler Intelligence Scale for Children digit-span and nonword repetition tasks – have been found to correlate significantly with speech perception, speech intelligibility, vocabulary, language comprehension, and reading outcomes (Cleary, Pisoni & Kirk, 2002; Dillon, Burkholder, Cleary & Pisoni, 2004; Pisoni & Cleary, 2003). Performance on our word-learning measure, which also correlated with vocabulary, may be related to differences in working memory span. Thus far, there is no strong evidence that working memory outcomes are related to age-at-implantation. For example, Pisoni and Cleary (2003) found no correlation between working memory skills and age-at-implantation among children implanted after 1 year of age. However, we do not know of any study that has compared working memory skills in children implanted under 1 year of age versus children implanted between 1 and 2 years of age. Thus the jury is still out on how very early auditory experience affects working memory. Comparing the digit span and nonword repetition skills of children implanted under 1 year of age and those implanted later would help determine the effects of very early auditory experience on working memory.

From a clinical perspective, determining how underlying cognitive mechanisms are affected by deafness and how they affect language outcomes would be very beneficial for clinicians in developing language habilitation strategies. For example, if word-learning skills were associated with particular cognitive processes that could be assessed early in infancy, then clinicians would be better able to anticipate which infants would be more likely to have particular difficulty acquiring a vocabulary. With this information, clinicians may adjust their intervention strategy to focus more on word learning – or the skills that underlie word learning – at an early age before the children fall behind in vocabulary development.

With respect to the correlational analyses, it must be noted that the findings that word-learning performance did not correlate with speech perception but did correlate with vocabulary should be interpreted with caution because of the small sample sizes. Nevertheless, this preliminary pattern of results raises the possibility that this word-learning task has the potential to serve as a relatively early measure of language performance that may be predictive of vocabulary outcomes. Such a tool would be valuable because it could help clinicians identify children who are at risk for poor vocabulary acquisition after cochlear implantation.

The pattern of findings does not suggest a disassociation between vocabulary and speech perception. Clearly, speech perception, vocabulary, and general language development are all interrelated. In our group of subjects, correlations between vocabulary and speech perception outcome measures were in the positive direction, and we predict that with a larger sample size that some of them would likely reach statistical significance. Thus, the relatively strong correlations between word-learning performance and vocabulary suggest that performance on our task may be particularly associated with learning words (at least early on) but do not suggest that vocabulary is somehow disassociated from other aspects of language in our group of participants. It should also be noted that the nonwords used for our word-learning task, *blick* and *modi*, are highly discriminable. It is possible that if our nonwords were more confusable – as is the case for many of the words children must learn – there would have been a stronger correlation between word-learning performance and speech perception outcomes.

In summary, this study found evidence suggesting that mechanisms for word learning are affected by early auditory experience. This study involved developing a word-learning test that turns out to be predictive of later vocabulary. It is possible that this assessment procedure could be developed into a clinical tool for early identification of children who may be at high risk for delays in vocabulary and general language development.

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References

Baddeley A, Gathercole S, Papagno C. The phonological loop as a language learning device. Psychological Review. 1998; 105(1):158–173. [PubMed: 9450375]

Blamey PJ, Sarant JZ, Paatsch LE, Barry JG, Bow CP, Wales RJ, Wright M, Psarros C, Rattigan K, Tooher R. Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. Journal of Speech, Language and Hearing Research. 2001; 44(2): 264–285.

Booth AE, Waxman SR. A horse of a different color: specifying with precision infants' mapping of novel nouns and adjectives. Child Development. 2009; 80(1):15–22. [PubMed: 19236389]

Carriere BN, Royal DW, Perrault TJ, Morrison SP, Vaughan JW, Stein BE, Wallace MT. Visual deprivation alters the development of cortical multisensory integration. Journal of Neurophysiology. 2007; 98(5):2858–2867. [PubMed: 17728386]

Cleary M, Pisoni DB, Kirk KI. Working memory spans as predictors of spoken word recognition and receptive vocabulary in children with cochlear implants. Volta Review. 2002; 102:259–280. [PubMed: 21666765]

Cohen, LB.; Atkinson, DJ.; Chaput, HH. Habit X: A new program for obtaining and organizing data in infant perception and cognition studies (version 1.0) [Computer Software]. University of Texas; Austin, TX: 2004.

