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Word Learning in Children Following Cochlear Implantation

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Abstract

An experimental procedure was developed to investigate word-learning skills of children who use cochlear implants (CIs). Using interactive play scenarios, 2- to 5-year olds were presented with sets of objects (Beanie Baby stuffed animals) and words for their names that corresponded to salient perceptual attributes (e.g., "horns" for a goat). Their knowledge of the word-object associations was measured immediately after exposure and then following a 2-hour delay. Children who use cochlear implants performed more poorly than age-matched children with typical hearing both receptively and expressively. Both groups of children showed retention of the word-object associations in the delayed testing conditions for words that were previously known. Our findings suggest that although pediatric CI users may have impaired phonological processing skills, their long-term memory for familiar words may be similar to children with typical hearing. Further, the methods that developed in this study should be useful for investigating other aspects of word learning in children who use CIs.

Introduction

A fundamental aspect of learning spoken language is attaching meaning to the sound patterns of words. This task was nearly impossible for children with profound hearing loss until cochlear implants (CIs) were approved as an intervention for deafness. CIs provide individuals who are deaf with access to sound by exposure to an electrical signal that codes the auditory input. Numerous investigations have reported that cochlear implantation improves the language comprehension and production skills of children who are deaf (Eisenberg, Martinez, Sennaroglu, & Osberger, 2000; Kirk, Osberger, Robbins, Riley, & Todd, 1995; Osberger, Robbins, Todd, & Riley, 1994; Svirsky, Robbins, Kirk, Pisoni, &

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Miyamoto, 2000; Tobey, Geers, & Brenner, 1994; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Zwolan et al., 1997). However, these investigations also have revealed that children with CIs do not perform as well as their age-matched peers with typical hearing on a wide range of speech and language measures. Moreover, there are enormous individual differences in language skills after implantation (Pisoni, Cleary, Geers, & Tobey, 2000). Other studies have reported that the vocabulary levels of children who are deaf or hard of hearing substantially lag behind those of children with typical hearing (Lederberg & Spencer, 2001).

The primary demographic factors that have been associated with differences in audiological and speech and language outcomes 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 speech-language therapy, etiology of hearing loss, number of electrodes inserted into the cochlea (Loizou, Dorman, & Tu, 1999), and the nature of the child's early linguistic environment (Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2002).

Another contributing source of variability in language outcomes is related to individual differences in underlying cognitive processing skills. Several years ago, Pisoni, Svirsky, Kirk, and Miyamoto (1997) reported that measures of speech perception, speech production, and language were highly intercorrelated in children who use CIs (see also Pisoni et al., 2000). The authors suggested that the common variance observed in these tasks might be due to several underlying cognitive and linguistic skills, including the phonological encoding, storage, and retrieval of spoken words. It is very likely that auditory deprivation experienced by children who are congenitally deaf during early childhood may lead to delays and/or disorders in these kinds of cognitive processing skills. Moreover, the absence or delay of these skills may be responsible for the poorer linguistic performance observed in pediatric CI users relative to children with typical hearing. Several fundamental cognitive and linguistic skills may be delayed and/or disordered in this clinical population and affect their spoken language development. One of the building blocks of language development is acquisition of a vocabulary. Thus, the most important underlying skills in language development are the abilities to learn the meanings of words and develop a lexicon of words in the language.

Word Learning in Children with Typical Hearing

Children with typical hearing begin producing words at approximately 12 months of age and begin recognizing words at even earlier age (Tincoff & Jusczyk, 1999). By 18 months, most infants can produce over 50 words and continue to acquire several words each day (Fenson et al. 1994). Phonological encoding—i.e., forming linguistic representations for the sounds that comprise words—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 (i.e., the amount of phonological information that can be held in a short-term memory store that is immediately accessible) and vocabulary size in children with typical hearing. 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 the phonological information of 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 and repetition also 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 processing skills that affect subsequent word-learning and language development.

To build a vocabulary and develop a lexicon of words in the language, 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 proposed 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 phonological information of 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 preschool children with typical hearing (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 novel 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 2 years of age showed fast mapping of shape and texture terms as well as color terms. More recently, Markson and Bloom (1997) tested the abilities of 3- and 4-year-olds with typical hearing 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 children with typical hearing 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.

Word Learning in Children with Hearing Loss

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 users of cochlear implants for several reasons. First, the auditory information provided by a cochlear implant is impoverished and highly degraded when compared to typical hearing. The cochlea of a adult with typical hearing has approximately 13,500 outer hair cells and 3,500 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 stimulate surviving spiral ganglion cells using up to 22 electrodes (Wilson, 2000). Not surprisingly, the frequency resolution of sound provided by a cochlear implant is not as high as that which 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 phonological information of spoken words.

Another reason why children who use cochlear implants may not develop phonological-processing and word-learning skills as well as children with typical hearing is that the period of early sensory deprivation prior to implantation may lead to a delayed and/or disordered course of language development. Indeed, 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 the abilities of children with hearing loss (speech reception threshold scores in the better ear ranged from 5 to 65 dB HL) to encode phonological information and learn novel words while wearing their hearing aids. They found that one group of children with hearing loss performed similarly to children with typical hearing on a word-learning task whereas another group of children with hearing loss performed more poorly. Moreover, the children with hearing loss who performed better on the word-learning task also performed better on tests of phonological processing than the children who performed more poorly on the word-learning task. 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. 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.

Although word learning is an important aspect of language development, there has been very little investigation of the word-learning abilities of children with profound hearing loss who are learning spoken language. The primary aim of this project was to investigate name-learning skills of children who are deaf and use CIs and to explore differences in performance between children who use CIs and children with typical hearing. Another aim of this investigation was to develop a set of experimental procedures that can be extended to investigate novel word learning in this clinical population.

