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**Auditory Learning and Adaptation after Cochlear Implantation:
A Preliminary Study of Discrimination and Labeling of Vowel Sounds by
Cochlear Implant Users¹**

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Auditory Learning and Adaptation after Cochlear Implantation: A Preliminary Study of Discrimination and Labeling of Vowel Sounds by Cochlear Implant Users

Abstract. This study examined two possible reasons underlying longitudinal increases in vowel identification by cochlear implant users: improved labeling of vowel sounds and improved electrode discrimination. The Multidimensional Phoneme Identification (MPI) model was used to obtain ceiling estimates of vowel identification for each subject, given his electrode discrimination skills. Vowel identification scores were initially lower than the ceiling estimates, but they gradually approached them over the first few months post-implant. Taken together, the present results suggest that improved labeling is the main mechanism explaining post-implant increases in vowel identification.

Introduction

Cochlear implants (CI's) have been shown to be a safe and effective treatment for profound sensorineural deafness in postlingually deafened adults and in prelingually deaf children. It is not surprising that speech perception scores of the latter continue to increase many years after implantation, because these children must develop an oral language system and develop speech perception and production skills after receiving a CI. However, the full benefit that CI's provide to postlingually deafened adults is not instantaneous either. Normally, asymptotic speech perception performance (i.e., identification of vowels, consonants, words, sentences or running speech) is not apparent for at least several months or weeks after implantation. What are the reasons for this delay, and what is the nature of the underlying process that is indexed by increases in speech perception scores?

There are at least two kinds of reasons for this process. First, CI users may improve their *discrimination* skills over time. To understand speech, CI users must be able to discriminate sounds along relevant acoustic dimensions. For example, vowels are reasonably well characterized by the first two or three formant frequencies (Peterson & Barney, 1952; Hillenbrand, Getty, Clark, & Wheeler, 1995). For CI users, different formant frequencies result in stimulation of different electrodes and thus different cochlear locations. Consequently, the ability to discriminate stimulation delivered to different electrodes may be an important prerequisite to identifying vowels. Unfortunately, the number of intracochlear electrodes is relatively small (22 at most) compared to the number of discriminable steps in a normal hearing cochlea, a factor that limits the spectral information that CI users can receive. Further limitations are due to the fact that even with this relatively small number of electrodes, the ability of CI users to discriminate stimulation delivered to different electrodes is less than perfect. Given that electrode discrimination ability is likely a limiting factor in CI users' reception of spectral information, longitudinal improvement in this ability may underlie the observed improvement in, for example, vowel perception.

Second, CI users may improve their vowel identification over time due to improved *labeling* of speech sounds. The percepts elicited from a cochlear implant are different from normal acoustic hearing, and listeners may be initially unable to label the sounds they hear. In other words, different speech sounds may be distinct from each other (i.e., discrimination may not be the limiting factor in the identification of these sounds), but they may not sound the way listeners *expect* them to sound, leading to identification errors. The possibility of labeling errors is quite plausible, given the fact that cochlear implants do not stimulate the entire neural population of the cochlea but only the most basal 25 mm at best because the electrode array cannot be inserted completely into the cochlea. Therefore, cochlear implants may

stimulate cochlear locations that are more basal and thus elicit higher pitched percepts than normal acoustic stimuli. For example, when the input speech signal has a low frequency peak (e.g. 300 Hz), the most apical electrode is stimulated. The neurons stimulated in response to this signal may have characteristic frequencies of 1000 Hz or even higher. This pronounced modification of the peripheral frequency map might lead to errors in identifying speech sounds, unless the auditory nervous system of CI users is adaptable enough to successfully “re-map” the place frequency code in the cochlea. This adaptation, however, may require weeks or months and may underlie the improvement in speech perception observed after cochlear implantation in postlingually deafened adults. It is important to remember that an individual listener may suffer both labeling and discrimination limitations to speech perception simultaneously.

The goal of this study was to assess the contribution of discrimination and labeling to vowel identification by Spanish-speaking cochlear implant users. To this end, vowel identification and electrode discrimination were assessed longitudinally over several months, starting the day of initial stimulation. The Multidimensional Phoneme Identification (MPI) model (Svirsky, Meyer, Kaiser, Basalo, Silveira, Suarez, Lai, & Simmons, 1999; Svirsky, 2000) was used to obtain “ceiling estimates” of vowel identification, representing the best performance a listener could achieve, given his electrode discrimination skills.

Materials and Methods

The subjects were seven cochlear implant users, all of them native Spanish speakers, implanted by Dr. Suárez in Montevideo, Uruguay. They all had postlingual, profound-to-total deafness. Six of them used the Nucleus-22 device while the remaining one used the Med-El Combi-40 device.