Colletti L. Long-term follow-up of infants (4–11 months) fitted with cochlear implants. Acta Otolaryngolica. 2009; 129(4):361–366.

Colletti L, Mandalà M, Zoccante L, Shannon RV, Colletti V. Infants versus older children fitted with cochlear implants: performance over 10 years. International Journal of Pediatric Otorhinolaryngology. 2011; 75(4):504–509. [PubMed: 21277638]

Dettman SJ, Pinder D, Briggs RJ, Dowell RC, Leigh JR. Communication development in children who receive the cochlear implant younger than 12 months: risks versus benefits. Ear and Hearing. 2007; 28(2 Suppl.):11S–18S. [PubMed: 17496638]

Dillon CM, Burkholder RA, Cleary M, Pisoni DB. Nonword repetition by children with cochlear implants: accuracy ratings from normal-hearing listeners. Journal of Speech, Language and Hearing Research. 2004; 47(5):1103–1116.

Dunn, LM.; Dunn, DM. Peabody Picture Vocabulary Test. 4th edn.. Pearson Education; Upper Saddle River, NJ: 2007.

Fenson, L.; Marchman, V.; Thal, DJ.; Dale, PS.; Reznick, S.; Bates, E. Macarthur-Bates Communicative Development Inventories. 2nd edn.. Brookes Publishing Company; Baltimore, MD: 2005.

Gathercole SE. Nonword repetition and word learning: the nature of the relationship. Applied Psycholinguistics. 2006; 27(4):513–543.

Geers A, Brenner C, Davidson L. Factors associated with development of speech perception skills in children implanted by age five. Ear and Hearing. 2003; 24(1 Suppl.):24S–35S. [PubMed: 12612478]

Geers AE, Nicholas JG, Moog JS. Estimating the influence of cochlear implantation on language development in children. Audiological Medicine. 2007; 5:262–273. [PubMed: 21243079]

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

Gogate LJ, Bahrick L. Intersensory redundancy facilitates learning of arbitrary relations between vowel sounds and objects in seven-month-old infants. Journal of Experimental Child Psychology. 1998; 69(2):133–149. [PubMed: 9637756]

Gogate LJ, Bolzani LH, Betancourt EA. Attention to maternal multimodal naming by 6- to 8-month-old infants and learning of word–object relations. Infancy. 2006; 9(3):259–288.

Golinkoff R, Hirsh-Pasek K, Cauley K, Gordon L. The eyes have it: lexical and syntactic comprehension in a new paradigm. Journal of Child Language. 1987; 14:23–45. [PubMed: 3558524]

Gupta P, MacWhinney B. Vocabulary acquisition and verbal short-term memory: computational and neural bases. Brain and Language. 1997; 59:267–333. [PubMed: 9299067]

Harrison RV, Gordon KA, Mount RJ. Is there a critical period for cochlear implantation in congenitally deaf children? Analyses of hearing and speech perception performance after implantation. Developmental Psychobiology. 2005; 46:252–261. [PubMed: 15772969]

Hirsh-Pasek, K.; Golinkoff, R. The intermodal preferential looking paradigm reveals emergent language comprehension. In: McDaniel, D.; Mckee, C.; Cairns, H., editors. Methods for assessing children's syntax. MIT Press; Cambridge, MA: 1996. p. 105-124.

Hollich G. Combining techniques to reveal emergent effects in infants' segmentation, word learning, and grammar. Language & Speech. 2006; 49(1):3–19. [PubMed: 16922060]

Horn DL, Houston DM, Miyamoto RT. Speech discrimination skills in deaf infants before and after cochlear implantation. Audiological Medicine. 2007; 5:232–241.

Houston, DM. Infant speech perception. In: Seewald, R.; Thapre, AM., editors. Comprehensive handbook of pediatric audiology. Plural Publishing, Inc.; San Diego, CA: 2011. p. 47-62.

