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Word-Learning Skills of Profoundly Deaf Children Following Cochlear Implantation: A First Report[1]

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Abstract. In recent years, cochlear implant (CI) technology has advanced substantially. Deaf children can now be provided with an electrical signal that codes sound input to facilitate spoken language learning. However, a great deal of variability has been observed in the audiological outcome measures obtained from pediatric CI recipients. Deaf children who have received CIs often lag substantially behind their normal hearing (NH) peers on a wide range of speech and language measures. Many factors contribute to this variability in performance, including age of implantation, amount of speech therapy, cognitive information processing factors, such as working memory span, as well as numerous linguistic factors. An important fundamental linguistic skill that plays a critical role in later language development is novel word learning, the ability to map the sound patterns of spoken words onto their physical referents. This paper describes an experimental procedure that was developed to investigate the word-learning skills of deaf children who have received CIs and reports some preliminary findings obtained from 2- to 5-year-old CI users. Each child was presented with a set of Beanie Babies™ and a set of associated labels for their names using interactive play scenarios. After training, the children's receptive and expressive knowledge of the new names was tested both immediately after exposure and then following a 2-hour delay. Pediatric CI users performed more poorly than age-matched NH children on both receptive and expressive word-learning tests. Both groups of children showed retention of the new names from immediate to delayed testing conditions for words that were previously known by the children. However, additional analyses of the deaf children's response revealed that they performed more poorly after a delay on both receptive and expressive tests when the words were unfamiliar to them before coming into the laboratory. Our findings on novel word learning suggest that although pediatric CI users may have impaired and/or delayed phonological processing skills their long-term memory for familiar spoken words that they are able to perceive and encode appears to be similar to NH children. Implications of these findings for receptive and expressive language development in this clinical population are discussed.

Introduction

Cochlear implants (CIs) provide profoundly deaf individuals with access to sound and offer the possibility of learning spoken language by exposure to an electrical signal that codes the auditory input. For postlingually deafened adults, CIs are a way of restoring hearing. For profoundly deaf children, CIs represent a new sensory modality that provides them with an opportunity to hear speech in their environment and learn spoken language. Several investigations have reported that cochlear implantation improves deaf children's language comprehension and production skills (Eisenberg, Martinez, Sennaroglu, & Osberger, 2000; Kirk, Osberger, Robbins, Riley, & Todd, 1995; Osberger, Robbins, Todd, & Riley, 1994; Tobey, Geers, & Brenner, 1994; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Zwolan et al., 1997). However, these investigations also have revealed that deaf children with CIs do not perform as well as their normal-hearing (NH) peers on a wide range of speech and language measures and that there are enormous individual differences in language skills after implantation (Pisoni, Cleary, Geers, & Tobey, 2000). In one study, Svirsky, Robbins, Kirk, Pisoni, and Miyamoto (2000) followed deaf children's language development before and at regular 6-month intervals after cochlear implantation for three years. They found that while deaf children performed better on language measures after cochlear implantation than would be predicted using conventional hearing aids, there was considerable individual variability among the deaf children, and their language skills continued to lag behind their NH peers. Other studies have reported that the vocabulary levels of deaf and hard-of-hearing children lag behind those of NH children (Lederberg & Spencer, 2001).

Several factors may contribute to the generally poorer performance on spoken language measures of deaf children who use CIs compared to their NH peers. The electrical signal transmitted by a CI is highly degraded compared to a normal acoustic signal. Thus, the initial quality of the speech signal that a deaf child hears is much poorer than the speech signals received by NH children. Also, congenitally deaf children who receive CIs have had some period of auditory deprivation caused by deafness, so they are exposed to less auditory input during critical stages of speech perception and language development than NH children.

Normal-hearing children also develop spoken language at much faster rates than deaf children who receive CIs. However, there are enormous individual differences in language performance among deaf children who use CIs. Some of these children acquire language quite well while others continue to be delayed relative to their NH peers (Pisoni et al., 2000). The primary demographic factors that have been associated with differences in audiological outcome measures among these children are duration of deafness, length of CI use, and age at implantation (Kirk, 2000). Several other factors also affect performance. These include the type and amount of therapy, etiology of hearing loss, number of electrodes inserted into the cochlea (Loizou, Dorman, & Tu, 1999), as well as the child's early linguistic environment and socioeconomic factors (Hart & Risley, 1995).

Another contributing source of variability is related to differences in underlying cognitive processing skills. Recently, Pisoni, Svirsky, Kirk, and Miyamoto (1997) reported that CI children's performance on speech perception, speech production, and language tests was highly correlated (see also Pisoni et al., 2000). The authors suggested that the common variance observed in these tasks might be attributed to some underlying skills, including the phonological encoding, storage, and retrieval of spoken words. It is very likely that auditory deprivation experienced by the congenitally deaf during early childhood may lead to delays and/or disorders in these kinds of cognitive processing skills. Moreover, loss of these skills may be responsible for the poorer linguistic performance observed in pediatric CI users relative to NH children.

A number of basic cognitive and linguistic skills may become delayed and/or disordered in this clinical population and affect their spoken language development. One of the building blocks of language development is the ability to learn words. Word learning requires listeners to encode the sound patterns of words into memory and associate these sound patterns with objects, actions, and concepts in the world. The sound-meaning associations that are learned must be maintained in memory and remain accessible for future use. Thus, phonological processing skills and memory are crucial for children's word learning and ultimately their language development. A period of auditory deprivation during development may have effects on how auditory information is encoded and maintained in memory even after interventions such as cochlear implantation. Thus, congenitally deaf children who have virtually no access to speech sounds until intervention may have particular difficulty with linguistic skills that involve perceiving and interpreting speech sounds and learning new words. The aim of this project was to develop procedures to investigate the early word-learning skills of deaf children following cochlear implantation and explore differences in performance between deaf children and NH children.

Normal-hearing children begin producing words at approximately 12 months of age. By 18 months, most infants can produce over 50 words and begin learning several words each day (Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994). Most research on word learning focuses on how children learn to correctly associate the sound patterns of words with their referents (e.g., Clark, 1973, 1983;

Markman, 1991; Nelson, 1988). Recently, some work has explored young children's ability to encode the sound patterns of novel words. Jusczyk and colleagues have shown that by 8 months of age, infants can encode the sound patterns of words and store them in memory (Houston & Jusczyk, submitted; Jusczyk & Aslin, 1995; Jusczyk & Hohne, 1997). The ability to encode phonological information into memory enables children to form lexical representations and eventually build a lexicon of the words in the target language.

Phonological encoding has been shown to play an important role in vocabulary development. Gathercole and Baddeley (1989, 1990) have found a strong relationship between phonological working memory span and vocabulary size in NH children. They suggest that proficient word learners are able to maintain words in working memory by internal verbal rehearsal procedures that facilitate the encoding of words into long-term memory and development of lexical representations. Repetition is also important for encoding words into memory. Huttenlocher, Haight, Bryk, Seltzer, and Lyons (1991) found a significant correlation between how often parents use words and children's acquisition of those words, suggesting that frequency of exposure affects how quickly children learn words (see also Hart & Risley, 1995). Taken together, these findings suggest that encoding phonological representations of words and maintaining them in memory are important underlying skills that affect subsequent novel word-learning and language development.

To build a vocabulary, children not only have to encode the phonological representations of spoken words but they must also map phonological representations onto meanings. In the late 1970s, Susan Carey and her colleagues suggested that learning the meaning of words involves two stages (Carey, 1978; Carey & Bartlett, 1978). The first stage, which they called "fast mapping," involves the initial encoding of the sound pattern of the words and some basic understanding of the meaning. The second stage involves developing a fuller, more detailed understanding of words by hearing them in several different contexts so that hypotheses about their meaning can be tested. In a well-known study, Carey and Bartlett (1978) used a novel word in a casual undirected way to NH preschool children (e.g., "…bring me the *chromium* one. Not the red one…") in the presence of an olive and a red colored tray. They found that after only a single presentation of the novel word, the children began forming basic hypotheses about the meaning of the word. For example, when asked later by the experimenter, some of the children indicated that the word chromium was a color.