Little is currently known about the word-learning skills of children who are prelingually deaf (but see Stelmachowicz, Pittman, Hoover, and Lewis (2004) for a word-learning study of older children with moderate hearing loss). Recent work by Lederberg and her colleagues has begun to explore the vocabulary development of children who are deaf or hard of hearing and who use both spoken and sign language. In one study, Lederberg, Prezbindowski, and Spencer (2000) assessed word-learning skills in children who are deaf or hard of hearing. The children were presented with novel object nouns in several contexts, each of which provided either an explicit or implicit reference to the novel objects. In the explicit condition, novel words were explicitly paired with novel objects. In the implicit condition, children were presented with a row of three familiar objects and one novel object and were asked to indicate which object was a *shoe*, which was a *dog*, and which was a *lep*, for example. Thus, they had to make an inference that the novel label should be associated with the novel object. The children's word-learning ability was judged based on if they could learn words and whether they needed an explicit context or could learn words with only an implicit context. The investigators also assessed the children's vocabulary using the *MacArthur Communication Development Inventory* (CDI), which is a parent report form that is used to assess individual infants' and young children's language and communication skills (Fenson et al., 1994). The inventory consists of lists of gestures, words, and sentences. Parents are asked to indicate whether or not their child understands and/or produces any of the items.

Lederberg et al. (2000) found that children who have larger vocabularies in their preferred mode of communication (i.e., either spoken or sign language) were able to learn words in that mode with fewer exposures and with less explicit teaching than children with smaller vocabularies. The authors concluded that there is a relationship between vocabulary size and word encoding skills—a larger vocabulary appears to be related to being able to use implicit reference to learn words.

The Lederberg et al. (2000) study is an important first step in understanding the word-learning skills and vocabulary development in children who are deaf and who use manual and/or oral communication. However, we have been unable to find any studies in the literature that focus specifically on the spoken word-learning skills of pre-school aged children who are deaf and who have received CIs and use oral-aural communication methods (but see Willstedt-Svensson, Löfqvist, Almqvist, & Sahlén (2004) for a word-learning study with older children who use CIs). This particular group of children is an unusual clinical population because until the time these children receive their CIs, their linguistic, cognitive, and perceptual skills have developed in the absence of sound and input from the auditory sensory modality. Once the 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 goals of this study were to develop a set of experimental procedures that could be used to study word learning in preschool-aged children after cochlear implantation and then to use the procedures to investigate their ability to learn object names.

In this study, we assessed children's ability to learn names for Beanie Baby stuffed animals. Most word-learning studies test children's ability to learn common nouns rather than names or proper nouns. We decided to use proper nouns because some studies have reported that they are easier to learn than common nouns (Gelman & Taylor, 1984; Katz, Baker, & Macnamara, 1974). Proper nouns have one-to-one relations to their referents whereas common nouns refer to categories with which particular referents are associated. Macnamara (1982) writes: "Proper names are the paradigm examples of words that refer. They reach out … to objects and designate them for comment. It is less clear that common nouns also refer … What common nouns certainly do is describe. If I say *Tom is a cat*, *Tom* refers to a particular creature; *cat* describes him." (pp. 3–4). Many of children's first words are proper nouns (e.g., "Mommy, Daddy, Sarah") (Bloom, 2000; Macnamara, 1982). Katz et al. (1974) investigated the ability of 17- to 24-month olds with typical hearing to learn labels for dolls and blocks when labels were presented in a proper noun context (e.g., "Look, this is Zav) and when the labels were presented in a common noun context (e.g., "Look, this is the zav). They found that children did not learn the labels for blocks in either condition and that boys did not learn labels for dolls in either condition. However, girls demonstrated learning of labels for dolls when they were presented in a proper noun context. Similarly, Gelman & Taylor (1984) found that 26- to 36-month-olds were much more likely to demonstrate word learning in a proper noun condition than in a common noun condition. These findings suggest that using a proper noun sentence context can facilitate children's linking of words to objects, at least when the objects represent people or animals. Thus, teaching proper names for stuffed animal stimuli to children who are deaf and use cochlear implants and testing their learning of these labels should be a relatively easy word-learning task.

Another advantage to using proper nouns rather than common nouns is that we were able to give the Beanie Babies names that corresponded to salient perceptual attributes. For example, the name "Horns" was assigned to the goat Beanie Baby and the name "Stripes" was assigned to a cat Beanie Baby that was striped. These word-object pairs are presumably easier to learn than arbitrary word-object pairs because they allow children to use their prior knowledge of the distinctive perceptual attributes. Thus, this investigation should provide a benchmark of the performance of children who use CIs on this task. If this task is successful at measuring learning of word-object associations, it could serve as a valuable methodological tool for assessing novel word learning in this clinical population.

This report describes the results of a preliminary study that assessed the abilities of children with CIs to learn names after a brief exposure period. Data from a group of preschool-aged children with typical hearing were also obtained for comparison. Specifically, we developed a name-learning task using a set of Beanie Baby stuffed animals. All children were taught the names for a set of Beanie Babies, one at a time, and were then tested for their knowledge of the names both immediately after learning and then following a 2-hour delay using both receptive and expressive measures. We report data from a group of 24 children who use CIs and a group of 24 age-matched children with typical hearing who served as a comparison group.

Within each hearing group, two ages were tested. The “young” group included children who were 2 and 3 years of age. The “old” group included children who were 4 and 5 years of age. The younger children were taught the names of eight Beanie Babies (in two sets of four) while the older children were taught the names of 16 (in two sets of eight). After training, both groups of children were tested for their receptive knowledge of the names using a forced-choice recognition task. The children also tested for their expressive knowledge of the names, using a cued-recall task. Finally, long-term memory of the names was subsequently assessed in a second session by re-testing each child 2 hours later on both receptive and expressive tasks. We predicted that if children who use CIs have impaired phonological processing skills and delayed name-learning strategies, they should not perform as well as children with typical hearing on the receptive and expressive tasks in both the immediate and the delayed testing conditions. Furthermore, if CI users’ ability to maintain representations of spoken words in memory is impaired or delayed, they might also show a greater effect of delay between training and testing phases than children with typical hearing. Finally, we predicted that if name-learning skills are an important source of variance in linguistic performance, then children who use CIs should display greater individual variability in their performance on these tasks than age-matched children with typical hearing.