Houston DM, Carter AK, Pisoni DB, Kirk KI, Ying EA. Word learning in children following cochlear implantation. Volta Review. 2005; 105(1):41–72. [PubMed: 21528108]

Houston DM, Miyamoto RT. Effects of early auditory experience on word learning and speech perception in deaf children with cochlear implants: implications for sensitive periods of language development. Otology & Neurotology. 2010; 31:1248–1253. [PubMed: 20818292]

Houston DM, Pisoni DB, Kirk KI, Ying EA, Miyamoto RT. Speech perception skills of deaf infants following cochlear implantation: a first report. International Journal of Pediatric Otorhinolaryngology. 2003a; 67:479–495. [PubMed: 12697350]

Houston DM, Ying E, Pisoni DB, Kirk KI. Development of pre word-learning skills in infants with cochlear implants. Volta Review. 2003b; 103(4):303–326. (monograph). [PubMed: 21643556]

Jerger, S.; Jerger, J. Pediatric speech intelligibility test. Auditec; St Louis, MO: 1984.

Kirk KI, Miyamoto RT, Ying EA, Perdew AE, Zuganelis H. Cochlear implantation in young children: effects of age at implantation and communication mode. Volta Review. 2002; 102:127–144. (monograph).

Kirk KI, Pisoni DB, Osberger MJ. Lexical effects on spoken word recognition by pediatric cochlear implant users. Ear and Hearing. 1995; 16(5):470–481. [PubMed: 8654902]

Knudsen EI. Sensitive periods in the development of the brain and behavior. Journal of Cognitive Neuroscience. 2004; 16(8):1412–1425. [PubMed: 15509387]

McConkey Robbins A, Koch DB, Osberger MJ, Zimmerman-Phillips S, Kishon-Rabin L. Effect of age at cochlear implantation on auditory skill development in infants and toddlers. Archives of Otolaryngology: Head & Neck Surgery. 2004; 130:570–574. [PubMed: 15148178]

Mervis CB, Bertrand J. Acquisition of the novel name–nameless category (N2C) principle. Child Development. 1994; 65:1646–1662. [PubMed: 7859547]

Miyamoto RT, Hay-McCutcheon MJ, Kirk KI, Houston DM, Bergeson-Dana T. Language skills of profoundly deaf children who received cochlear implants under 12 months of age: a preliminary study. Acta Otolaryngologica. 2008; 128(4):373–377.

Moog, JS.; Kozak, VJ.; Geers, AE. Grammatical analysis of elicited language – pre-sentence level. Central Institute for the Deaf; St Louis, MO: 1983.

Nicholas JG, Geers AE. Effects of early auditory experience on the spoken language of deaf children at 3 years of age. Ear and Hearing. 2006; 27(3):286–288. [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.

Nott P, Cowan R, Brown PM, Wigglesworth G. Early language development in children with profound hearing loss fitted with a device at a young age: Part I – the time period taken to acquire first words and first word combinations. Ear and Hearing. 2009; 30(5):526–540. [PubMed: 19739282]

Pisoni DB, Cleary M. Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. Ear and Hearing. 2003; 24(Suppl.):106S–120S. [PubMed: 12612485]

Putzar L, Goerendt I, Lange K, Rösler F, Röder B. Early visual deprivation impairs multisensory interactions in humans. Nature Neuroscience. 2007; 10(10):1243–1245.

Schafer G, Plunkett K. Rapid word learning by fifteen-month-olds under tightly controlled conditions. Child Development. 1998; 69:309–320. [PubMed: 9586207]

Spelke ES. Perceiving bimodally specified events in infancy. Developmental Psychology. 1979; 15:626–636.