In another study of fast mapping, Heibeck and Markman (1987) reported that children as young as two years of age showed fast mapping of shape and texture terms as well as color terms. More recently, Markson and Bloom (1997) tested the ability of NH 3- and 4-year-olds to learn novel names for objects and remember them over a delay. Children participated in several tasks with the experimenter where they played with 10 objects and were casually taught a novel name (e.g., "koba") for one of the novel objects. Although they were not asked to repeat the name or even acknowledge that they had heard it. The children were then tested in one of three delay conditions (immediate, 1 week, 1 month) in which they were presented with the original 10 objects and asked to identify the object called "koba." Markson and Bloom found that children performed well above chance in selecting the correct object in all delay conditions. There was also no main effect of delay, suggesting that when NH children learn novel words, lexical representations persist in long-term memory. While a complete understanding of novel words may involve a complex and lengthy process, the basic process appears to begin with an initial "fast mapping" stage of word learning that is immediate and obligatory in establishing a solid foundation for later lexical development.

The fast mapping stage of early word learning requires children to encode the phonological form of spoken words very rapidly on-the-fly without repetition or practice. Children who have difficulty with speech perception and phonological encoding may show difficulties in learning novel words. There may be a high incidence of poor phonological encoding skills among CI users for several reasons. First, as noted earlier, the auditory information provided by a CI is impoverished and highly degraded when compared to normal hearing. The cochlea of a NH adult has approximately 13,500 outer hair cells and 3500 inner hair cells that respond to different acoustic frequency ranges and contribute to stimulating the spiral ganglion cells. In contrast, cochlear implants bypass these hair cells and other cochlear mechanisms to stimulate the spiral ganglion cells with only a few dozen electrodes. Not surprisingly, the frequency resolution of sound provided by a cochlear implant is not as high as what a healthy cochlea normally provides. As a consequence, it is possible that the initial sensory input from a cochlear implant may be a limiting factor in encoding the sound pattern of spoken words.

Another reason why pediatric CI users may not develop word-learning skills as well as NH children is that the period of early sensory deprivation prior to implantation may lead to a delayed and/or disordered course of language development. There is some evidence to suggest that any degree of hearing loss may cause problems in phonological processing and word learning. For example, Gilbertson and Kamhi (1995) assessed hearing-impaired children's ability to encode phonological information and learn novel words while wearing their hearing aids. They found that hearing-impaired children's unaided level of hearing loss (ranging from mild to moderate) did not correlate significantly with word-learning abilities. However, the ability to encode phonological information did correlate with word-learning proficiency. Gilbertson and Kamhi concluded that even a mild hearing loss was a significant risk factor for language impairments related to the development of phonological processing skills. One possible reason the investigators did not find that unaided degree of hearing loss was an important factor in word-learning could be that the children's hearing may have been improved enough to learn words from incomplete or partial phonological representations when using hearing aids. It is possible that pediatric CI users who have more substantial profound hearing losses may display similar or even more severe long-term phonological processing deficits because, prior to CI intervention, they experienced long periods of auditory deprivation that could not be ameliorated by conventional hearing aids.

Little is currently known about the word-learning skills of prelingually deaf children who have a severe to profound hearing impairment. Recent work by Lederberg and colleagues has begun to explore the vocabulary development of deaf and hard-of-hearing children who use both spoken and sign language. In one study, Lederberg, Prezbindowski, and Spencer (2000) tested deaf and hard-of-hearing children's ability to learn novel object nouns in several contexts in which they were given either implicit or explicit reference to the novel objects with which they were to associate the novel words. They also assessed the children's vocabulary using the MacArthur Communication Development Inventory (CDI). The CDIs are parent report forms that are used to assess individual infants' and young children's language and communication skills (Fenson et al., 1994). The forms consist of lists of gestures, words, and sentences, and parents are asked to indicate whether or not their child understands and/or produces any of the items.

Lederberg and colleagues found that deaf and hard-of-hearing children who have larger vocabularies in their preferred mode of communication (i.e., spoken language vs. sign) were able to learn words using their preferred mode of communication with fewer exposures and with less explicit teaching than children with relatively smaller vocabularies. They concluded that there is a relationship between vocabulary size and word encoding skills: a larger vocabulary appears to be related to learning words by implicit reference. Lederberg et al.'s study is an important step in understanding the word-learning skills and vocabulary development in deaf children who use manual and/or oral communication. However, there are no studies in the literature that focus specifically on the spoken word-learning skills of profoundly deaf children who received CIs and use oral-aural communication.

The acquisition of word-learning skills by deaf and hard-of-hearing children with CIs might take on a very different developmental course depending on whether the children use manual or oral-aural communication methods. Deaf and hard-of-hearing children may be able to learn words in the manual communication mode as readily as NH children do in the oral communication mode. However, deaf CI users' ability to encode spoken words aurally and become oral communicators may be quite different because they receive degraded and highly impoverished acoustic representations of speech that encode partial information about the phonological structure of the sound patterns of the language. Deaf and hard-of-hearing children have poorer phonological processing skills than NH children (Briscoe, Bishop, & Norbury, 2001; Gilbertson & Kamhi, 1995) and poorer phonological processing skills have been shown to be related to poorer performance on oral word-learning tasks (Gilbertson & Kamhi, 1995). Assessing the early word-learning skills of deaf children who are oral-aural communicators and who use cochlear implants is an important step for understanding the linguistic processes that play a role in deaf children's phonological processing skills and learning spoken language after received a CI. The time course of deaf children's language development may be delayed and/or disordered compared to NH children. Moreover, it is possible that phonological processing disorders may contribute to the enormous individual variability observed/reported among pediatric CI users on a wide range of speech and language outcome measures.

To date, we know of no other investigations of the word-learning skills of deaf children following cochlear implantation. This particular group of children is an unusual and unique clinical population because until the time they receive their CIs, their linguistic, cognitive, and perceptual skills have developed in the absence of sound and input from the auditory sensory modality. Once these children receive their CIs, they are able to gain access to auditory information and begin to acquire knowledge of speech and properties of spoken language. The initial goal of this study was to develop a set of experimental procedures that could be used to determine whether CIs could enable deaf children to develop the skills necessary to learn spoken words rapidly after only a few exposures. We were interested in exploring how quickly deaf children with cochlear implants can map sound patterns onto referents in a laboratory setting. We were also interested in determining the relationship between measures of early word learning and other audiological outcome measures such as spoken word recognition, speech intelligibility and receptive and expressive language abilities. Another goal of this study was to assess pediatric CI users' long-term memory for spoken words. While NH children may display little difficulty learning novel words and recalling them after a short period of time, deaf children with CIs may not have developed the same memory skills. It is possible that early auditory deprivation may not only affect children's immediate phonological processing skills, but also their ability to encode, verbally rehearse and store the sound patterns of spoken words in long-term memory.

This report describes the results of a preliminary study that assessed the abilities of preschool-aged NH and hearing-impaired children with CIs to learn words quickly after a brief exposure period. Specifically, we developed a name-learning task using a set of Beanie Baby™ stuffed animals. The first part of the project involved selecting new names for the Beanie Baby™ animals that would be taught to the children. This was done by eliciting names from adult participants that corresponded to perceptual attributes of the animals. In the second part of the project, we conducted a novel word-learning experiment with these materials. All children were taught the names for a set of Beanie Babies™, one-at-a-time, and were then tested receptively and expressively for their knowledge of the names both immediately after learning and then following a 2-hour delay. We report data from a group of 24 deaf children who use CIs and a group of 24 age-matched NH children who served as a comparison group.

Construction of Stimulus Materials

The stimulus materials used in the experiment reported below consisted of a set of sixteen Beanie Baby™ stuffed animals. Each Beanie Baby™ comes with a name assigned by the manufacturer (Ty Corporation®). We did not use these names because some children might already know them while others might not and because some of the names were related to physical attributes of the stuffed animals while others were not. We obtained a set of new names from a group of adult participants that corresponded to salient physical attributes of the Beanie Babies™. This was done to facilitate learning an association between the attribute names and the referent Beanie Babies™. Because many of the Beanie Babies™ have several perceptual features that could be considered perceptually salient, a pilot experiment was conducted to determine which characteristics of each Beanie Baby™ were most distinctive. The goal of this initial study was to select a label for each Beanie Baby™ that could then be used in the subsequent word-learning experiment with children.

Method

Participants. The participants were 37 undergraduates at Indiana University who reported no prior history of speech or hearing disorders. Thirty-five of the subjects were native English speakers. All subjects were recruited from the Indiana University community and all received partial credit towards an Introductory Psychology class requirement for their participation. The mean age of the participants was 19.9 years (SD = 1.3).

Materials. Sixteen Beanie Baby™ stuffed animals were used as stimuli. These Beanie Babies™ were selected from a larger set of Beanie Babies™ on the basis of whether they had distinguishing perceptual attributes that could be easily named, such as a long tail, horns, or a bright color.