Vowel identification and electrode discrimination were measured up to 6.5 to 32 months after initial stimulation. The first testing session for 6 of the 7 subjects took place immediately after initial stimulation, before they heard any other speech sounds through the implant. Vowel identification testing was repeated at the end of the initial stimulation session for two of the seven subjects. The other subject (subject 4, who was the Med-El user) was tested for the first time 10 days after initial stimulation. Vowel identification testing was done by presenting each one of the five Spanish vowels ten times, in random order, in j-vowel-d context (where “j” indicates the Spanish velar fricative). Each one of the ten repetitions of each vowel was separately uttered, recorded and presented. The speaker was either a male or a female speaker of Uruguayan Spanish, whose utterances were recorded on a personal computer. Results were scored as the percentage of correct responses for the 50 stimuli. In one case (Subject 2, session done three months post-implant), both the male and the female vowels were presented, and the analyses described below were conducted separately for the male speaker and the female speaker datasets.

Electrode discrimination (or, equivalently, discrimination of place of stimulation in the cochlea) was assessed with a pitch-ranking task. Two adjacent electrodes were stimulated in sequence, for 500 ms each with a 500 ms pause in between, and the subject had to say which one of the two sounds was higher pitched. All sounds were presented at maximum comfortable level, and these levels were balanced for equal loudness prior to presentation. Due to the limited available testing time, only nine pairs of adjacent electrodes were tested in Nucleus-22 users: these were pairs 1-2, 2-3 and 3-4 (at the basal end of the electrode array); 9-10, 10-11 and 11-12 (in the middle of the array); and 17-18, 18-19 and 19-20 (at the apical end of the array). Each pair of electrodes was stimulated eight times in random order, with the more basal electrode being stimulated first about 50% of the time. The Med-El user had 11 active electrodes and in her case all pairs of adjacent electrodes were tested. Average d' , an index of the ability to correctly pitch rank electrodes was calculated for each subject based on a procedure similar to that

described by Levitt (1972). A d' of 0 indicates no discrimination, $d'=1$ indicates minimum discrimination ability, and a d' that is greater than 3 indicates near perfect discrimination.

A previous study (Svirsky et al., 1999) provided evidence that the relevant perceptual dimensions for vowel perception in Spanish were A2 (i.e., the amount of energy delivered to electrodes encoding frequencies in the second formant region), F1 and F2 (i.e., the centers of gravity for stimulation pulses delivered to electrodes encoding the F1 and F2 formant frequency ranges, respectively, weighted by pulse amplitude). The MPI model (for a full description see Svirsky, 2000) was used to obtain ceiling estimates of vowel identification, assuming that F1, F2 and A2 were indeed the perceptual dimensions used by all subjects. The MPI model generates a predicted confusion matrix based on a listener's just noticeable differences (JND's) along the relevant perceptual dimensions. In this study, the JND's for the F1 and F2 dimensions were estimated as the inverse of the d' values that were derived from the pitch ranking experiment. Because JND for the A2 dimension was not measured in this study, predictions of vowel perception scores were obtained for each individual using a wide range of JND values for A2. Normally, the MPI model can be used to estimate a listener's maximum possible vowel (or consonant) identification performance, given his JND's for all the relevant perceptual dimensions. Instead of calculating a single ceiling estimate, in this study we obtained a range of values where the actual maximum was expected to fall. These ranges sometimes changed over time, as the listener's pitch ranking skills (and therefore the estimates for F1 and F2 JND's) increased or decreased. The ceiling ranges were compared to each listener's actual vowel identification scores. When the vowel identification scores fall within the ceiling range (which is partly determined by the listener's pitch ranking skills), this suggests that the listener may be labeling vowels in an optimal fashion, and vowel identification is only limited by his ability to discriminate these speech sounds. Conversely, when vowel identification scores are substantially below the ceiling range predicted by the MPI model, this represents strong evidence that the listener is not using all the acoustic information that is available to him, possibly due to limitations in vowel labeling.

Results

Table I shows electrode discrimination scores (d') for all subjects as a function of time. The first four subjects did not show any systematic improvement after the first testing session. In fact, Subject 1 showed a substantial decrease in d' between the day of initial stimulation and a second testing session seven months later. Subjects 5, 6, and 7, on the other hand, showed better discrimination in later testing sessions than they did on the day of initial stimulation.

Although a detailed description exceeds the scope of this manuscript, it should be noted that the MPI model provided good fits to the subjects' confusion matrices that were obtained at least a few months after initial stimulation. In other words, the model was able to predict which vowel pairs would be confused by the subjects as well as which vowel pairs would not be confused. In addition, the model predicted that, for given levels of frequency and amplitude discrimination, vowel identification scores would be higher when the female speaker was used than when the male speaker was used. This is precisely what happened during the three-month post-implant session for Subject 2, the only session where both the male and the female vowels were administered (see the top right panel of Fig. 1). These results provide some validation for the choice of dimensions employed in this study and for the MPI model itself, validating the use of ceiling estimates obtained with it.

Subject	Time after initial stimulation (months)	Average electrode discrimination (d')
1	0	2.3
	7	0.76
2	0	1.2
	3	0.94
	20	0.86
3	0	0.69
	0.1	1.02
	11	0.35
	25	0.64
4	0.3	3.21
	15	2.30
5	0	0.65
	3	2.17
	15	1.94
6	0	0.56
	4	1.75
7	0	0.56
	12	1.18

Table 1. Average electrode discrimination as a function of time. For subjects 1–4, discrimination did not improve after the day of initial stimulation (and it even decreased in some cases), but subjects 5, 6 and 7 did show better electrode discrimination when they were tested a few months after initial stimulation.