Experiment

Methods

Participants

Children with CIs: Twenty-four children who were prelingually deaf and 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 including children in this study. First, at the time of testing the children had to be between the ages of 2 and 5 years, 11 months. Second, the children had to use oral-only communication (i.e., no use of any form of manual communication). Third, the children had to have had at least 1 year of experience with their CI. The 12 children who fell into the young group were 2 and 3 years of age (mean = 37.7 months), and the remaining 12 children who fell into the older group were 4 and 5 years of age (mean = 59.5 months). The demographics of the children who use CIs were as follows: one Hispanic or Latino (male), one Asian/Pacific Islander (male), two Black/African American (one male, one female), 20 White/Non Hispanic (14 male, six female). Table 1 displays the children’s age at testing, age at which they received their CI, and the length of CI use.

Children with typical hearing: Twenty-four age-matched children with typical hearing were recruited from the Bloomington, Indiana area and the Center for Young Children on the Indiana-University-Purdue-University-Indianapolis campus. Twelve children were assigned to the young children with typical hearing group (mean age = 38.0 months) and 12 were assigned to old children with typical hearing group (mean age = 58.4 months). The demographics of the children with typical hearing were as follows: one Hispanic or Latino (female), one Asian/Pacific Islander (male), 20 White/Non Hispanic (9 male, 11 female), two Other/Unknown (two male). Ages are displayed in Table 1.

Materials—The stimulus materials consisted of a set of 16 Beanie Baby stuffed animals, selected on the basis of whether they had any distinctive perceptual attributes that could be easily named, such as a long tail, horns, or a bright color. Each Beanie Baby comes with a given name that was 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 37 undergraduates (mean age = 19.9 years; SD = 1.3 years) at Indiana University who reported no prior history of speech or hearing disorders at the time of testing. The Beanie Babies were presented one at a time in a random order to three groups of participants who were instructed to create up to three new names for the Beanie Babies, as if they were going to teach the names to a young child. They were also instructed to create names that described some salient physical attribute of the Beanie Babies.

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: First, if the name was the most frequent response among students, and second, if it reflected a true physical perceptual 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, while “Teddy” was the most frequent response for the brown bear, it was inappropriate for our purposes because this name did not represent a physical attribute. The second most common response to the bear 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 2 provides a list of the descriptions of the Beanie Babies, their new names, and the percentage of subjects who used the new attribute name.

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, in Set A “Wings,” “Pink,” and “Blue” all have wings. This was done so that the children would not be able to completely rely on one unique perceptual feature to identify the test animal in the tasks. For example, when the children were asked to identify “Wings,” three of the four Beanie Babies had wings, so they had to learn to map a specific visual feature to a unique Beanie Baby object.

Procedure—Children were explicitly taught a set of names for either four or eight Beanie Babies using play scenarios (Training Phase 1). They were then given receptive (forced-choice) and expressive (cued-recall) tests for the first test set (Testing Phase 1). Children were then taught a second set of Beanie Babies (Training Phase 2) and were subsequently given the same tests with these stimuli (Testing Phase 2). Finally, after a 2 hour delay[*], all children were given the same receptive and expressive tests over again, first with the set of Beanie Babies presented in Training Phase 1 and then with the set presented in Training Phase 2. Two of the young children with cochlear implants and one of the old children with

[*]For 16 of the children with typical hearing, 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.

typical hearing were not able to participate in the long-term memory portion of the experiment due to scheduling conflicts.

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 Experimenter 1 in following the correct presentation order. Experimenter 2 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 and ensure that the child's attention was fully engaged. 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 used during each phase instead of only four.

Immediate Tests

Testing Phase 1: The testing phase used two procedures to assess name 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 any 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 from the set displayed in front of him or her but was not given any feedback as to whether the response was the correct choice. The experimenter simply 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, "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, which was checked by Experimenter 1. The response was considered correct when it was either the correct pronunciation of the word or if both experimenters agreed that it was the same pronunciation that was elicited during the training phase. This procedure was repeated for each Beanie Baby (four for young children, eight 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.

Delayed Tests: About 2 hours after the completion of Testing Phase 2, the child was tested a second time, in order to assess long-term memory of the Beanie Baby names that were presented during training. In traditional investigations of human memory, tests are typically given immediately after learning or familiarization as measures of short-term or working memory and then followed with tests from around 30 minutes to days or weeks afterwards as measures of long-term memory (Baddeley, 1990). Items must be retrieved from long-term memory as opposed to short-term memory when the subject must do an attention-demanding task between learning and recall (Glanzer & Kunitz, 1966; Postman & Phillips, 1965). In the present study, all children were given several other tasks or games to play between Test Phase 2 and the long-term memory test in order to ensure that we were indeed testing long-term memory. We chose 2 hours because that amount of time was convenient with completing other testing. The long-term memory test consisted of a second implementation of Testing Phase 1 and Testing Phase 2 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 specific words may have contributed to the children's ability to associate them with the Beanie Babies during the course of the experiment. Names that are entries in a child's lexicon and are already known should be much easier to learn in this procedure because their phonological representations are already stored in memory and 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. One parent (the primary caregiver) of each child was 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)". Parents were also asked to rate, on a scale of 1 to 5, "How familiar is your child 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

All of the children who were tested in the procedure were able to complete the task. Only four of the children who use cochlear implants and none of the children with typical hearing performed at chance levels on all of the testing conditions. We also observed a wide range of performance across children, especially among the children who use CIs. For the immediate receptive test, the range of scores varied from 6% to 100% correct for the children who use CIs and from 69% to 100% for the children with typical hearing. Similar variation was found for the delayed receptive test. For the expressive tests, the ranges for the children who use CIs were from 0% to 63% for both immediate and delay conditions. We also observed a wide range of scores on the expressive tests for the children with typical hearing as well

(25%–100% for the immediate test; 0%–100% for the delayed test). However, the lower ends of the ranges were due to two of the children with typical hearing who did not give many responses at all, presumably because of shyness. All other children with typical hearing performed at or above 50%. The median scores for the immediate and delayed expressive tests were 88% and 92.5%, respectively. In all of the following statistical analyses, the criterion for significance was set to an alpha level of 0.05. However, we report all p values less than 0.10.