Procedure. Subjects were tested in three groups in a small experimental classroom. They were given written instructions in which they were told that the experimenter would hold up each of the sixteen Beanie Babies™ individually, and they would be asked to invent new names for the Beanie Babies™, as if they were teaching the names to a young child. Subjects were asked to re-name the original Beanie Babies™ using names that described some physical attributes of the Beanie Babies™. Subjects were instructed to provide up to three new names for each animal, and to use one-word names only. Subjects were provided with response sheets on which to write the new names. The Beanie Babies™ were presented individually, one at a time, in a random order to the three groups.

Results

For each Beanie Baby™, the responses were recorded and tallied to calculate the frequency of the names generated. A new Beanie Baby™ attribute name was chosen from the response distributions based on two criteria: (1) that the name was the most frequent response among students, and (2) that it reflected a true physical attribute of the animal. For example, the name “Red” was the most frequent response and was also an appropriate name for the red bull because it refers to the color of the bull. In contrast, a non-attribute name, “Teddy,” was the most frequent response for the brown bear, but was inappropriate for our purposes because it did not represent a physical attribute. The second most common response was “Fuzzy”, which we used since it describes a perceptual attribute of the bear. The new attribute name was the most frequent response for seven of the Beanie Babies™ (“Blue,” “Red,” “Stripes,” “Pink,” “Spots,” “Ears,” “Tail”), the second most frequent response for four of the animals (“Wings,” “Fuzzy,” “Legs,” “Cottontail”), the third most frequent response for five of the animals (“Horns,” “Gray,” “Teeth,” “Bushy”), and the fourth most frequent response for “White.” Table 1 provides a list of each of the original Beanie Baby™ stuffed animal names and descriptions, the new attribute names derived from this procedure, along with the percentage of subjects who used the new attribute name.

Original Beanie Baby™ name	"New" attribute name	Frequency of new name response (%)	Original Beanie Baby™ name	"New" attribute name	Frequency of new name response (%)
Crunch the Shark	*Teeth*	11.8	*Dotty* the Dalmatian	*Spots*	46.6
Rocket the Bird	*Blue*	36.6	*Halo* the Angel Bear	*White*	6.1
Batty the Bat	*Wings*	13.7	*Spunky* the Cocker Spaniel	*Ears*	14.9
Kuku the Bird	*Pink*	29.6	*Nuts* the Squirrel	*Bushy*	11.1
Snort the Bull	*Red*	32.4	*Nibbly* the Bunny	*Cottontail*	14.1
Goatee the Goat	*Horns*	8.2	*Spinner* the Spider	*Legs*	14.9
Buster the Bear	*Fuzzy*	9.8	*Prance* the Tabby Cat	*Stripes*	25.6
Tiptoe the Mouse	*Tail*	18.5	*Spike* the Rhino	*Gray*	7.8

Table 1. Original names of Beanie Babies™, new given attribute names, and the frequency with which each new name was generated.

Novel Word-learning Experiment

In order to establish a starting point for future research, we designed a task that we thought would optimize the children's performance in learning the novel names of Beanie Babies™. To study early word-learning skills in these children, we asked the children to learn novel names of Beanie Babies™ that corresponded to salient attributes, although in most cases each attribute name fit more than one Beanie Baby™. Two groups of children were studied. One group was coded as "young" and included children who were 2 and 3 years of age, and one group was coded as "old" and included children who were 4 and 5 years of age. The young children were taught the names of eight Beanie Babies™ (in two sets of four) while the old children were taught the names of sixteen (in two sets of eight). After training, children were tested for their receptive knowledge of the names using a forced-choice recognition task. They were also tested for their expressive knowledge of the names, using a cued-recall task. Finally, their long-term memory of the names was subsequently assessed in a second session by re-testing them at least two hours later on both receptive and expressive tasks. We predicted that if CI children have impaired phonological processing and word-learning skills, they should not perform as well as NH children on the receptive and expressive tasks. Furthermore, if pediatric CI users' ability to maintain spoken words in memory is impaired, they might also show a greater effect of delay on performance than NH children. Finally, we predicted that if word-learning skills are an important source of variance in linguistic performance, then deaf children who use CIs should display a wider range of individual variability in their performance on these tasks than NH children.

Method

Participants. *CI Children:* Twenty-four prelingually deaf children who use cochlear implants were recruited from five locations: Indiana University School of Medicine, Indianapolis, Indiana; St. Joseph's Institute for the Deaf, St. Louis, Missouri; St. Joseph's Institute for the Deaf, Kansas City, Kansas; Child's Voice, Chicago, Illinois; and Ohio Valley Oral School, Cincinnati, Ohio. Three criteria were used for inclusion in this study. First, at the time of testing the deaf children had to be between the ages of 2;0 and 5;11. Second, the children had to be oral-only communicators (i.e., not use any form of manual communication). Third, the children had to have had at least one year of experience with their CI. The twelve children who fell into the young group were two and three years of age (mean = 37.7, and the remaining twelve children who fell into the old group were four and five years of age.[3] Table 2 displays the children's age at testing, age at which they received their CI, and the length of CI use.

NH Children: Twenty-four age-matched normal-hearing controls were recruited from the Bloomington, Indiana area and the Center for Young Children daycare center on the Indiana-University-Purdue-University-Indianapolis campus. Twelve children were assigned to the young NH group and twelve were assigned to old NH children group.[4] Ages are displayed in Table 2.

Group	Age at Testing		Age at Implantation		Length of CI use	
	Mean	Range	Mean	Range	Mean	Range
Young CI	37.7	28 – 46	20.6	10 – 34	17.1	12 – 26
Old CI	59.5	49 – 68	37.3	25 – 55	22.3	12 – 37
Young NH	28.0	28 – 46				
Old NH	58.4	49 – 64				

Table 2. Chronological age at testing, age at initial stimulation of cochlear implant, and length of cochlear implant use for the young and the old groups of pediatric cochlear implant users. Ages are given in months.

Materials. The stimulus materials consisted of 16 Beanie Babies™ that were assigned names by normal-hearing college students (see Stimuli Selection above). Each name corresponded to a salient physical attribute (e.g., "Red" is a red bull). The Beanie Babies™ were grouped into sets of four as shown in Table 3. The Beanie Babies™ were selected so that most of the attribute names could describe at least two Beanie Babies™ in the group. For example, "Wings," "Pink," and "Blue" all have wings. This was done so that the children would not be able to completely rely on a unique perceptual feature to identify the attributes in the tasks. For example, when they were asked to identify "Wings," three of the four Beanie Babies™ had wings, so they had to learn to map a specific feature to a specific Beanie Baby™.

Set	Beanie Baby™ Attribute Name	Description
A	Teeth	Shark
	Blue	Blue jay
	Wings	Bat
	Pink	Cockatoo
B	Red	Bull
	Horns	Goat
	Fuzzy	Brown bear
	Tail	Rat
C	Spots	Dalmatian
	White	White bear with halo
	Ears	Cocker spaniel
	Bushy	Squirrel
D	Cotton tail	Rabbit
	Legs	Spider
	Stripes	Cat with stripes
	Gray	Rhino

Table 3. Word set stimuli.

[3] The CI children's demographics were as follows: 1 Hispanic or Latino (male), 1 Asian/Pacific Islander (male), 2 Black/African American (1 male, 1 female), 20 White/Non Hispanic (14 male, 6 female).
[4] The NH children's demographics were as follows: 1 Hispanic or Latino (female), 1 Asian/Pacific Islander (male), 20 White/Non Hispanic (9 male, 11 female), 2 Other/Unknown (2 male).

Procedure. Children were explicitly taught a set of names for four or eight Beanie Babies™ using play scenarios (Training Phase 1). They were then given receptive (forced-choice) and expressive (cued-recall) tests for that set (Testing Phase 1). Children were then taught another set of Beanie Babies™ (Training Phase 2) and subsequently given the same tests with the second set (Testing Phase 2). Finally, after at least a two-hour delay[5], the children were given the same receptive and expressive tests over again, first with the Beanie Babies™ presented in Training Phase 1 and then with the set presented in Training Phase 2.[6]

Training Phase 1. *Young Children.* Each child was exposed to a set of four Beanie Babies™. Before the experiment, the exact order of Beanie Baby™ presentation was randomized and recorded on a form that was then followed during the experiment for each child. One experimenter (Experimenter 1) interacted with the child while a second experimenter (Experimenter 2) assisted the first experimenter in following the correct presentation order. The second experimenter also recorded the children's responses and tallied the number of times Experimenter 1 produced the name of each Beanie Baby™.