Svirsky MA, Teoh SW, Neuburger H. Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. Audiology & Neuro-Otology. 2004; 9:224–233. [PubMed: 15205550]

Tajudeen BA, Waltzman SB, Jethanamest D, Svirsky MA. Speech perception in congenitally deaf children receiving cochlear implants in the first year of life. Otology & Neurotology. 2010; 31(8): 1254–1260. [PubMed: 20814343]

Tomblin JB, Barker BA, Hubbs S. Developmental constraints on language development in children with cochlear implants. International Journal of Audiology. 2007; 46(9):512–23. [PubMed: 17828667]

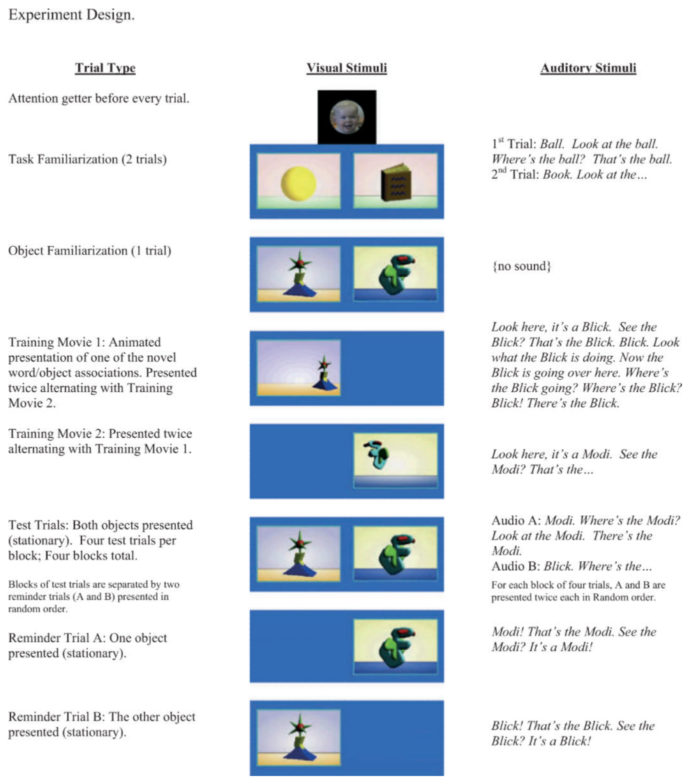
Wallace MT, Stein BE. Early experience determines how the senses will interact. Journal of Neurophysiology. 2007; 97(1):921–926. [PubMed: 16914616]

Waxman SR, Booth AE. Seeing pink elephants: fourteen-month-olds' interpretations of novel nouns and adjectives. Cognitive Psychology. 2001; 43(3):217–242. [PubMed: 11689022]

Willstedt-Svensson U, Löfqvist A, Almqvist B, Sahlén 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(9):506–515. [PubMed: 15726841]

Zimmerman, IL.; Steiner, VG.; Pond, RE. Preschool language scale. 4th edn.. The Psychological Corporation; San Antonio, TX: 2002.

Zwolan TA, Ashbaugh CM, Alarfaj A, Kileny PR, Arts HA, El-Kashlan HK, Telian SA. Pediatric cochlear implant patient performance as a function of age at implantation. Otology & Neurotology. 2004; 25(2):112–120. [PubMed: 15021769]



Experiment Design.

Trial Type	Visual Stimuli	Auditory Stimuli
Attention getter before every trial.		
Task Familiarization (2 trials)		1st Trial: *Ball. Look at the ball. Where's the ball? That's the ball.* 2nd Trial: *Book. Look at the…*
Object Familiarization (1 trial)		{no sound}
Training Movie 1: Animated presentation of one of the novel word/object associations. Presented twice alternating with Training Movie 2.		*Look here, it's a Blick. See the Blick? That's the Blick. Blick. Look what the Blick is doing. Now the Blick is going over here. Where's the Blick going? Where's the Blick? Blick! There's the Blick.*
Training Movie 2: Presented twice alternating with Training Movie 1.		*Look here, it's a Modi. See the Modi? That's the…*
Test Trials: Both objects presented (stationary). Four test trials per block; Four blocks total. Blocks of test trials are separated by two reminder trials (A and B) presented in random order.		Audio A: *Modi. Where's the Modi? Look at the Modi. There's the Modi.* Audio B: *Blick. Where's the…* For each block of four trials, A and B are presented twice each in Random order.
Reminder Trial A: One object presented (stationary).		*Modi! That's the Modi. See the Modi? It's a Modi!*
Reminder Trial B: The other object presented (stationary).		*Blick! That's the Blick. See the Blick? It's a Blick!*

Figure 1.