Figure 1 shows the vowel identification scores for subjects 1-4, as a function of time. Vertical bars indicate the ceiling ranges for subjects 1-3, as predicted by the MPI model. Predictions were not obtained for subject 4, who used a different device than the other subjects. The day of initial stimulation, subjects 1-3 obtained scores that were substantially lower than the ceiling ranges, but within 2-5 months they all reached vowel scores that were within, or quite close to the ceiling ranges.

Figure 2 shows similar data for subjects 5-7. Because in these cases d' increased with time, the ceiling ranges increased accordingly as a function of time. However, subjects 5 and 6 showed the same pattern as subjects 1-3, failing to reach their ceiling ranges at initial stimulation but reaching those ranges 3-6 months later. Subject 7 was the only one whose initial vowel scores were within his ceiling range at initial stimulation.

Subjects 1 and 5, who were tested at the beginning and at the end of the initial stimulation session, showed a marked increase in vowel identification during the session. Both scored only 28% correct immediately after the implant was turned on, and they increased their scores to 58% (subject 1) and 48% (subject 5) by the end of the two-hour session.

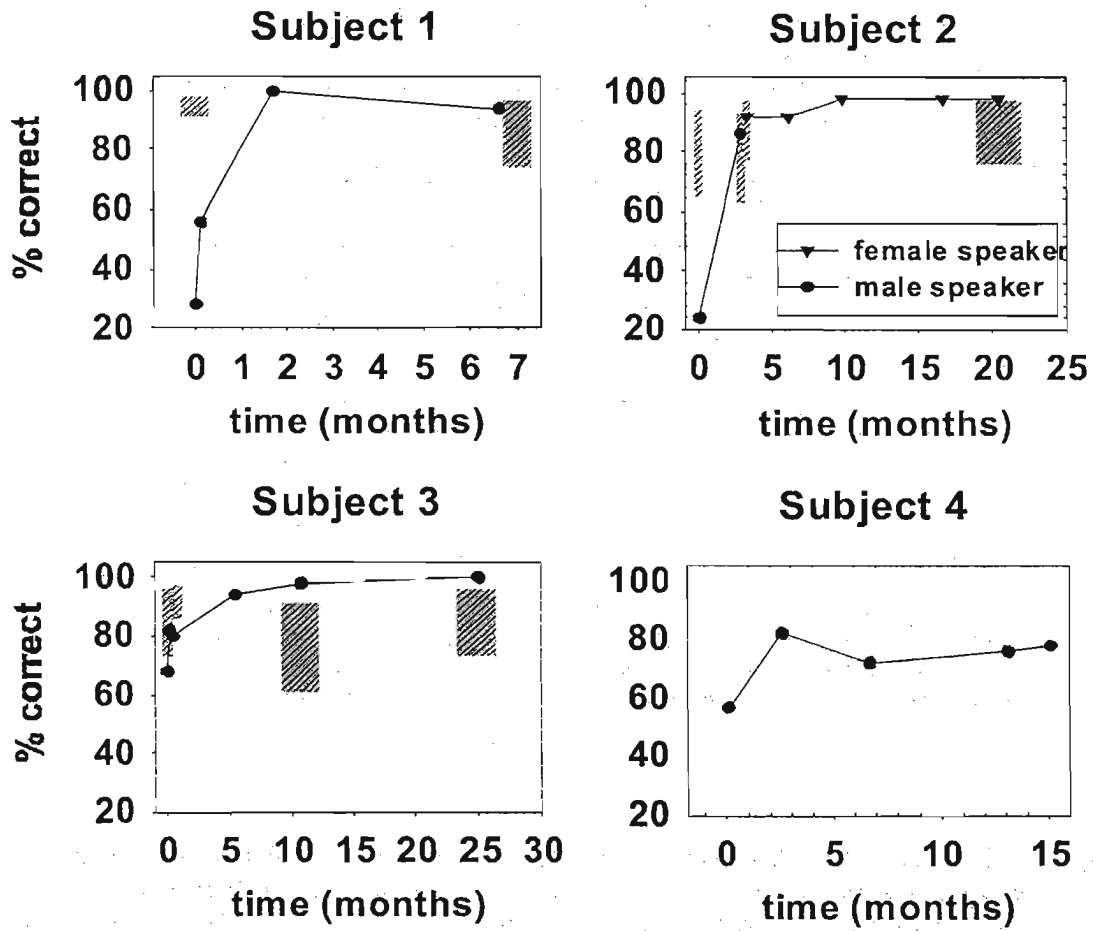


Figure 1. Vowel identification as a function of time for subjects 1-4, whose electrode discrimination skills did not increase post-implant. The vertical bars represent ceiling estimates of vowel identification performance for each individual, as estimated with the MPI model based on the listener's electrode discrimination. Estimates were not obtained for subject 4, who used a different device than the others. Vowel identification by subjects 1, 2 and 3 reaches ceiling estimates by 2-5 months post-implant.