The mean proportion of correct responses (out of eight trials for the young groups or 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 children who use CIs; the lower panels display the scores for the children with typical hearing. 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 scores for each test were subjected to a mixed model with repeated measurements in SAS with Group (CI, TH) and Age (Young, Old) as between-subjects factors and with Test (Receptive, Expressive) and Delay (Immediate, Delay) as the repeated factor.[1] The model revealed significant main effects of Group (F (1, 45) = 123.79, p < .0001), reflecting higher mean scores for the children with typical hearing than the children who use CIs. There was also a main effect of Test (F (1, 45) = 97.41, p < .0001), reflecting higher scores for the receptive test than the expressive test. The model also revealed a significant Age X Test interaction (F (1, 45) = 12.39, p = .001) as well as a significant Group X Test interaction (F (1, 45) = 9.00, p = .004). No other main effects or interactions were significant.

Because there were interactions of Test (receptive vs. expressive) with two other variables (Age and Group), we conducted additional analyses separately for receptive and expressive tests. There was no main effect of Age for either the receptive or the expressive test. Thus, the Age X Test interaction is likely due to spurious non-significant trends of the young group having slightly higher scores on the receptive tests and the old group having slightly higher scores on the expressive tests.[2] However, the main effect of Group was replicated for both the receptive test (F (1, 45) = 85.45, p < .0001) and the expressive test (F (1, 45) = 134.09, p < .0001). In both cases, the children with typical hearing performed better than children who use CIs. The Group X Test interaction found in the earlier model is thus likely due to a larger proportion-correct difference in the expressive test than in the receptive test. Averaging across Delay and Age factors, children with typical hearing scored .82 and children who use CIs scored .19 on the expressive test. By contrast, the children with typical hearing scored .95 and the children who use CIs scored .42 on the receptive—a smaller difference. None of the other main effects or interactions were significant.

Word Familiarity and Name Learning—We selected the names used in this experiment so that they would correspond to salient perceptual attributes of the Beanie Babies in order to facilitate rapid word learning in the children who use CIs. We expected that these children

[1]A mixed model was used rather than a repeated-measures ANOVA because we had some missing data points due to some children not being able to complete the delayed tests. In a standard repeated-measures ANOVA, all data is eliminated from each subject who has any missing data points. By contrast, mixed models are able to deal with missing values without eliminating data (Wolfinger & Chang, 1995) by calculating estimated (or least squared) means from the variability in the data.

[2]Averaging across the Delay and Group factors, there was a slightly higher proportion correct for the young group (.70) than the old group (.63) on the receptive test whereas the old group scored slightly higher (.52) on the expressive test than the young group (.47).

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would only be able to use this information if they had some prior familiarity of the words. To assess the role of prior word familiarity on name learning, we correlated the word familiarity scores obtained from the parent questionnaires with the proportion correct responses obtained on the word-learning task. We then 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. The correlations are summarized in Table 4.

For the young CI group, the mean word familiarity score (on a scale of 1 to 5) was 2.95 (SD = 1.22; range: 1.33–4.67) and the scores were positively correlated with performance on both the receptive ($r = +.53$, $p = .037$) and expressive tests ($r = +.53$, $p = .036$) in the delay condition and accounted for a moderate amount (28%) of the variance in the performance. Although the correlations were in the same direction for the receptive ($r = +.13$) and expressive ($r = +.43$, $p = .10$) tests in the immediate conditions, they were not statistically significant and accounted for small amounts of the variance (2% and 18%, respectively). For the old CI group, the mean familiarity score was 3.14 (SD = 1.32; range = 1.08–4.83). Familiarity scores correlated significantly with both tests in the immediate testing condition (receptive: $r = +.60$, $p = .015$; expressive: $r = +.64$, $p = .008$) and accounted for a moderate amount (36% and 41%) of the variance of the receptive and the expressive tests, respectively. The familiarity scores also correlated with both tests in the delayed testing condition (receptive: $r = +.63$, $p = .01$; expressive: $r = +.81$, $p < .001$) and accounted for a moderate (40%) and a large amount (66%) of the variance of the receptive and the expressive tests, respectively. These correlations suggest that prior word familiarity was related to a child's ability to make new associations between words and objects in these tasks.

Analyses with Word Knowledge as a Factor—The correlations of word familiarity with name-learning test scores of children who use CIs showed a relation between their prior familiarity with the stimulus words and their performance on the name-learning tests, especially in the delay conditions. To analyze these findings further, we recalculated the scores of children who use CIs, separating their performance on words they knew prior to testing from words they did not know before they began the study, based on information obtained from the parent report questionnaire. We separated the scores based on parents' report of 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. As described above, word knowledge was assessed for each word on the Parent Questionnaire by asking, yes or no, whether the child knows the meaning of each word. Word knowledge scores were strongly correlated with word familiarity scores ($r = .97$, $p < .001$).