Schematic of the word learning experiment. Before each trial, children were presented with a video of an infant laughing to orient their attention to the monitor. The first two trials familiarized children to the task by presenting them with images of familiar objects – a ball and a book – and auditory stimuli encouraging them to look at one and then the other (see right-hand column). Next, children were familiarized with the two novel objects without sound. Children were then presented with 24-second training movies in which the novel objects were labeled with novel words. After training, children's learning of the novel-word/novel-object pairs was tested over four blocks of four test trials. Between each block of test trials, children were presented with two reminder trials in which each novel-word/novel-object pair was reintroduced. All trials other than the training trials were 7 seconds.

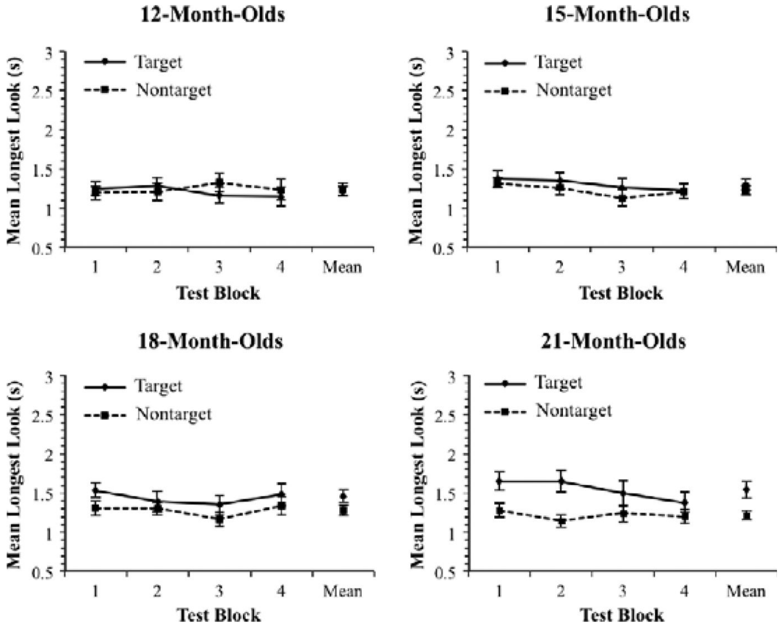


Figure 2.

Normal-hearing 12-, 15-, 18-, and 21-month-olds' mean longest looks to the target and nontarget computed over each block of test trials and over all of the blocks combined. Error bars represent standard errors.

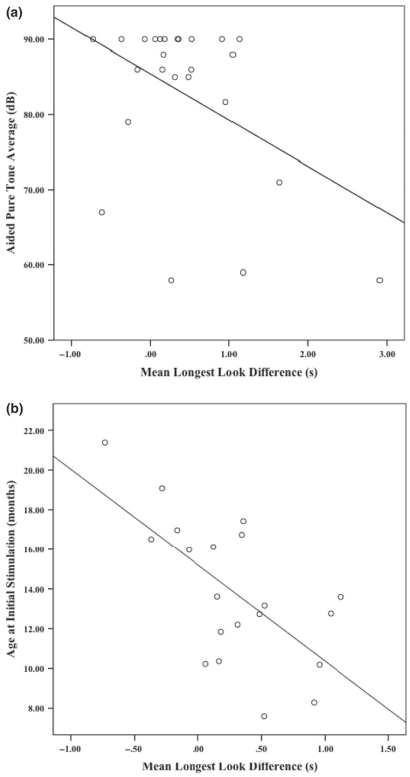


Figure 3.

(a) Scatterplot and regression line of the first regression analyses, plotting mean difference in longest look to the target versus the nontarget by aided pure-tone average before cochlear implantation. (b) Scatterplot and regression line of the second regression analyses, plotting mean difference in longest look by age at which the subjects' cochlear implants were initially simulated.