Experimenter 1 presented each Beanie Baby™, one at a time, to the child in a play scenario. Several toy props were used to create different play scenarios with each Beanie Baby™ in order to keep the task interesting. During each play interaction with a Beanie Baby™, Experimenter 1 used the name of the Beanie Baby™ exactly eight times. During the play scenario, Experimenter 1 tried to elicit three productions of the name from the child by encouraging the child to repeat the name after the Experimenter. Experimenter 2 recorded how many times the child produced each name. Positive feedback was given when the child produced the correct names. See Appendix for a sample scenario.

Older Children. The training phase was the same with the older children as with the younger children, except that eight Beanie Babies™ (two sets from Table 3) were taught during each phase instead of only four.

Testing Phase 1. The Testing Phase used two procedures to assess learning – a receptive test, which employed a forced-choice identification task, and an expressive test, which used a cued-recall task. Both tasks were given immediately after the training phase was completed Children were not given feedback about whether or not they gave correct responses during either of the test phases.

Receptive Test. For the forced-choice receptive test, all of the Beanie Babies™ (four or eight) were placed in a row in front of a child but they were initially hidden from view with a piece of cardboard. Then a toy bus or truck was brought out and placed in front of the child. Experimenter 1 then asked the child to "please put {*one of Beanie Babies™*} into the truck {*or bus*}." The child was encouraged to select one of the Beanie Babies™ in front of him/her but was not given any feedback as to whether the response was the correct choice. For example, the experimenter said "thank you," "good job," or clapped when the child made a selection, regardless of whether or not the correct Beanie Baby™ was selected. The Beanie Baby™ was then placed back in the row and the next trial was initiated. Each Beanie Baby™ was requested exactly once during each test phase.

Expressive Test. For the expressive test, Experimenter 1 played a "knock knock" game with the child. One Beanie Baby™ was placed behind a toy doorway. Experimenter 1 and/or the child said,

[5] For sixteen of the normal hearing children, the Long-term Memory test was conducted within 30 minutes after Testing Phase 2 (or approximately 40 to 60 minutes after the beginning of Training Phase 1). However, on all four of the tests, their performance did not differ significantly from those who had the full 2-hour delay. Thus, we included their data in our analyses.

[6] Two of the young CI children and one of the old NH children were not able to participate in the long-term memory portion of the experiment due to scheduling conflicts. In the analyses, missing cells were filled by computing the means of related data (i.e. scores on the same test by participants from the same subject group).

"knock knock," the door would open, and Experimenter 1 would ask the child, "Who's there?" The child was asked to name the Beanie Baby™, up to three times, until the child gave a response. Experimenter 2 recorded the child's response. This procedure was repeated for each Beanie Baby™ (4 for young children, 8 for old children).

Training Phase 2. This phase was the same as Training Phase 1 except that the second set of four or eight Beanie Babies™ was presented to the child using the same procedures.

Testing Phase 2. This phase was the same as Testing Phase 1 except that the second set of Beanie Babies™ was used.

Long-Term Memory Test. About two hours after the completion of Testing Phase 2, the child was tested a second time, in order to assess long-term retention of the Beanie Baby™ names that were presented during training. For the long-term memory test, Testing Phase 1 and Testing Phase 2 were repeated again without any retraining or feedback.

Parent Questionnaire. The names we selected for the Beanie Babies™ were real English words that the children may have known prior to participating in the experiment. It is possible that prior knowledge of the words may play a role in children's ability to associate them with the Beanie Babies™ during the course of the experiment. Names that are entries in the lexicon and are already known may be easier to learn in this procedure because their phonological representations are already stored in memory and so do not require learning a new sound pattern. To evaluate this possibility, we wanted to know which test words each child had prior knowledge of and how familiar the child was with each word. The parents of each child were given a questionnaire about their child's knowledge and familiarity with the words used in the experiment. For each word (e.g., "Red"), the parents were asked to indicate whether "you think your child knows what the word means when he or she hears it spoken (yes or no)". They were also asked to rate, on a scale of 1 to 5, "How familiar your child is with the spoken versions of each word (1: not familiar, 5: very familiar). In other words, to what extent do you feel he or she would recognize each word as something he or she has heard before?" The scores obtained from the parent questionnaires were used to compare children's knowledge and familiarity with the words to their performance with those words on the receptive and expressive tests.

Results

Immediate Tests. The mean proportion of correct responses (out of 8 trials for the young groups and out of 16 trials for the old groups) on the receptive and expressive tests was calculated separately for each child and then averaged for each group. A summary of the results is displayed in the four panels in Figure 1. The left-hand panels display the young children's mean proportion correct response while the right-hand panels display the old children's mean proportion correct response. The upper panels display the scores for the CI children; the lower panels display the scores for the NH children. Within each panel, the mean scores of the receptive and expressive tests are displayed separately. The dark bars in each panel represent the mean proportion correct response on the immediate test; the light bars represent the mean proportion correct response on the delayed test.

The proportion correct response scores were subjected to a four-way repeated-measures ANOVA with Group (CI, NH) and Age (young, old) as between-subjects factors and with Test (receptive, expressive) and Delay (immediate, delay) as within-subjects factors. The ANOVA revealed a significant main effect of Group (F (1, 44) = 132.61, p < .001), reflecting higher overall scores for the NH children than the CI children. There was also a significant main effect of Test (F (1, 44) = 82.67, p < .001). Overall, the scores were higher on the receptive tests than the expressive tests. CI children demonstrated a larger difference in performance on the receptive versus expressive tests than the NH children. This interaction was significant (F (1, 44) = 7.44, p < .01). Similarly, young children displayed a larger effect of test condition than old children (F (1, 44) = 10.15, p < .01). The Group X Age cross-over interaction approached statistical significance (F (1, 44) = 3.23, p = .08). Young CI children performed better than old CI children, whereas old NH children performed better than young NH children. None of the other main effects or interactions was significant (F values < 1).

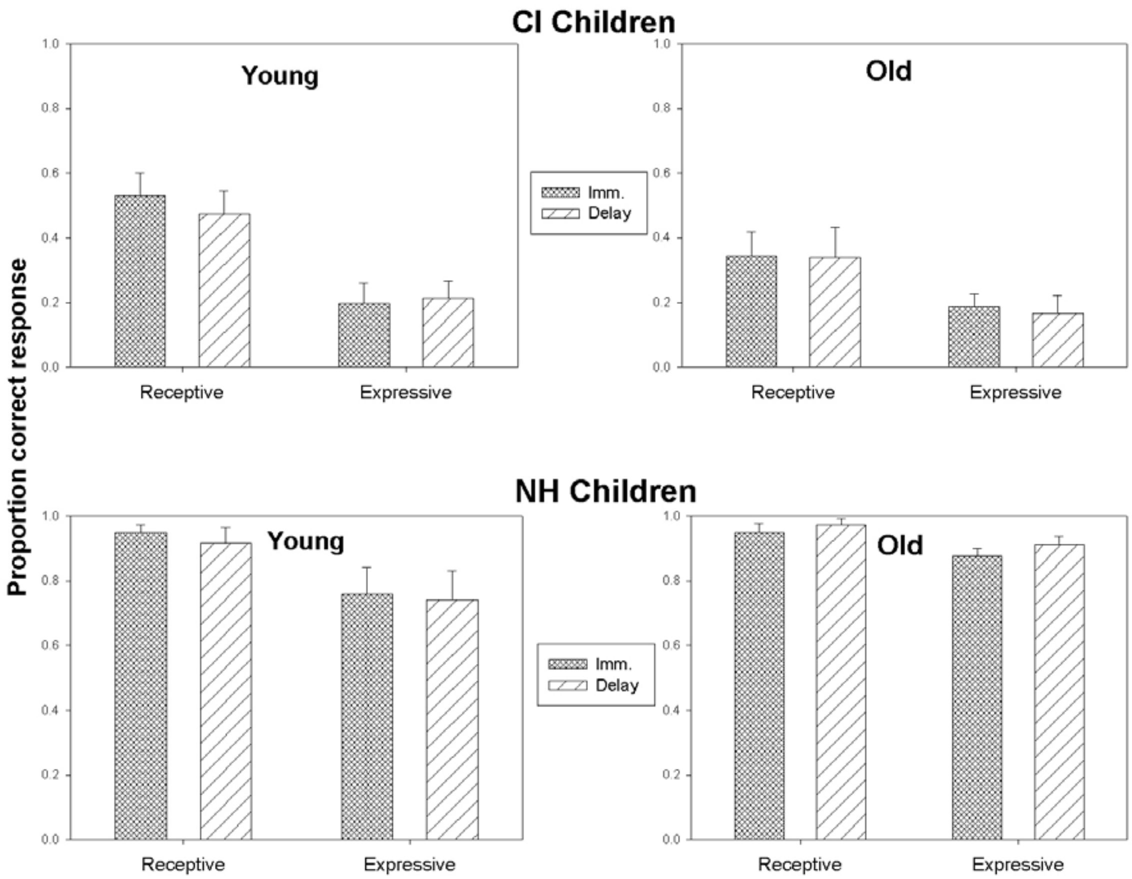

Figure 1. Mean proportion correct for all words for CI and NH children.