Figure 2 displays the performance of the young children who use CIs in the left-hand panel and the performance of old children who use CIs in the right-hand panel. As in Figure 1, the scores within each panel are plotted separately by test type and delay condition. However, in this figure the data are displayed separately for words that were known (dark bars) versus words that were unknown (light bars). A mixed model in SAS was used to analyze the proportion correct responses for the tests. Age was a between-subjects factor; Test, Delay, and Word Knowledge (known, unknown) were within-subjects factors. A main effect of Word Knowledge (F (1, 23) = 19.95, $p = .0002$) was observed, reflecting higher mean scores for known words than unknown words. A main effect of Test (F (1, 22) = 61.50, $p < .0001$) was also observed again, reflecting higher mean scores on the receptive test than on the expressive test. Unlike the previous analyses, however, there was a main effect of Delay (F

(1, 21) = 4.75, p = .041), reflecting higher mean scores on the immediate tests than on the delayed tests. There was again a significant Test X Age interaction (F (1, 22) = 7.36, p = .012), reflecting slightly higher mean scores by the young children on the receptive tests and slightly higher mean scores by the old children on the expressive tests. The data for the receptive and expressive tests were subsequently analyzed separately using mixed models in order to clarify the nature of the Test X Age interaction. There was no significant main effect of Age for either test, suggesting that the Test X Age interaction does not reflect a meaningful interaction. Interestingly, unlike the original analyses, the effect of Delay was not significant for either test, suggesting that the main effect of Delay in the original analyses is not very robust. Finally, the significant main effect of Word Knowledge was replicated for both the receptive (F (1, 23) = 9.44, p = .005) and the expressive (F (1, 23) = 11.60, p = .002) tests, separately.

Re-analysis with Known Words Only—In the previous analysis, we found a significant main effect of prior word knowledge on name learning with the children who use cochlear implants. Higher scores were observed for known words than unknown words. Using data from the parent questionnaires, the children with typical hearing knew an average of 95% of the test names whereas the children who use CIs knew only 60% of the names. It is possible that the difference in performance observed earlier between children who use CIs and children with typical hearing was based on prior word knowledge rather than differences in name learning and encoding skills acquired during the course of the present experiment. To assess this possibility, we reanalyzed the proportion correct scores of both groups of children using only the scores for the known words.

Figure 3 displays the same test conditions as the data shown in Figure 1 but now only scores from the known words are shown. Again, the scores for the test were analyzed using mixed models with repeated measurements in SAS with Group and Age as between-subjects factors and with Delay and Test as the repeated factors. However, this time only the scores for the known words were used. Overall, the pattern of results was quite similar to the original analyses shown in Figure 1. There was a significant main effect of Group (F (1, 45) = 87.97, p < .0001), reflecting higher mean scores for the children with typical hearing than the children who use CIs. There was also a main effect of Test (F (1, 45) = 71.13, p < .0001), reflecting higher mean scores on the receptive than on the expressive tests. There were also significant Test X Age (F (1, 45) = 10.01, p = .0028) and Test X Group (F (1, 45) = 10.48, p = .0023) interactions. Subsequent analyses separating the receptive and expressive tests revealed no main effect of Age suggesting that, again, the Test X Age interaction was not meaningful. However, the main effects of Group were significant on both the receptive tests (F (1, 45) = 53.27, p < .0001) and the expressive tests (F (1, 45) = 111.84, p < .0001), suggesting that the Test X Group interaction reflected a relatively larger advantage of the receptive over the expressive tests for the children with CIs than children with typical hearing.

Correlations with Demographics—As noted in the introduction, many studies have reported that demographic factors contribute to differences in language outcomes measures. Thus, it is of interest to see if our word-learning measures also correlate with these same demographic factors. In order to assess the relationship of performance on the name-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 (r = −.42), accounting for a small amount of the variance (18%). This pattern suggests that children who received cochlear implants at younger ages, and hence had shorter periods of auditory deprivation, tended to perform better on name learning than children who received their implants at older ages. The correlations between age at implantation and the other tests were also in the same direction but were not statistically significant. None of the other correlations were significant.

General Discussion

The aim of this study was to investigate the word-learning skills of children with hearing loss who have cochlear implants and to develop procedures that can be used to investigate word learning in this clinical population of children. Almost all children tested in this study were able to follow the directions of the task and give responses. There were only a handful of cases, noted earlier, where some children with typical hearing and some children with CIs refused to give responses on the expressive tests, presumably due to shyness. On the whole, the task demands of this new procedure seem to be suitable for this population of children with hearing loss—only four of the children with CIs performed at chance levels. Also, there was a wide range of performance by both the children with typical hearing and the children who use CIs. Thus, this procedure also appears to be an effective tool in providing a new measure of the variable performance of children's linguistic abilities after cochlear implantation. These new measures may be particularly useful in the future because they provide a methodology to investigate a specific linguistic skill—the ability to learn words after only a few exposures.

The ability to learn words after only a few exposures, or "fast mapping," is an important component of language development and has been well documented in children with typical hearing (Carey, 1978; Carey & Bartlett, 1978; Heibeck & Markman, 1987; Markson & Bloom, 1997). The ease with which children can learn words reflects their abilities to quickly encode phonological information into long-term memory and make links to referents. We predicted that many children who use cochlear implants might have difficulty learning words after only a few exposures because there is a high degree of variability in phonological processing skills among children with hearing loss (Gilbertson & Kamhi, 1995). Moreover, previous investigators have found that children who use CIs have an atypical working memory capacity (Pisoni & Cleary, 2003) and have argued that a limited working memory capacity may reflect an impairment in their ability to use verbal rehearsal procedures and maintain phonological information in working memory (Burkholder & Pisoni, 2003; Cleary, Dillon, & Pisoni, 2002; Dillon, Burkholder, Cleary, & Pisoni, 2004a). Because maintaining words in working memory facilitates transfer and encoding of words into long-term memory, working memory capacity has been thought to be very important for building a vocabulary. Indeed, Gathercole and Baddeley have found that phonological working memory capacity is a strong predictor of vocabulary knowledge (Gathercole & Baddeley, 1989; 1990) and of long-term phonological learning of new sound patterns in children with typical hearing (Baddeley, Gathercole, & Papagno, 1998).