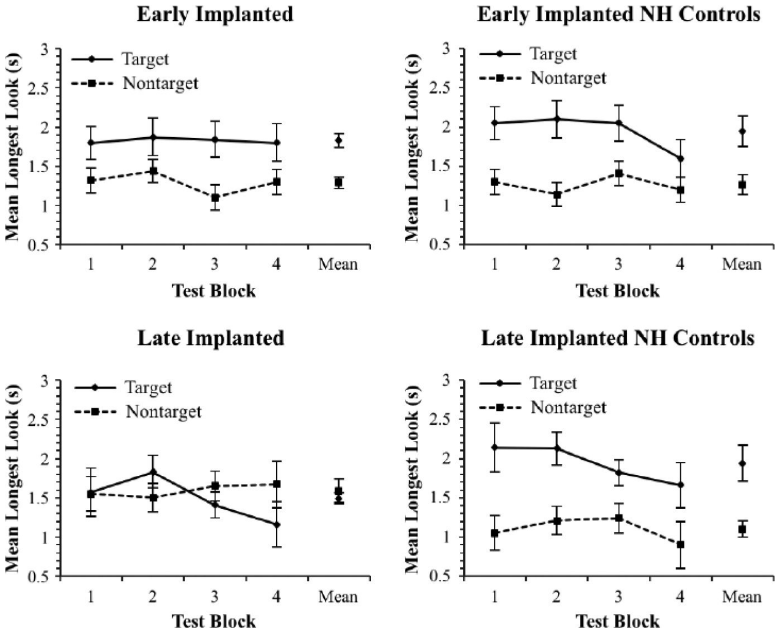


Figure 4.

Mean longest looks to the target and nontarget computed over each block of test trials and over all of the blocks combined for early and late implanted deaf children and normal-hearing age-matched controls. Error bars represent standard errors.

Table 1

Demographic information for CI children and NH age-matched controls

												Outcome measures obtained		NH controls		
Sub #	Sex	Etiology	PTA (dB)	Age HL ID	Age at HA	Age at CI	Uni or bi	HA in other ear?	Age at test	H-Age at test	Com Mode	2 years post-CI	4 years post-CI	Age at test	Sex	MCDI
01	M	Unknown	86	1.8	2.0	7.6	Uni	No	25.8	18.2	OC	G, PSI, PPVT	LNT, PPVT	25.1	F	Yes
02	F	Genetic	90	0.0	1.0	8.3	Uni	No	26.5	18.2	TC	G, PSI, PPVT	LNT, PPVT	26.8	M	Yes
03	M	Genetic	82	0.0	0.7	10.2	Bi	N/A	21.7	11.5	OC			21.1	M	Yes
04	M	Unknown	90	1.0	4.0	10.2	Uni	No	23.6	13.4	OC	PPVT		24.5	M	Yes
05	M	Unknown	88	0.0	2.0	10.4	Uni	No	22.3	11.9	OC		LNT, PPVT	22.4	F	Yes
06	M	Genetic	90	0.0	3.0	11.8	Uni	No	29.8	18.0	OC	G, PSI, PPVT	LNT, PPVT	30.0	M	Yes
07	F	Unknown	85	0.0	6.1	12.2	Uni	No	30.5	18.3	OC	G, PSI, PPVT	LNT, PPVT	31.2	F	Yes
08	M	Unknown	85	0.0	3.0	12.7	Uni	No	23.5	10.8	TC	G, PSI, PPVT	LNT, PPVT	23.2	M	Yes
09	M	Genetic	88	0.0	6.0	12.8	Bi	N/A	29.4	16.6	OC	PPVT		29.2	F	Yes
10	F	Unknown	67	1.0	2.5	12.8	Bi	N/A	32.9	20.1	OC			32.9	M	Yes
11	F	Unknown	90	0.0	4.0	13.2	Uni	No	25.2	12.0	TC			24.1	F	Yes
12	M	Unknown	90	0.0	3.0	13.6	Uni	No	31.5	17.9	OC	PPVT		30.8	F	Yes
13	M	Unknown	86	0.0	4.1	13.6	Bi	N/A	23.9	10.3	TC			23.9	M	Yes
14	M	Genetic	71	0.0	3.0	13.9	Uni	Yes	30.9	17.0	OC			31.2	F	Yes
15	F	Unknown	90	0.0	5.0	16.0	Uni	No	29.1	13.1	TC	PPVT		29.4	M	Yes
16	M	Unknown	90	0.0	6.0	16.1	Uni	No	28.6	12.5	OC	G, PSI, PPVT	LNT, PPVT	27.9	F	Yes
17	M	BOR	90	3.0	4.0	16.5	Uni	No	30.4	13.9	OC	G, PSI, PPVT	PPVT	29.1	M	Yes
18	F	Mondini	90	4.0	9.0	16.7	Uni	No	29.0	12.3	OC			28.3	F	Yes
19	M	Unknown	59	0.0	4.1	16.9	Uni	Yes	28.4	11.5	TC			28.4	F	Yes
20	M	Unknown	86	0.0	5.0	17.0	Uni	No	34.2	17.2	TC	G, PPVT	PPVT	34.2	F	Yes
21	M	Unknown	58	0.0	8.1	17.3	Uni	No	28.7	11.4	OC			28.6	M	Yes
22	F	Unknown	90	9.5	10.0	17.4	Uni	No	35.7	18.3	OC	G, PSI, PPVT	LNT, PPVT	36.2	M	Yes
23	F	Unknown	79	9.0	14.0	19.1	Uni	No	37.0	17.9	OC	G, PSI, PPVT	LNT, PPVT	37.1	F	Yes
24	F	Genetic	90	6.0	12.0	21.4	Uni	No	40.1	18.7	OC			39.6	F	No
25	M	Unknown	58	11.0	16.1	21.5	Uni	Yes	33.2	11.7	OC	PPVT		33.1	F	No