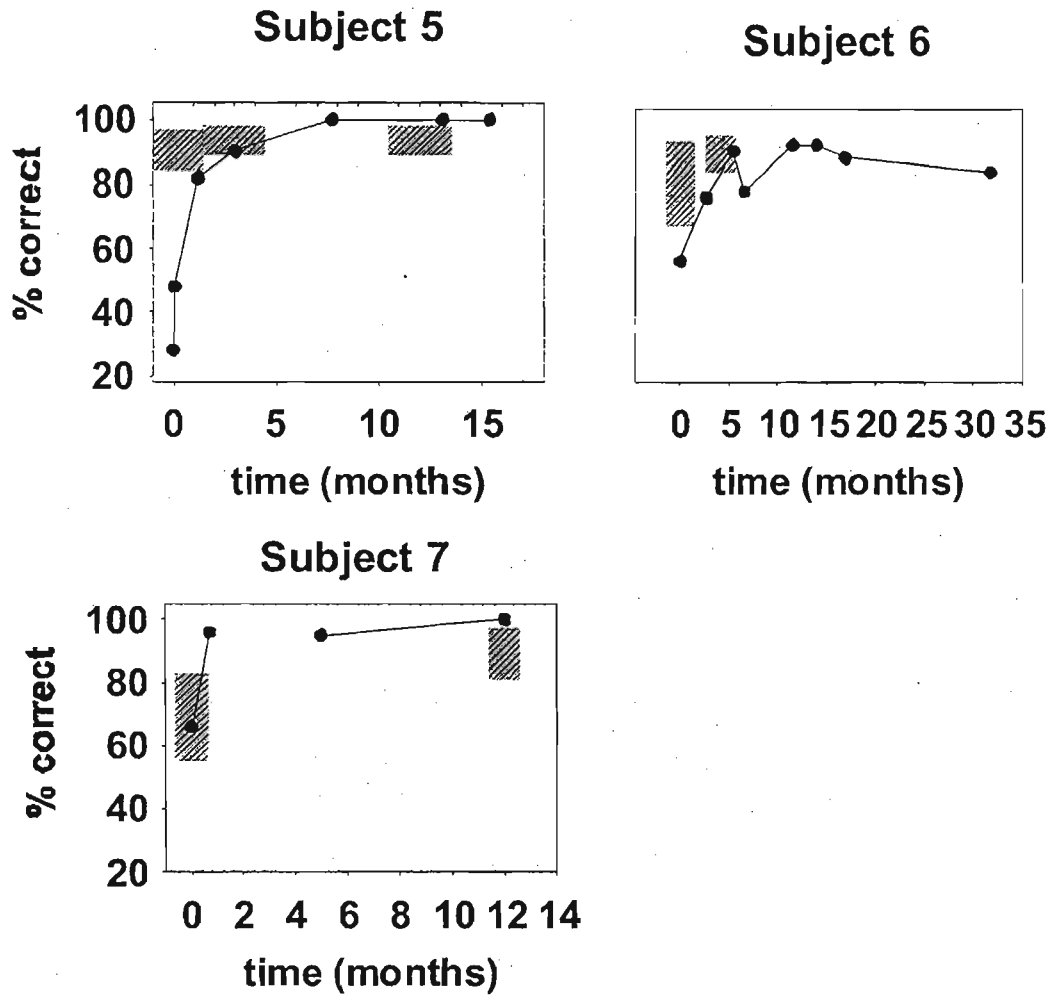


Figure 2. Vowel identification as a function of time for subjects 5-7, whose electrode discrimination skills did increase post-implant. Vowel identification by subjects 5 and 6 reaches ceiling estimates by 3-5 months post-implant, while subject 7 was the only one whose vowel identification scores were within the ceiling estimate range the day of initial stimulation.

Discussion

All subjects showed the expected pattern of improvement in vowel scores over the first few months after initial stimulation. In four of the seven subjects, this change was not accompanied by an increase in electrode discrimination. Taken together, these data suggest that improvement in labeling of vowel sounds was the main mechanism underlying longitudinal increases in vowel identification for these four subjects. The other three subjects presented a more mixed picture, with simultaneous increases in electrode discrimination and in vowel identification. However, predictions obtained with the MPI model suggest that the improvement in electrode discrimination was insufficient to explain the pronounced increases in vowel identification observed in two of these three subjects: in their case, the improvement in vowel identification may have been due to parallel increases in discrimination and labeling skills. These results are consistent with those of Harnsberger et al. (in press), who asked cochlear implant users to select the regions of the F1-F2 plane that sounded like a given vowel. One goal of their study was to determine whether the basalward frequency shift imposed by cochlear implants results in systematic response biases in this task. No such bias was found, indicating that their subjects (who, unlike the subjects in the present study, had used their cochlear implants for at least one year) had learned to label vowels correctly; and their vowel perception was limited mostly by their ability to discriminate formant frequencies. An interesting direction for future research may be to use the method-of-adjustment task employed by Harnsberger et al. longitudinally, starting immediately after implantation, to directly measure changes in the CI users' ability to label vowels correctly. Additionally, it would be informative to image the cochleas of these subjects in order to obtain estimates of electrode location and cochlear length, which in turn would help refine estimates of the amount of basalward shift in these cochlear implant users.