Word Familiarity and Word Learning. We selected the words for this experiment so that they would correspond to salient perceptual attributes of the Beanie Babies™ in order to facilitate rapid word learning in the deaf children who use CIs. We expected that these children would only be able to use this information if they had some prior knowledge and familiarity of the words in the first place. To test the role of prior word knowledge on the deaf children's ability to learn the names we correlated their word familiarity scores obtained from the parent questionnaires to their proportion correct responses on the word-learning task. For each word, we calculated an average familiarity score by taking the mean of the familiarity ratings on the parent questionnaires. Then, for each word, we calculated a proportion correct score by taking the mean proportion correct for that word separately for each test condition. Both average familiarity and proportion correct scores were calculated separately for the young and the old CI groups.

Figure 2 displays scatter plots showing the proportion correct for each word in the receptive and expressive tests plotted against the word's average familiarity score. The left-hand panels display the plots for the immediate testing conditions; the right-hand panels display the plots for the delayed testing condition. Scatter plots for the young CI group are shown in the upper panels while those for the old CI group are shown in the lower panels. Correlations are summarized in Table 4.

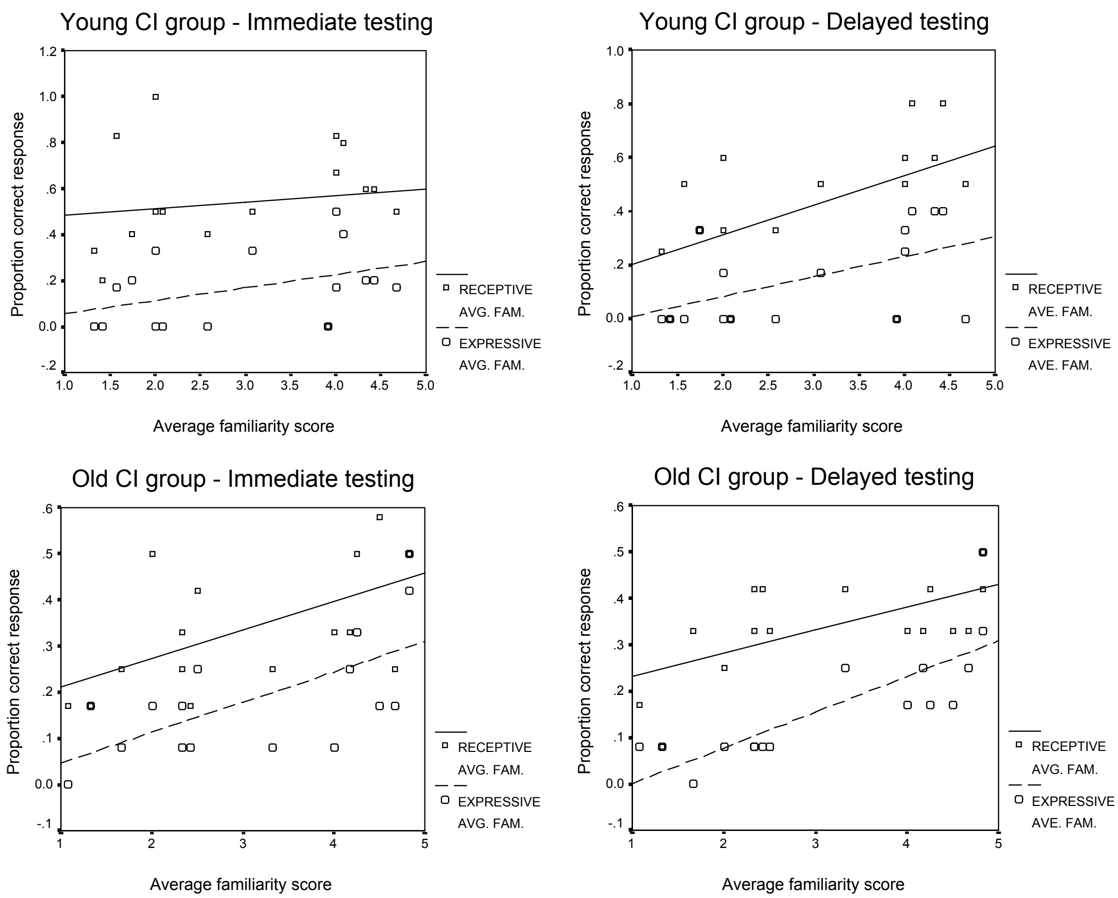

Figure 2. Scatter plots of word analyses for CI children, separated by age group and testing condition.

Score	1	2	3	4	5
CI Young Group					
1. Average familiarity rating	–	.13	.53*	.43	.53*
2. Receptive immediate mean score		–	.76**	.46	.33
3. Receptive delay mean score			–	.62*	.66**
4. Expressive immediate mean score				–	.71**
5. Expressive delay mean score					–
CI Old Group					
1. Average familiarity rating	–	.60*	.63**	.64**	.81**
2. Receptive immediate mean score		–	.41	.66**	.43
3. Receptive delay mean score			–	.44	.47
4. Expressive immediate mean score				–	.69**
5. Expressive delay mean score					–

Table 4. Item correlations between average familiarity ratings of stimulus name and proportion correct response for receptive and expressive tests.

For the Young CI group, average familiarity was positively correlated with both the receptive (r = +.53, $p < .05$) and expressive tests (r = +.53, $p < .05$) in the delayed condition. Although the correlations were in the same direction for the receptive (r = +.13, p = .62) and expressive (r = +.43, p = .10) tests in the immediate conditions, they were not statistically significant. For the old CI group, average familiarity was correlated significantly with both tests in the immediate testing condition (receptive: r = +.60, $p <$ .05; expressive: r = +.64, $p < .01$) and for both tests in the delayed testing condition (receptive: r = +.63, $p < .01$; expressive: r = +.81, $p < .01$). These correlations suggest that prior word knowledge produced effects on word learning in this task.

Analyses with Word Knowledge as a Factor. The item correlations of word familiarity with word-learning test scores showed a relation between CI children's prior familiarity with the stimulus words and their performance on the word-learning tests, especially in the delay conditions. To analyze these findings further, we recalculated the CI children's scores, separating their performance on words they knew prior to testing from words they did not know before they began the study, based on information in the parent report questionnaire.[7]

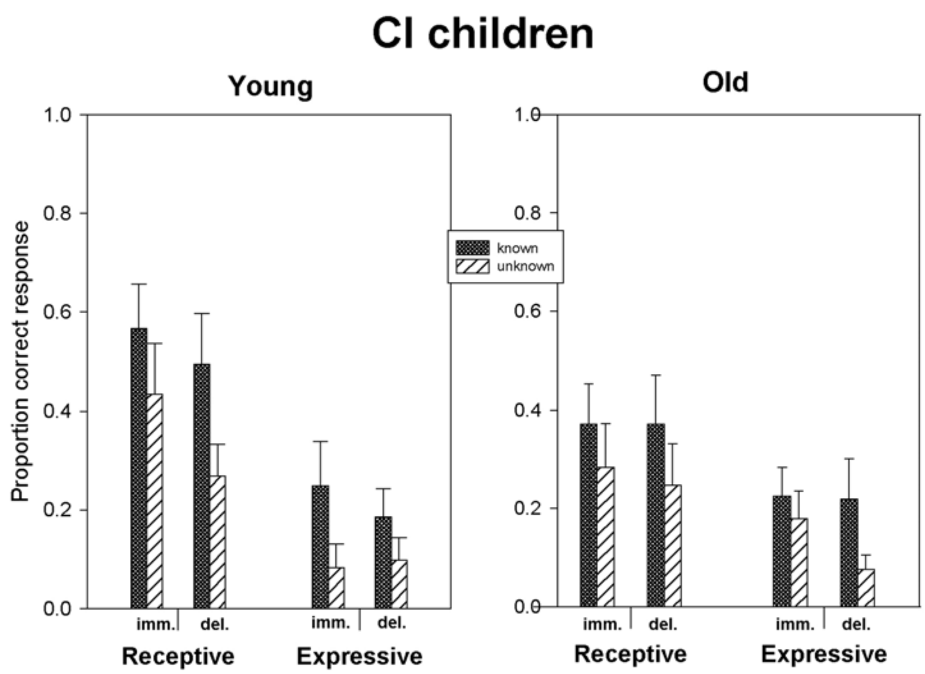

Figure 3. Mean proportion correct for CI children separated by whether they had prior knowledge of the words.