Note: All ages are reported in months. BOR = branchiootorenal syndrome; Mondini = Mondini type cochlear malformation; PTA = Pure-tone average before implantation with hearing aids; Underlined numbers = PTA scores that fall more than 1 standard deviation outside the mean; HL = hearing loss; HA = hearing aid; Uni or Bi = unilateral or bilateral implantation at time of test; H-Age = Hearing Age; Com Mode = The type of communication program the child was following in speech-language therapy; OC = oral-only communication program; TC = total communication program, involving spoken English and Signed-Exact English; G = Grammatical Analysis of Elicited Language – Pre-Sentence Level; PSI = Pediatric Speech Intelligibility Test; PPVT = Peabody Picture Vocabulary Test; LNT = Lexical Neighborhood Test; MCDI = MacArthur-Bates Communicative Developmental Index.

Table 2

Predictors of performance on word-learning task

	B	*SE B*	β
All subjects (1)			
Constant	4.15	1.59	
Age at CI	−0.04	0.04	−.17
Aided PTA	−0.03	0.02	−.46 *
Hearing age	−0.04	0.05	−.14
Excluding better hearing subjects (2)			
Constant	1.26	2.58	
Age at CI	−0.09	0.03	−.66 **
Aided PTA	0.00	0.03	.01
Hearing age	0.01	0.03	.05

Note: R^2 = .23 for (1) and .43 for (2).

* $p < .05$;

** $p < .01$.

Table 3

Correlation table for word-learning performance and speech and language outcomes

			2 years post-CI			4 years post-CI	
	Measure	**Word learning**	**PPVT**	**GAELP**	**PSI**	**PPVT**	**LNT**
	Word learning	–					
2 years post-CI	PPVT	**.61* (15)**	–				
	GAELP	.29 (10)	.18 (10)	–			
	PSI	.33 (9)	.39 (9)	.80* (9)			
4 years post-CI	PPVT	.53^{+} (11)	.73* (10)	.35 (10)	.43 (9)	–	
	LNT	.36 (9)	.18 (8)	.60 (8)	.77* (8)	.62 (9)	–

Note: Word Learning = The word-learning task; PPVT = Peabody Picture Vocabulary Test; GAELP = Grammatical Analysis of Elicited Language – Pre-Sentence Level; PSI = Pediatric Speech Intelligibility test; LNT = Lexical Neighborhood Test.

$^{+}$ $p < .1$;

* $p < .05$;

** $p < .01$;

*** $p < .001$.