The MPI model was used in this study to tease apart the effect of improved labeling and improved discrimination on speech perception by CI users. This kind of information may be clinically useful because it may suggest areas to be stressed during auditory rehabilitation following cochlear implantation. Subjects whose scores are well below their ceiling estimates may especially benefit from training designed to help them label speech sounds. Conversely, subjects who do reach their ceiling may benefit from training that helps them discriminate better along the acoustic and perceptual dimensions known to be important in speech perception.

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**Early Word Learning Skills of Hearing-Impaired Children
Who Use Cochlear Implants: Development of Procedures
and Some Preliminary Findings¹**

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Early Word Learning Skills of Hearing-Impaired Children Who Use Cochlear Implants: Development of Procedures and Some Preliminary Findings

Abstract. In recent years, cochlear implant (CI) technology has advanced and can now greatly facilitate the spoken language learning of prelingually deafened children. However, there is a great deal of variability in linguistic outcome measures among pediatric CI recipients. Many factors may contribute to this variability in performance, including age of implantation, amount of speech therapy, cognitive factors (such as memory span), and numerous linguistic factors. An important basic linguistic skill that may play a central role in later language development is the ability to map the sound patterns of spoken words onto their referents. This report summarizes and describes the development of a procedure and some preliminary findings of 2- to 5-year-old CI users' and normal-hearing controls' word learning abilities. Each child was presented with either four (2- and 3-year-olds) or eight (4- and 5-year-olds) Beanie Babies™ and labels for their names using interactive play scenarios. Across multiple sessions, the participants were tested for receptive and expressive knowledge of the learned names. This report also describes current plans to test more children and to compare the results of this test with subsequent outcome measures in order to ascertain whether there are any correlations between early object labeling abilities and later language skills.

Introduction

Cochlear implants (CIs) provide profoundly deaf children with the possibility of learning spoken language by allowing them to receive auditory input. However, CIs provide an impoverished signal, and children who receive them have had some amount of prior auditory deprivation. These two factors and others may contribute to the finding that some profoundly deaf children do not succeed in learning spoken language. One of the most interesting and challenging discoveries about pediatric CI users is that there are enormous individual differences in language skills after implantation. Recently, Pisoni, Svirsky, Kirk, and Miyamoto (1997) showed that for individual children with CIs, performance on speech perception, speech production, and language tests were highly correlated with each other. They postulated that the common variance might be attributed to cognitive processing skills, including the phonological encoding, storage, and retrieval of spoken words. In this project, we investigate the early word learning abilities of hearing-impaired children with cochlear implants.

Normal-hearing children begin producing words at approximately 12 months of age. By 18 months, most infants can produce over 50 words and they seem to learn 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 to their referents (e.g., Clark, 1973, 1983; Markman, 1991; Nelson, 1988). Recently, some work has explored children's ability to encode the sound patterns of words. Jusczyk and colleagues have shown that by 8 months, infants can encode the sound pattern of words into memory (Houston & Jusczyk, submitted; Jusczyk & Aslin, 1995; Jusczyk & Hohne, 1997). The ability to encode phonological information into memory enables children to form word representations. Gathercole and Baddeley (1989, 1990) have found a strong relationship between phonological working memory span and vocabulary size. Huttenlocher, Haight, Bryk, Seltzer, and Lyons (1991) found a

significant correlation between how often parents use words and their children's acquisition of those words, suggesting that frequency of exposure affects how quickly children learn words. Taken together, all these findings suggest that early word learning may be an important subcomponent or skill that affects later language development.

Children with hearing impairment may be at a disadvantage for encoding phonological information because, to varying degrees, they are unable to discriminate the fine acoustic-phonetic details of speech in their surrounding environment. There is some evidence to suggest that any degree of hearing loss may lead to problems in phonological processing and word learning. For example, in a study of hearing-impaired children who used hearing aids, Gilbertson and Kamhi (1995) assessed children's ability to encode phonological information and to learn words when wearing their hearing aids. The investigators found that hearing-impaired children's unaided level of hearing loss (ranging from mild to moderate) did not correlate significantly with word learning abilities but the ability to encode phonological information did correlate. One group of the hearing-impaired children, when using sensory aids, performed as well as normal-hearing children on language learning tasks, whereas another group had much more difficulty. However, whether any particular hearing-impaired child fell into the normally performing group or the group that had more difficulty did not depend on his/her unaided level of hearing loss. The authors concluded that even a mild hearing loss was a significant risk factor for language impairments characteristic of children with Specific Language Impairment (SLI)³.

It is possible that difficulty in early word learning for some children may be due to difficulty with a specific aspect or stage of word learning. Susan Carey and colleagues have described the word learning process in terms of two stages (Carey, 1978; Carey & Bartlett, 1978). The first stage, "fast mapping", refers to the initial encoding of the sound pattern of the words and some basic understanding of the meaning. The second stage involves developing a fuller understanding of words by hearing them in several different contexts so that hypotheses about their meaning can be tested. Carey and Bartlett (1978) showed that after a single presentation of a word, preschool children already started to form some basic hypotheses of the meaning of the word when the word was used to name a color term. In another study, Heibeck and Markman (1987) have shown that children as young as two years show fast mapping of shape and texture terms as well as color terms. Hence, while a complete understanding of words may involve a complex and lengthy process, the basic process may begin with an initial "fast mapping" stage of word learning that is immediate and crucial in establishing a solid foundation for later lexical development.