In accord with our initial predictions, we found that the mean performance of children with CIs on both receptive and expressive tests of word learning was significantly lower than the mean performance of children with typical hearing. We also observed a greater range of performance on the receptive tests in the children with CIs than in children with typical hearing. These findings are consistent with the results of other investigations that have found that although the spoken language skills of children who are deaf or hard of hearing typically improve following cochlear implantation, children with CIs generally do not display linguistic skills that are equivalent to their age-matched peers with typical hearing (e.g., Eisenberg et al., 2000; Kirk et al., 1995; Osberger et al., 1994; Svirsky et al., 2000; Tobey et al., 1994; Tomblin et al., 1999; Zwolan et al., 1997). The present findings provide additional evidence that children who have profound hearing loss at an early age continue to have difficulty acquiring linguistic skills even after cochlear implantation. In this case, the linguistic skill is the ability to learn words quickly after only a few exposures.

As discussed above, one possible reason that children who are deaf or hard of hearing and use CIs have more difficulty learning words as quickly as children with typical hearing is that they may have atypical or delayed phonological processing skills. We did not directly assess their phonological processing skills in this investigation, but it is possible that comparing the performance of the children with CIs on words that they knew before the tests versus words that they did not know may provide some insights into the underlying differences. Presumably, learning a novel association for a word that a child already knows requires forming a new link to a referent but does not require encoding novel phonological information. By contrast, learning a novel word requires both encoding a novel phonological pattern and learning a link between a sound pattern and a referent. We found that children who use CIs performed worse on unknown words than on known words, suggesting that having to encode novel phonological information did have a negative impact on their performance. Unfortunately, we were not able to assess the effect of word knowledge on the performance of children with typical hearing because those children knew almost all of the words. However, previous research has shown that children with typical hearing are very adept at "fast mapping" novel phonological information (e.g., Carey, 1978; Carey & Bartlett, 1978), and it is possible that, unlike the children with CIs, their performance would not have been worse with unknown words than with known words. Further investigations using non-word names would provide more insight into the role of encoding novel phonological information on rapid word learning difficulties in children who use CIs.

Another prediction that we made was that the performance of children with typical hearing would be less affected by delay than children who use CIs. The rationale for this prediction was based on the previous studies that have found that children who use CIs tend to have a more limited working memory capacity than children with typical hearing (Burkholder & Pisoni, 2003; Pisoni & Cleary, 2003). As discussed above, several groups of researchers have argued that being able to maintain words in phonological working memory facilitates the process of encoding words into long-term memory in both children with typical hearing (e.g., Baddeley et al., 1998; Gupta & MacWhinney, 1997) and in children who use CIs (Cleary et al., 2002; Dillon et al., 2004a; Dillon, Cleary, Pisoni, & Carter, 2004b). We reasoned that children with CIs who have, on average, a more limited working memory would likely also have difficulty encoding the words into long-term memory and hence be more affected by the delay than children with typical hearing. Our findings with respect to this prediction were mixed. The first analyses of the data suggested that the mean performance on the delayed tests did not differ significantly from the mean performance on the immediate tests for either group of children. However, when the second set of analyses were performed there was a weak but statistically significant ($p = .041$) main effect of delay. This second set of analyses separated known and unknown words and was conducted only on the children with CIs. The same analyses could not be carried out on the data of children with typical hearing because there were not enough words that they did not know. Because we do not have similar analyses from children with typical hearing to compare to this second set of analyses, there is no way of knowing whether or not the effect of delay is different for the two groups of children.

One possible reason that there was little, if any, effect of delay may be because real words were used in this study and many of these words were previously known by the children. All known words would already have stable phonological representations in the children's long-term memory. For the known words, children simply had to learn the correct associations between the words and the Beanie Babies. They did not have to learn novel patterns of phonological information for the known words. Had encoding novel phonological information into long-term memory been a more consistent aspect of the investigations (i.e., by using non-word names), we may have observed more consistent effects of a delay period and greater effects of delay in children with CIs than in children with typical hearing.

Given the absence of an effect of delay for both groups of children and that many of the words were already known, it is possible that the children who use CIs may not have demonstrated any word learning at all in this study. 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 children who use CIs 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 word learning during the training phase played an important role in the children's responses. First, the children who use CIs did not perform perfectly for any of the familiar words and their performance on unfamiliar words was not at chance levels. 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 Babies.

Second, if the children who use CIs relied only 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 children with CIs 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 children with CIs 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 contribute to the children's success in selecting the correct animals from a closed set of responses on the receptive tests or recalling the names of the animals from memory on the expressive tests. Thus, while prior word knowledge and familiarity did facilitate the ability of children with CIs 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, name learning took place during the training phase of the experiment.

Another possible reason that children with CIs did not perform as well as children with typical hearing on these word-learning tasks is that there may have been factors that differentiated the groups other than hearing. We were not able to obtain general language measures from all of the children, but it is possible that many of the children with CIs did not have the same language skills as their age-matched peers with typical hearing. Thus, some of the differences in performance on the word-learning tests may reflect general language abilities in addition to differences in hearing. Future studies comparing children with CIs to children with typical hearing with equivalent language abilities would provide additional information about the role of global language abilities on this word-learning task.

In addition to finding differences in name-learning performance between children who use CIs and children with typical hearing, we also observed a main effect for the type of test. Both children with typical hearing and children who use CIs performed significantly better on the receptive word-learning tests than on the expressive tests. The pattern of results was the same for both groups under the delay conditions. The difference in performance between receptive and expressive tasks is also 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 abilities to rapidly encode the spoken names into memory and then learn to associate them with the correct Beanie Baby referent Expressive tests are more difficult because they require the child to construct linguistic 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 words can be accessed more easily from memory because the experimenter provides explicit retrieval cues and context at the time of the test. The child only has to recall the association between the given word and the corresponding Beanie Baby and does not have to construct a phonological representation of the word "on-the-fly" without cues or context. The children with CIs in this study showed larger differences in performance between receptive and expressive tests than the children with typical hearing. It is possible that some of the representations of the words that children with CIs formed were not phonologically well specified and were thus difficult to access from the mental lexicon although they could be recognized in the receptive tests, even from partial information.