Figure 3 displays the young CI children's performance in the left-hand panel and the old CI children's performance in the right-hand panel. As in Figure 1, the scores within each panel are separated by test type and delay condition. However, in this figure the data are further separated by scores for words that were known (dark bars) versus scores for words that were unknown (light bars). The proportion correct responses for known and unknown words were then subjected to a four-way repeated-measures

[7] We separated the scores based on word knowledge rather than word familiarity because familiarity would have been a factor with five levels, and some of the levels would have been empty for many of the children. Word knowledge scores were highly correlated with word familiarity scores (r = .97, $p < .001$).

ANOVA with Age as the between-subjects factor and Test, Delay, and Word Knowledge (known, unknown) as within-subjects factors. As in the first analysis, performance on the receptive tests was higher than on the expressive tests (F (1,22) = 56.00, p < .001). We also observed a significant Test (receptive vs. expressive) X Age (young vs. old) interaction (F (1,22) = 6.21, p < .05), reflecting a larger difference in performance across tests for the younger children than for the older children. Unlike the first analysis, however, we found a significant main effect of Delay (F (1,22) = 5.41, p < .05), reflecting higher scores on the immediate than the delayed testing condition. Finally, the CI children performed significantly better on known than on unknown words (F (1,22) = 12.54, p < .01). No other main effects or interactions were statistically significant.

Re-analysis with Known Words Only. In the previous analysis, we found a significant main effect of word knowledge on learning with the CI children. Higher scores were observed for known words than unknown words. According to the parent questionnaires, the NH children knew an average of 95% of the words whereas the CI children knew only 60% of the words. It is possible that the difference in performance observed earlier between the CI and NH children was based on prior word knowledge rather than differences in word learning and encoding skills acquired during the course of the present experiment. To assess this possibility, we reanalyzed the proportion correct scores of the CI and NH children using only the scores for the known words.

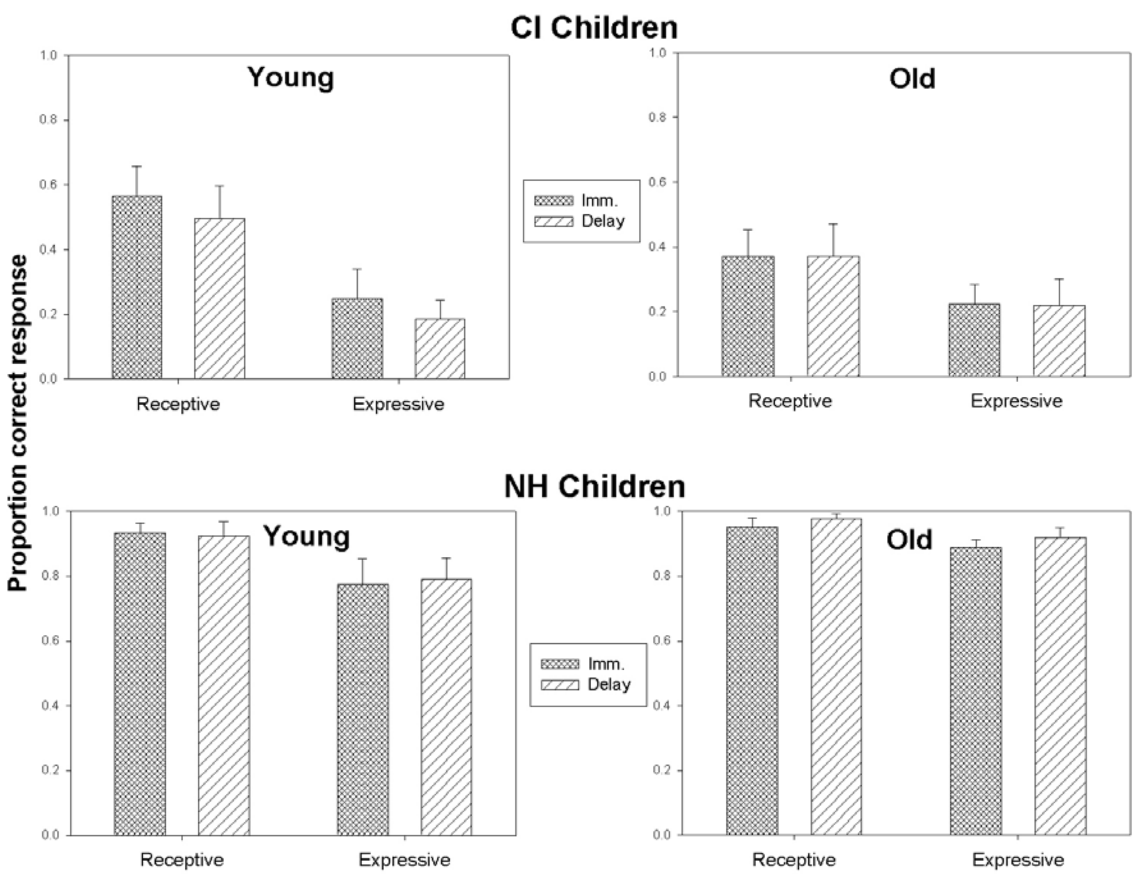

Figure 4. Mean proportion correct of known words only for CI and NH children.

Figure 4 displays the same test conditions as Figure 1 but now only data from the known words is shown. The scores for the known words were subjected to a four-way repeated-measures ANOVA with Group and Age as between-subjects factors and with Test and Delay as within-subjects factors. Overall, the pattern of results was quite similar to the original analyses. In the first analysis, the NH children out-performed the CI children (F (1,44) = 92.17, p < .001) and both groups of children performed significantly better on the receptive than the expressive tests (F (1,44) = 68.66, p < .001). Also, inspection of the interactions revealed that the differences between the test conditions (receptive vs. expressive) were significantly greater for the CI children than the NH children (F (1,44) = 10.129, p < .01) and greater for young children than old children (F (1,44) = 9.54, p < .01). As in the earlier analysis, the Group X Age cross-over interaction for known words did not approach statistical significance, although it was in the same direction (F (1,44) = 1.80, p = .19), reflecting better performance by the young CI and old NH groups. All other main effects and interactions were not significant (F values < 2).

Correlations with Demographics. In order to assess the relationship of performance on the word-learning tests with demographic measures, we correlated the mean proportion correct responses with chronological age, age at implantation, and length of CI use. A summary of these correlations is shown in Table 5. As can be seen in this table, significant negative correlations were observed between age at implantation and scores on the immediate receptive tests, suggesting that children who received cochlear implants at younger ages, and hence had a shorter periods of auditory deprivation, tended to perform better on this receptive test of word learning than children who received their implants at older ages. The correlations between age at implantation and the other tests were in the same direction but were not statistically significant. None of the other correlations were significant.

	1	2	3	4	5	6	7
1. Chronological age	–	.86**	.46*	-.30	-.30	-.02	-.13
2. Age at implantation		–	-.07	-.42*	-.32	-.17	-.22
3. Length of CI use			–	.15	-.03	.26	.14
4. Receptive immediate mean score				–	.75**	.57**	.76**
5. Receptive delay mean score					–	.61**	.79**
6. Expressive immediate mean score						–	.64**
7. Expressive delay mean score							–

Table 5. Correlations between mean proportion correct responses and chronological age, age of implantation, and length of CI use for all children with CIs.

General Discussion

The aim of this study was to develop a procedure that could be used to investigate the word-learning skills of profoundly deaf children who have received CIs. We are interested in understanding the cognitive and linguistic factors that contribute to differences in audiological outcome and language development that have been found between deaf children who use CIs and NH children and the high degree of variability in the linguistic skills of profoundly deaf children following cochlear implantation. A word-learning task using Beanie Babies™ was developed and implemented to study the receptive and expressive skills of deaf children. This study represents the first investigation of novel “word” learning skills in this clinical population and provides an important initial step in understanding the fundamental mechanisms and building blocks of language development after a period of auditory deprivation due to deafness and the restoration of hearing following cochlear implantation.