The fast mapping stage of early word learning requires children to encode the phonological information of words very rapidly. Children who have difficulty with phonological encoding may show great difficulty learning words. There may be a high incidence of poor phonological encoding ability among CI users for two reasons. First of all, the auditory information provided by a CI is impoverished when compared to normal hearing. It is possible that this impoverished signal may be a limiting factor in encoding the sound pattern of words. Second, hearing impairment may be a risk factor for SLI (Gilbertson & Kamhi, 1995), and one of the factors of SLI is difficulty with phonological processing skills (Leonard, 1998). Thus, it is possible that children with SLI have difficulty with fast mapping. Support for this possibility has come from a series of studies by Rice and colleagues who have shown that children with SLI

³ Specific Language Impairment (SLI) is often operationally defined as the presence of language impairments in the absence of other cognitive and sensory impairments, including hearing loss. However, it is possible children could have language impairments associated with SLI (e.g., mapping sound to meaning) in addition to language impairments specifically caused by hearing loss (e.g., encoding phonological information). In this respect, it is reasonable to discuss the possibility of hearing impaired children also having 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 normal language learners in order to display even a basic understanding of the words. Moreover, children with SLI were particularly prone to forgetting the meaning of words after a short delay, suggesting that their long-term memory representation for words was impoverished. In sum, hearing-impaired children who use CIs may have some difficulty quickly learning novel words because the speech signal they receive is impoverished. Some of these children might have difficulty due to poorly developed phonological processing skills.

It is possible that the ability to quickly encode the sound patterns of words and some basic aspects of meaning may account for the individual variability observed in the language skills of children who use CIs. In the present investigation, we explore the possibility that children who use CIs will demonstrate a high degree of variability in learning novel words after only a few exposures. If this hypothesis is correct, then we would expect there to be a correlation between performance on an early word learning task and other language outcome measures, such as vocabulary knowledge and language development.

The goal of this project was to develop a procedure that assesses young children's ability to learn words after only a few exposures. This project is part of an ongoing investigation to explore how quickly children with cochlear implants can map sound patterns onto referents and to determine the relationship between measures of early word learning and other outcome measures such as spoken word recognition, speech intelligibility and receptive and expressive language abilities. This report describes the results of a preliminary study that was conducted to develop a procedure that can be used to test preschool-aged children's ability to learn words after a brief exposure period. The first part of the project involved selecting names for the Beanie Baby™ stuffed animals that would be taught to the children. This was done by eliciting names from adult participants. Next, we describe the results of a pilot study with several children with CIs who were given variations on our initial word-learning procedure. The results of the pilot testing with the children helped us modify several aspects of the procedure. Finally, we present preliminary data from twenty-four normal-hearing children and two children with CIs.

Pilot Phase

Selection of Stimulus Materials

The stimulus materials used in all of the experiments 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 the names while others might not and because some of the names were related to physical attributes of the stuffed animals while others were not. We decided to elicit names from adult participants that corresponded to salient physical attributes of the Beanie Babies™. This was done to facilitate the association between the names and the Beanie Babies™. Because many of the Beanie Babies™ have several features that could be considered salient, a pilot experiment was conducted to determine the characteristics of each Beanie Baby™ that were most perceptually salient. The goal of this pilot study was to select labels for each Beanie Baby™ that would be used in the experimental study.

Methods

Participants. The participants were 37 IU undergraduates, with no reported 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 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. In order to control for possible familiarity effects with the original names, we developed a new set of names for the Beanie Babies™. We decided as a first pass to create the new names in such a way as to give a semantic bootstrap to enable word learning, for example, by using a distinguishing physical characteristic of the animal. The Beanie Babies™ were therefore selected from a larger set of Beanie Babies™ on the basis of whether they had distinguishing characteristics that could be easily named, such as a very 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 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 answer 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 tallies 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. The second most common response was "Fuzzy," which we used as it describes an 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 lists each original Beanie Baby™ stuffed animal name and description, its new attribute name derived from this procedure, and 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 (%)
<i>Crunch</i> the Shark	<i>Teeth</i>	11.8	<i>Dotty</i> the Dalmatian	<i>Spots</i>	46.6
<i>Rocket</i> the Bird	<i>Blue</i>	36.6	<i>Halo</i> the Angel Bear	<i>White</i>	6.1
<i>Batty</i> the Bat	<i>Wings</i>	13.7	<i>Spunky</i> the Cocker Spaniel	<i>Ears</i>	14.9
<i>Kuku</i> the Bird	<i>Pink</i>	29.6	<i>Nuts</i> the Squirrel	<i>Bushy</i>	11.1
<i>Snort</i> the Bull	<i>Red</i>	32.4	<i>Nibbly</i> the Bunny	<i>Cottontail</i>	14.1
<i>Goatee</i> the Goat	<i>Horns</i>	8.2	<i>Spinner</i> the Spider	<i>Legs</i>	14.9
<i>Buster</i> the Bear	<i>Fuzzy</i>	9.8	<i>Prance</i> the Tabby Cat	<i>Stripes</i>	25.6
<i>Tiptoe</i> the Mouse	<i>Tail</i>	18.5	<i>Spike</i> the Rhino	<i>Gray</i>	7.8