Finally, in order to explore whether the variability in performance among children with CIs might be related to any demographic differences, we tested for correlations between the test scores and chronological age, age at implantation, and length of CI use. Only one of the four test scores, receptive immediate mean score, had a statistically significant correlation with any of the demographic factors—age at implantation. Moreover, the one statistically significant correlation accounted for only about 18% of the variance. This is surprising, considering that many studies have shown that age at implantation and length of CI use are significant predictors of outcome performance (e.g., Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1997; Kirk et al., 2002; Miyamoto et al., 1997). One possible reason that we did not observe stronger correlations between performance on the word-learning tests and demographic factors was that our inclusion criteria for this study were such that there was a restricted range of demographics (See Table 1). For example, studies that directly address age at implantation generally have a much larger age-at-implantation range than we did. Kirk et al. (2002) compared 14 children who received their CIs at less than 2 years of age, 70 children who received their CIs at 2–4 years of age, and 22 children who received their CIs after 5 years of age. In contrast, all but three of the children in our study received their CIs between 16 and 42 months of age—a range of only 26 months. Also, we tested only 24 children, which may be too few to detect significant correlations, especially given that the children did not vary much with respect to demographic factors. Given the small sample size and the amount of variance in our sample, it may not be surprising that we failed to detect correlations that are often found in larger studies.

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Implications for Education

The results of this study demonstrate that children who have profound hearing loss have much more difficulty quickly learning novel associations between words and objects, even when the words are familiar phonological patterns. Moreover, their recall of the words, as measured by the expressive tests, was poorer relative to children with typical hearing. It should be noted that these children were all enrolled in excellent oral-only programs and had had between 1 and 3 years of experience with their cochlear implant. Also, most of the children had received their CIs when they were less than 3 years of age. Because they received their CIs at an early age and received excellent education early on, many of these children are likely to be placed into mainstream schools. But while these children are sometimes able to acquire a proficiency in spoken language processing that is comparable to their peers with typical hearing, it is achieved through an enormous amount of speech and language therapy. The findings from this study support the proposal that children who are deaf or hard of hearing and use CIs will need continuous additional assistance even as they enter mainstream school systems. Their learning of novel phonological information may never be as rapid as the learning of their peers with typical hearing. Thus, additional practice

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and repetition with new material may continue to be important for this clinical population of children.

In this study, we did not find any evidence that a 2-hour delay had any greater effect on the performance of children who use CIs than on children with typical hearing. This is an important result because it suggests that while children with early profound hearing loss may have some continued difficulties quickly encoding novel phonological information and word-object associations, they may not have additional problems maintaining representations in long-term memory once they are encoded.

Future Directions

The present study investigated name-learning skills of children following cochlear implantation. We found that although children who use CIs have more difficulty learning names after only a few exposures than children with typical hearing, they do not necessarily display 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 the ability of children who use CIs 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 substantial differences in the quality of the acoustic-phonetic input that CIs deliver for each child, resulting in differences in auditory acuity. Some children who use CIs may be able to form quite detailed phonological and lexical representations from the auditory input provided by their CIs while other children with CIs may only be able to form coarser phonological representations that are easily confused with other phonetically similar words in their lexicons (Cleary, Pisoni, & Kirk, 2005). One way to address this possibility would be to conduct novel word-learning experiments using sets of non-words that are specifically designed to have different degrees of phonological confusability and phonotactic coherence (Cleary et al., 2002; Dillon et al., 2004a; Dillon et al., 2004b; Edwards, Beckman, & Munson, 2004).

Another factor that may affect vocabulary size is phonological processing skills and working memory capacity. Even if children with CIs 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 (Pisoni & Cleary, 2004). 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 phonological processing skills (i.e., phoneme identification, phoneme monitoring, non-word repetition, etc.) and working memory capacities of children who are deaf would help in understanding the relations between phonological coding, working memory, and novel word learning in this clinical population.

In the present experiment, children with CIs, like the children with typical hearing, 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, children with CIs performed worse on the name-learning tasks after a delay than during the immediate testing. These findings suggest that the long-term memory of children who use CIs may be atypical relative to that of children with typical hearing. Markson and Bloom (1997) reported that children with typical hearing were able to recall novel non-words after a 1-month delay, suggesting that their long-term memory for the sound patterns of novel words is very robust. Similar studies with longer delay periods would be useful for investigating the long-term encoding and memory capacities of children who use CIs, topics that have never been studied in this clinical population.

Several traditional demographic factors may also contribute to individual differences in performance among 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 only weak correlations between age at implantation and performance on name-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.

Conclusions

We found that children who received CIs were able to perform a 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 atypical in this clinical population of children compared to age-matched children with typical hearing.

Children who use CIs performed worse than children with typical hearing in all test conditions, but neither group exhibited a decline in performance across delay conditions for familiar words that they knew before testing began. The lower performance of children with CIs on word-learning tasks may be due to differences in phonological processing or verbal working memory capacity rather than storage or retrieval from long-term memory after the words are encoded and stored in lexical memory. Most importantly, this study established the efficacy of a new methodology that can be used in further investigations of the novel word-learning skills of children after cochlear implantation.

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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 Beanie Baby}

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*”}

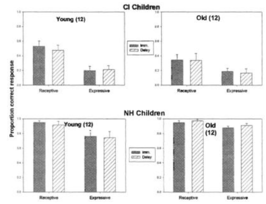

Figure 1.

Mean proportion correct for all names for children who use CIs and children with typical hearing. For each test, there were eight items for the young groups and 16 items for the old groups.