All of the children who were tested in the procedure were able to complete the task. Only four of the deaf children and none of the NH children performed at chance levels on all of the testing conditions. Thus, the training and testing procedures we developed appeared to be at a level of difficulty appropriate for testing these two populations of children. We also observed a wide range of performance across children, especially among the deaf children. For the immediate receptive test, the range of scores varied from 6% to 100% correct for the deaf children and from 69% to 100% for the NH children. Similar variation was found for the delayed receptive test. For the expressive tests, the ranges for the deaf children were from 0% to 63% for both immediate and delay conditions. We also found a wide range of scores on the expressive tests for the NH children as well (25%-100% immediate; 0%-100% delay). However, the lower ends of the ranges were due to two of the NH children who did not give many responses at all, presumably because of shyness. All other NH children performed at or above 50%. The median scores for the immediate and delay expressive tests were 88% and 92.5%, respectively.

In addition to individual variability on the word-learning measures among deaf children who use CIs, we also found significant differences in performance between the two groups of children. NH children performed significantly better than the deaf children on both receptive and expressive tests of word learning at both immediate test and under delayed conditions. These findings are not surprising and are consistent with the results of other investigations which have found that while CIs improve spoken language skills of deaf children, these implanted children generally do not display linguistic skills that are comparable to NH children (Svirsky et al., 2000). The present findings suggest that hearing impairment not only affects speech perception but it also affects cognitive and linguistic skills that are important for novel word learning. There are several possible ways in which early auditory deprivation and hearing impairment can affect the development of word-learning skills, including impairments in phonological processing and phonological working memory. These possibilities will be considered later.

In addition to finding differences in word-learning performance between deaf and hearing children, we also observed a main effect for the type of test. Both NH children and deaf children performed significantly better on the receptive word-learning test than on the expressive test. The pattern of results was the same for both groups under the delay conditions. The difference in performance between receptive and expressive tasks is not surprising because there are fundamental differences in the information processing demands of these two kinds of tasks. In both procedures, performance depends on the child's ability to rapidly encode the spoken names into memory and then learn to associate them to the correct Beanie Baby™ referent. Expressive tests are generally more difficult because they require the child to form mental representations of the names that are robust enough to access from memory without any explicit retrieval cues or context. In receptive tests, on the other hand, phonological and lexical representations of the correct names can be accessed more easily from memory because the experimenter provides retrieval cues and context at the time of the test. The child only has to recall the association between the given name and the corresponding Beanie Baby™ and does not have to construct a phonological representation "on-the-fly" without cues or context.

The deaf children also showed larger differences in performance between receptive and expressive tests than the NH children. It is possible that some of the representations of the names that deaf children formed were not robust or well specified and were thus difficult to access from the mental lexicon although they could be recognized in the receptive tests. If this account is correct, then we might expect that words that were identified successfully on the expressive tests would also tend to be recognized on the receptive tests. To assess this possibility, we calculated the proportion of correctly identified words in the expressive tests that were also correctly recognized in the receptive tests. For the younger children, 91% of items that were responded to correctly during the expressive tests were also responded to correctly during the receptive tests. For the older children, the proportion was 76%. These results are consistent with the proposal that the deaf children were able to form robust representations for some of the names and these names were responded to correctly in both the receptive and expressive tests.

The extent to which deaf children are able to form robust representations that are easily retrievable from memory may be crucial for their ability to learn novel words. To assess the robustness of the children's lexical representations, we also measured retention of the names several hours after the immediate tests. The initial ANOVA on all of the stimuli using both known and unknown words combined revealed no effect of delay, suggesting that the word representations that were formed during the acquisition phase were robust enough to persist in long-term memory. However, a re-analysis based on only the words that children knew prior to the experiment also failed to reveal any effects of delay. Other analyses demonstrated that 69% of responses that were correct in immediate testing were also correct in delay testing for the younger group. For the older group of children, the proportion was 73%. These findings suggest that once a name was successfully learned and encoded in memory during the training phase, the particular name was retained even after a delay of several hours.

Our initial analyses were calculated using either all of the test words or only a subset of the words that the children had previous experience with before the experiment. In both of these cases, we found no effects of delay on performance. However, two interesting patterns emerged when we examined the performance of the deaf children on words they knew before the experiment compared to unfamiliar words that were previously unknown to them. First, we found that the CI children performed significantly better on known than unknown words. Second, we found that the deaf children performed significantly worse on the delayed tests than on the immediate tests with the words that were previously unknown. In contrast, they did not perform significantly worse across delay conditions for the words that were previously known. These results suggest that deaf children had more difficulty encoding novel sound patterns than familiar sound patterns in these name-learning tasks. NH children did not display the same pattern of results.

Given the absence of an effect of delay for both groups of children on familiar words, it is possible that the deaf children may not have demonstrated any novel word learning at all. Instead, they may have simply selected the animals based on their prior knowledge of the word attributes without consideration as to how the objects were named during the training. While the deaf children may have used their prior knowledge of the attribute names to help them in narrowing down their response choices, there are at least two reasons why we think that learning during the training phase played an important role in the children's responses. First, the deaf children did not perform near ceiling for any of the familiar words and their performance on unfamiliar words was not at floor. Thus, word knowledge per se was not sufficient for generating a correct response, and not knowing a word did not always result in failure to learn the attribute names of the Beanie Baby™ stuffed animals. Second, if the deaf children relied solely on their prior knowledge of attribute names to select the Beanie Babies™ during the tests, we would expect them to perform much better with the animals that had unique attribute names than the animals whose attribute names could have been applied to at least one other Beanie Baby™ in the test set. However, this did not occur. The mean familiarity score for the deaf children on the uniquely named words was 3.09 and the mean proportion correct across the tests for those words was 0.29. Similarly, the mean familiarity score for the deaf children on the confusable names was 3.03 and the mean proportion correct for those was also 0.29. Clearly, the uniqueness of the attribute names did not appear to play a role in these children's ability to select the correct animals from a set or to recall the names of the animals. Thus, while prior word knowledge and familiarity did facilitate CI children's ability to match the names to the correct Beanie Babies™, they apparently did not rely solely on their prior knowledge of the attribute names to select the Beanie Babies™ during the tests. In other words, novel word learning took place during the training phase of the experiment.

Several other factors may have also contributed to the variability in word-learning performance among the deaf children and to the overall differences in performance between the two groups of children. It is well known that hearing loss and early auditory deprivation lead to impairment in the ability to process and encode phonological information. Deaf children may have had more difficulty in the word-learning tasks than the NH children simply because they were not able to encode and store the phonological information and form representations of the sound patterns of the words. However, this possibility does not seem likely because all of the children were able to repeat the words back to the experimenter, in some form or another immediately after presentation, during both the study and acquisition phases of the procedure. Also, we observed a larger difference between receptive and expressive tests for the deaf children than the NH children. Performance of the deaf children on the receptive tests was much better than on the expressive tests. These results suggest that the deaf children were able to form coarse phonological representations of the sound patterns of the names, but these representations may not be detailed and robust enough to access them and use them in an expressive recall task. Furthermore, the deaf children demonstrated an effect of delay with the unknown words, which suggests that they formed lexical representations, but that these representations were not robust enough to be retained in long-term memory over a period of a few hours.

Another factor that may be responsible for differences in performance between the two groups of children is working memory capacity. According to Baddeley's (1986) model, one of the components of working memory is the phonological loop that maintains phonological representations for a short period of time. The phonological representations of words enter the phonological loop through the "inner ear" or the "inner voice" and are maintained there by repeating the words to the inner ear either by repetition from an external source or by the inner voice rehearsing the words. Investigations of working memory in NH children have found that children who have larger working memory capacities also tend to have better word-learning skills and larger vocabularies (e.g., Gathercole & Baddeley, 1989; Gupta & MacWhinney, 1997). Baddeley and his colleagues have suggested that working memory serves as an important mechanism for word learning – the phonological loop is a temporary store for novel sound pattern of words until the words can be encoded and stored into long-term memory (Baddeley, Gathercole, & Papagno, 1998).

In a recent paper, Pisoni and Cleary (in press) summarized a series of recent experiments that investigated the working memory and word recognition skills of deaf children following cochlear implantation. They measured 8- and 9-year-old deaf CI users' immediate memory spans using the WISC-III digit span task and assessed their word recognition skills using both open and closed-set word recognition tests. Pisoni and Cleary found strong positive correlations between performance on the forward digit span task, which is assumed to measure the capacity of verbal short-term memory and performance on several word recognition tasks. They also tested a group of age-matched NH children on the forward digit span task and found that these children performed better on the forward digit span task than the deaf children with CIs. Pisoni and Cleary's findings suggest that the word recognition skills of deaf children who use CIs are closely associated with the phonological coding of the sound patterns of words and working memory, which appears to be "atypical" and somewhat delayed in deaf children after cochlear implantation compared to age-matched NH children.