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

Procedure Development

Once the new names were chosen, a piloting phase was initiated to develop a procedure for assessing word learning in young children with cochlear implants after a brief exposure period. The initial conception of the experiment was as follows. Children would be taught the new names of the Beanie Babies™. Younger children (2;0 – 3;11) would be taught four names and older children (4;0 – 5;11) would be taught eight names. In order to get a baseline measure of how likely it was that the children would spontaneously label the Beanie Babies™ with the target labels, the experiment started with two pretests. In the first pretest, children were presented with each of the Beanie Babies™ they would be taught and were simply asked to give it any name, using a free response format. The second pretest used a forced-choice procedure. The Beanie Babies™ were placed in a row in front of the child, and the child was asked to select the one that might have the name that the experimenter presented to them. For example, the experimenter might say, “Which one do you think is named *Fuzzy*?” The experimenter did this for each of the Beanie Babies™.

Following the pretests, each child was given a sequence of training phases in which they were taught the names of the Beanie Babies™, one at a time, using play scenarios. The experimenter provided the name of each Beanie Baby™ exactly three times. Toys were used to give each Beanie Baby™ some sort of memorable personality. For example, in one scenario, the experimenter would say, “This is *Fuzzy*. *Fuzzy* likes to eat grapes. Can you give the grapes to *Fuzzy*?” After exposure and training with each Beanie Baby™, the children were given tests to assess whether or not they learned to associate the names with the Beanie Babies™. The first test used a forced-choice procedure, exactly like the second pretest. The second test used a cued-recall procedure. The cued-recall test required an expressive response from the child. In this procedure, each Beanie Baby™ was presented one at a time to the child as a cue, and the child was asked to recall its name from memory.

The initial procedure underwent several stages of development during the piloting phase. Six children who use cochlear implants participated in the piloting phase: SHM (4;1), SHZ (6;2), SHS (2;5), SNW (3;2), SMH (5;11), and SOC (4;1). Here, we will summarize our major observations during the piloting phase and describe how these pilot results shaped the final design of the experimental procedures.

- **Children often persevere on the names they initially choose for the Beanie Babies™.** The initial conception of the procedure involved two pretests. During the procedures, we discovered that the children who were given the pretests (SHM and SHZ) were very resistant to learning new names for the Beanie Babies™. Instead, they tended to persevere on the names that they initially selected. Hence, the pretests were dropped from the procedure.

- **Children who use cochlear implants need several exposures to words.** In the first stage of the pilot, children received only three exposures to each name before they were tested. With only three exposures per item, two of the participants in the pilot study did not perform above chance. Given the poor performance of the pilot subjects tested under this condition, the number of exposures was increased from three to eight for each name.

- **Imitation is important for word learning.** Another factor that seemed to contribute to the poor performance in the early stages of our pilot testing was that no measure was taken to ensure that the children actually encoded the names they were being taught. To make sure that the children encoded the sound pattern of the words, we asked the children to repeat the names that we produced. It is possible that the act of producing the words helps with children's memory for words because there may be a strong developmental interaction between perception and production (e.g., Vihman, 1993). There are recent data supporting the importance of immediate memory and imitation in novel word learning (Gupta & MacWhinney, 1995).

- **Children often show a preference for new Beanie Babies™.** During one phase of the pilot testing we decided to try teaching the names of the Beanie Babies™ to the children one at a time. Thus, they were first presented with one animal and then were given the forced-choice and cued-recall tests for that animal. If they were correct, they were taught the name of an additional Beanie Baby™. If they were incorrect, they were re-taught the original name. Each time they were correct on both the forced-choice and cued-recall tests, the set size increased by one. The set size increased until the child could no longer respond correctly on three consecutive trials. In carrying out this procedure with SHS, SNW, and SMH, we discovered that as the set size increased, the children showed a novelty preference for the most recent Beanie Babies™ presented. As a result, we decided that during each session, the child would be presented with all of the Beanie Babies™ (four or eight), one at a time, and then tested on all of them.

- **A minimum of one year of cochlear implant experience is necessary.** One of our initial criteria for inclusion in the study was that the child must have had at least six months of implant use. The participant SOC, who had exactly six months of experience, clearly did not have sufficient auditory skills to participate in the study and carry out the tasks. Hence, we increased the criterion to one year of implant use.

Experiment

The piloting phase ended when a procedure was settled on that was simple enough for the pilot participants to complete but did not yield ceiling performance. Children were taught and tested on two sets of Beanie Babies during one session. Their long-term memory of the names

was subsequently assessed in a second session by re-testing them at least two hours later. The final design is described here and some preliminary results from two children with CIs and twenty-four normal-hearing children are reported below.