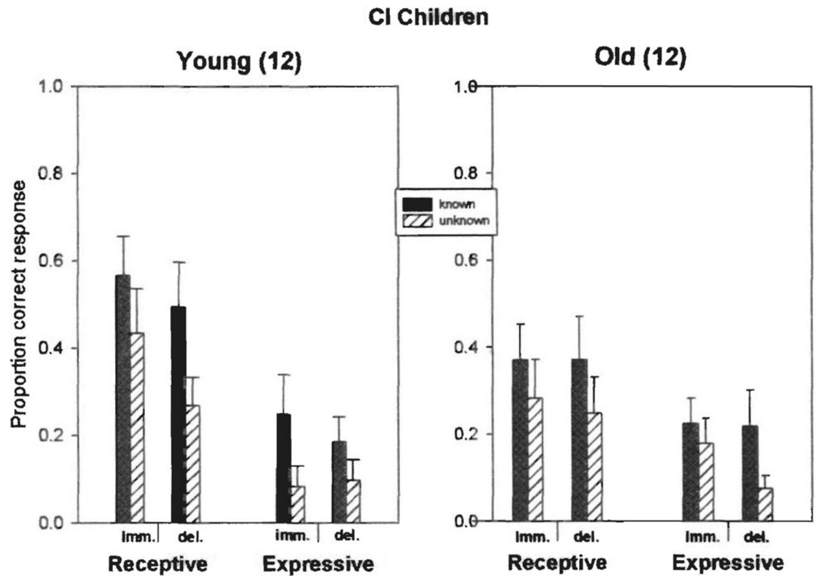

Figure 2.
Mean proportion correct for children who use CIs separated by whether they had prior knowledge of the words.

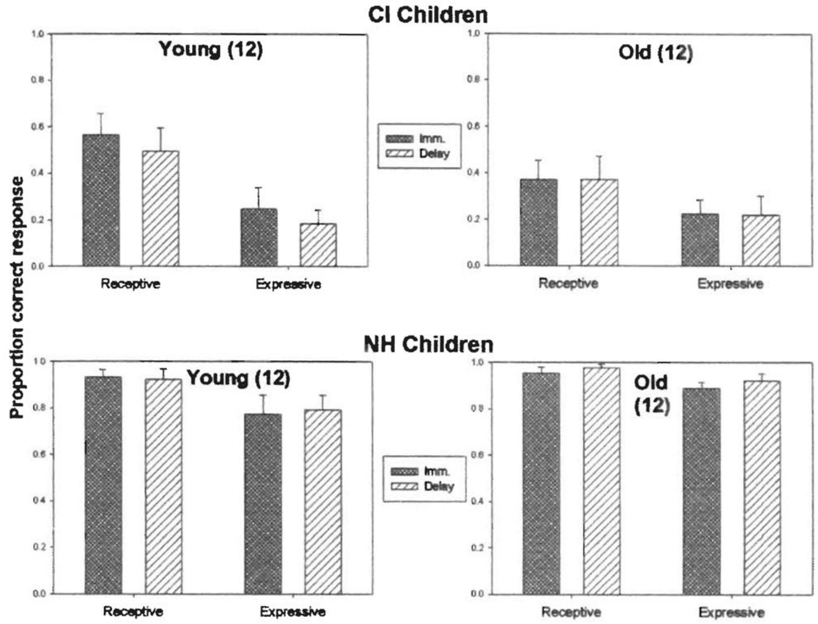

Figure 3.

Mean proportion correct of known words only for children who use CIs and children with typical hearing.

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Table 1

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.

	Age at Testing		Age at Implantation		Length of CI use	
Group (N)	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Young CI (12)	37.7	28–46	20.6	10–34	17.1	12–26
Old CI (12)	59.5	49–68	37.3	25–55	22.3	12–37
Young NH (12)	38.0	28–46				
Old NH (12)	58.4	49–64				

Table 2

Description of Beanie Babies, new attribute names, and the frequency with which each new name was generated.

Description	New attribute name	Frequency of new name response (%)	Description	New attribute name	Frequency of new name response (%)
Shark	*Teeth*	11.8	Dalmatian	*Spots*	46.6
Blue Jay	*Blue*	36.6	Bear with Halo	*White*	6.1
Bat	*Wings*	13.7	Cocker Spaniel	*Ears*	14.9
Cockatoo	*Pink*	29.6	Squirrel	*Bushy*	11.1
Bull	*Red*	32.4	Rabbit	*Cottontail*	14.1
Goat	*Horns*	8.2	Spider	*Legs*	14.9
Brown Bear	*Fuzzy*	9.8	Striped Cat	*Stripes*	25.6
Rat	*Tail*	18.5	Rhinoceros	*Gray*	7.8

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Table 3

Word set stimuli.

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	Bear with Halo
	Ears	Cocker Spaniel
	Bushy	Squirrel
D	Cottontail	Rabbit
	Legs	Spider
	Stripes	Striped Cat
	Gray	Rhinoceros

Table 4

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

Score	AF	RI	RD	EI	ED
CI Young Group					
Average familiarity rating (AF)	-	.13	.53*	.43	.53*
Receptive immediate mean score (RI)		-	.76**	.46	.33
Receptive delay mean score (RD)			-	.62*	.66**
Expressive immediate mean score (EI)				-	.71**
Expressive delay mean score (ED)					-
CI Old Group					
Average familiarity rating (AF)	-	.60*	.63**	.64**	.81**
Receptive immediate mean score (RI)		-	.41	.66**	.43
Receptive delay mean score (RD)			-	.44	.47
Expressive immediate mean score (EI)				-	.69**
Expressive delay mean score (ED)					-

Table 5

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

	CA	AI	CI use	RI	RD	EI	ED
Chronological age (CA)	-	.86**	.46*	−.30	−.30	−.02	−.13
Age at implantation (AI)		-	−.07	−.42*	−.32	−.17	−.22
Length of CI use (CI use)			-	.15	−.03	.26	.14
Receptive immediate mean score (RI)				-	.75**	.57**	.76**
Receptive delay mean score (RD)					-	.61**	.79**
Expressive immediate mean score (EI)						-	.64**
Expressive delay mean score (ED)							-