The present investigation did not directly assess the children's working memory capacity or immediate memory span. However, several of our findings are consistent with the hypothesis that the deaf children have atypical verbal working memory capacity relative to the NH children. For example, the poorer performance after a period of delay with unknown words suggests that the deaf children had more difficulty encoding novel unfamiliar words into long-term memory, which suggests impairment in the operation of their phonological loop and verbal rehearsal mechanisms (Baddeley et al., 1998). One reason why deaf children may have more difficulty forming robust lexical representations of novel words than

NH children is that they may not be able to verbally rehearse and maintain phonological patterns as efficiently in working memory so that they can be encoded into long-term memory (see Cleary, Dillon, & Pisoni, 2002).

There are several reasons why phonological processing and/or working memory may be impaired in deaf children following cochlear implantation. As mentioned earlier, deaf children may have difficulty encoding phonological information because their auditory processing skills are poorer relative to NH children in terms of frequency discrimination and temporal coding of the speech waveform. However, there may be factors other than their auditory capacities and discrimination skills that may play a role in processing, encoding, and storing phonological information. It is important to remember that prior to cochlear implantation these children had a profound hearing loss and experienced a period of sensory deprivation and lack of auditory stimulation. Neural and cognitive development developed and unfolded in the absence of auditory stimulation during critical periods in development (Shepherd, Hartmann, Heid, Hardie, & Klinke, 1997). One consequence of early auditory deprivation appears to be a diminished ability to selectively attend to auditory information due to lack of stimulation during early stages of development. Attention to sound and especially speech sounds is critical for processing and encoding phonological information and it is even more important for the development of working memory and verbal rehearsal processes used in word learning and lexical development. If attention to speech sounds is not highly automatic, then words may not be as readily encoded into the phonological loop for rehearsal and eventual storage into long-term memory.

Another factor that may contribute to the development of phonological skills that are important for word learning is vocabulary size. As we noted in the introduction, Lederberg et al. (2000) found that deaf and hard-of-hearing children with larger vocabularies displayed more advanced word-learning skills than deaf and hard-of-hearing children with smaller vocabularies. They speculated that some word-learning skills, such as implicit fast mapping skills, might emerge only when vocabulary size becomes large enough. It is possible that deaf children who have received CIs may not develop typical phonological processing and encoding skills necessary for the implementation of fast mapping strategies until they have acquired a sufficiently large vocabulary of words in their mental lexicons.

The present study was designed to investigate the novel word-learning skills of deaf children following cochlear implantation. We found that deaf children who use CIs have more difficulty learning names after only a few exposures than NH children but that they do not necessarily exhibit an impaired ability to retain familiar words in long-term memory. One of the issues raised by these findings is how vocabulary size is related to deaf children's ability to learn novel words. Because large vocabularies reflect more advanced word-learning skills (Lederberg et al., 2000), it would be worth exploring further the underlying lexical processes that contribute to individual differences of vocabulary size in this clinical population. One possibility is that there may be large differences in the quality of the acoustic-phonetic input that CIs deliver for each child, resulting in differences in auditory acuity. Some deaf children may be able to form quite detailed phonological and lexical representations from the auditory input provided by their CIs while other deaf children may only be able to form coarser representations that are easily confused with other phonetically similar words. One way to address this possibility would be to conduct a novel word-learning experiment using sets of nonwords that are specifically designed to have different degrees of phonological confusability.

Another factor that may affect vocabulary size is the deaf children's phonological processing skills and working memory capacity. Even if deaf children are able to discriminate fine-grained acoustic-phonetic properties in speech, they may be unable to build a vocabulary and develop a lexicon of words if they are not able to initially encode these sound patterns into working memory and store them in long-term memory. Gilbertson and Kamhi (1995) found that for children with mild to moderate hearing-losses, measures of their phonological processing skills predicted their subsequent word-learning abilities. Similarly, Gathercole and Baddeley have found that working memory is an important factor for building a vocabulary (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1989; 1990). Obtaining several measures of a deaf child's phonological processing skills (i.e., phoneme identification, phoneme monitoring, nonword repetition, etc.) and working memory capacities would help in understanding the relations between phonological coding, working memory and novel word learning in this clinical population.

In the present experiment, deaf children, like the NH children, did not exhibit any decline in performance on the receptive and expressive word-learning tasks across delay conditions when the words they had to learn were familiar. However, for unfamiliar words, deaf children performed worse on the word-learning tasks after a delay than during the immediate testing. These findings suggest that the long-term memory of deaf children who use CIs may be impaired relative to that of NH children. Markson and Bloom (1997) reported that NH children were able to recall novel nonwords after a 1-month delay, suggesting that NH children's long-term memory for the sound patterns of novel words is very robust. Similar novel word-learning studies with longer delay periods would be useful for investigating the long-term encoding and memory capacities of deaf children who use CIs.

Several traditional demographic factors may also contribute to individual differences in performance on word-learning tasks among deaf children who use CIs. These factors include age at implantation, length of CI use, communication mode, length of deafness before implantation and number of active electrodes. In the present study, we found weak correlations between age at implantation and performance on word-learning tasks. However, we intentionally selected children in this study who came from oral-only educational environments and had at least 1 year of CI experience so that they would be able to complete these auditory tasks. A better assessment of the contribution of the demographic factors will require investigations with groups of children in which there is more variance in these demographic factors across children.

Finally, it is important to investigate the effects of early auditory deprivation on novel word-learning skills of deaf children after intervention with a cochlear implant. Some researchers have noted that profoundly hearing-impaired children may develop phonological processing deficits that are similar to children who have been diagnosed with Specific Language Impairment. Indeed, some investigators have considered the possibility that hearing impairment may be a risk factor for SLI (Gilbertson & Kamhi, 1995), and one of the factors observed in SLI is difficulty with phonological processing skills (Leonard, 1998). Thus, it is possible that both hearing-impaired children and children with SLI have similar difficulties in encoding speech sounds and maintaining the phonological pattern of words in both short- and long-term memory. In particular, both groups of children may have difficulty with rapid learning of words.

Support for this hypothesis comes from a series of studies by Rice and her colleagues who report that children with SLI have difficulty with "quick and incidental learning" which is similar to fast mapping (Oetting, Rice, & Swank, 1995; Rice, Buhr, & Nemeth, 1990; Rice, Oetting, Marquis, Bode, & Pae, 1994). In one investigation, Rice et al. (1994) found that children with SLI needed many more exposures to words than normally developing children in order to display even a basic understanding of the words. Moreover, children with SLI appeared to be more likely to forget the meanings of words after a short delay, suggesting that their long-term memory retention of words and word meanings was atypical as well. In sum, deaf children who use CIs may have difficulties quickly learning novel words due to poorly developed phonological processing skills, and these differences may be similar to the results found with children who have SLI. Further novel word-learning studies with deaf children who use CIs and hearing-impaired children who use hearing aids may provide further insights into how hearing impairment affects language development and, especially how degraded sensory information influences novel word learning and vocabulary development.

Conclusions

We found that deaf children who received CIs are able to perform a novel word-learning task in which they were exposed to names for Beanie Babies™ and then tested for their receptive and expressive knowledge of these names. We observed a high degree of variability in performance in this task, suggesting that some of the underlying phonological skills needed for novel word learning are delayed or disordered in this population of children.

Deaf children who use CIs performed worse than NH children in all test conditions, but neither group exhibited a decline in performance across delay conditions for familiar words that they knew before testing began. Only when we examined the learning of unfamiliar words did we see that deaf children's performance declined across delay. These findings suggest that the poorer performance on novel word-learning tasks of deaf children with CIs may be due to differences in phonological processing or verbal working memory capacity than storage or retrieval from long-term memory. However, additional research is needed to further explore the relations between in phonological processing skills, working memory capacity, and long-term retention in deaf children who use CIs and their contributions to novel word learning.

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Appendix

Sample Scenario:

This is *Name.*
Can you say hi to him?
Say “Hi *Name!*”
Now your turn {child says “hi *Name*”}
Name likes to climb the tree.
Can you put him on the tree? {child interacts with BB}
Look – *Name* is on the tree.
Tell him to get down. {child says, “get down *Name*”}
Good. Now, *Name* has to go bye bye.
Say, bye bye *Name.* {child repeats “bye bye *Name*”}