Methods

Participants. Two groups of children participated in this study. One group of four children was recruited from the population of children with cochlear implants who are routinely followed as part of the ongoing longitudinal studies at Indiana University. The criteria for inclusion was that they were between the ages of 2;0 and 5;11, use oral communication, and had at least one year of cochlear implant experience. Two children who use CIs (ages: 3;2 and 3;10) completed the experiment, but the other two children (ages: 2;4 and 4;2) were unable to complete the experiment due to failure to give any responses and are not included in the Results section. 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. All 24 completed the initial experiment. Seven of the normal-hearing children and the two children with CIs who completed the initial testing participated in the long-term memory test.

Materials. The stimulus materials consisted of 16 Beanie Babies™ that were assigned names by normal hearing college students (see Stimuli Selection above). Each name corresponds 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 2. 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 identifying the attributes in the tasks. For example, when they were asked to identify “Wings”, three of the four Beanie Babies™ had wings.

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 2. Word set stimuli.

Procedure. Children were taught a set of Beanie Babies™ (Training Phase 1) and then given forced-choice and 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, children were given the same tests using the first set of Beanie Babies™ and then using the second set (Long-Term Memory Test).

Training Phase 1. *Children younger than four years.* Each child is exposed to 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. One experimenter (Experimenter 1) interacted with the child while a second experimenter (Experimenter 2) assisted Experimenter 1 in following the correct order. Experimenter 2 also recorded the children's responses and 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. A different toy prop was used to create a different play scenario with each Beanie Baby™ in order to keep the task interesting. During the play interaction with each 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. 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.

Children between four years and six years. The training phase was the same with older children as with the younger children, except that eight Beanie Babies™ were taught instead of four.

Testing Phase 1. *Forced-Choice Test.* The Testing Phase consisted of a forced-choice identification task and a cued-recall test given immediately afterwards. For the forced-choice identification test, all of the Beanie Babies™ (four or eight) were placed in a row in front of each child and 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™ 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 response was correct. The Beanie Baby™ was then placed back in the row and the next trial was initiated. Each Beanie Baby™ was requested exactly once.

Cued-Recall Test. For the cued-recall task, 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. Experimenter 2 recorded any response. This procedure was repeated for each Beanie Baby™.

Training Phase 2. This phase was the same as Training Phase 1 except that a different group of four or eight Beanie Babies™ was presented to the child.

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

Long-Term Memory Test. On the same day of testing, but at least two hours after the completion of Testing Phase 2, the child was tested a second time, in order to assess long-term memory for the names. During the long-term memory test, Testing Phase 1 and Testing Phase 2 were repeated again without any retraining or feedback.

Results

The mean accuracy scores for all of the tests are summarized in Table 3 for normal-hearing children, and in Table 4 for hearing-impaired children with CIs. The preliminary data revealed that the normal-hearing children had very high scores for the forced-choice test in both the Immediate and Delay conditions. So far, the children who use CIs have performed comparably on the immediate forced-choice task. However, their performance on the cued-recall test, and both tasks after a delay, were very low.

Immediate Test

	Forced-choice accuracy	standard deviation	Cued-recall accuracy	standard deviation
< 4 yrs (12)	0.95	0.08	0.92	0.17
> 4 yrs (12)	0.95	0.10	0.97	0.08

Delay Test

	Forced-choice accuracy	standard deviation	Cued-recall accuracy	standard deviation
< 4 yrs (3)	0.88	0.22	0.75	0.25
> 4 yrs (4)	0.94	0.13	0.89	0.14

Table 3. Mean accuracy response for normal-hearing children (N=24).

Immediate Test

	Forced-choice accuracy	standard deviation	Cued-recall accuracy	standard deviation
< 4 yrs (2)	0.63	0.18	0.25	0.18

Delay Test

	Forced-choice accuracy	standard deviation	Cued-recall accuracy	standard deviation
< 4 yrs (2)	0.13	0	0.19	0.27

Table 4. Mean accuracy response for hearing-impaired children who use cochlear implants (N=2).

Discussion

The procedures that were developed in this project will allow us to assess the word-learning skills of children, which will be valuable in tracking the language development of children who use CIs. The results thus far are very preliminary because only a small number of children who use CIs have been tested. We will test at least 12 children who use CIs from each of the two age groups before analyzing the data and comparing it to the results from the normal-hearing children. Another step in the project is to analyze the results from this test and compare them to the results obtained on several outcome measures. The children who use CIs are routinely given a battery of speech perception, word recognition and language tests up to several years after they receive their CIs. One of our goals is to assess how the variability of children's performance in learning novel words in these tasks is related to the variability of language outcome measures. Measures of early word learning and "fast mapping" in this clinical population may be important new predictors of language development and other language-based outcome measures.

A future direction for this project is to manipulate the phonological properties of the names of the Beanie Babies™. Currently, we are using real names that correspond to salient visual attributes in order to make the learning task as easy as possible. Once these procedures are validated, subsequent experiments will use Beanie Babies™ with nonword names, which will vary in terms of phonological difficulty (e.g., phonotactic probabilities, syllable number or stress). These other projects should provide valuable new information about the ability of children who use CIs to encode phonological information in tasks that require novel word learning skills, imitation, and long-term retention.

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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*"}