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Perceptual Learning and Nonword Repetition Using a Cochlear Implant Simulation[1]

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Abstract. This study examined the effects of perceptual learning on the nonword repetition performance of normal-hearing adult listeners who were exposed to degraded auditory signals that were designed to simulate the auditory input of a cochlear implant. Twenty normal-hearing listeners completed a nonword repetition task, using an 8-band, frequency-shifted cochlear implant simulation strategy, both before and after training on open- and closed-set word recognition tasks. Feedback was provided during the training tasks. The nonword responses obtained from each participant were digitally recorded and then played back to four different normal-hearing listeners. These listeners rated the nonword repetition accuracy in comparison to the original unprocessed target stimuli using a 7-point scale. The mean nonword accuracy ratings were significantly higher for the nonwords repeated after the period of training with the processed stimuli than for nonwords repeated prior to training. These results suggest that the word recognition training tasks facilitated auditory perceptual learning that generalized to the production of novel, nonword auditory stimuli. In addition, adaptation and learning from the degraded auditory stimuli produced by a cochlear implant simulation can be achieved even in a very difficult perceptual-motor task such as nonword repetition which involves both speech perception and production. Our nonword repetition findings extend previous reports of adaptation and perceptual learning with cochlear implant simulations which showed that word and sentence recognition scores and vowel perception improved in normal-hearing listeners after experience with an acoustic simulation of a cochlear implant.

Introduction

The ability to recognize speech from the degraded auditory input provided by a cochlear implant has been shown to be related to pediatric cochlear implant users' digit spans (Cleary, Pisoni, & Geers, 2001; Pisoni & Cleary, 2003) and nonword repetition skills (Cleary, Dillon, & Pisoni, 2002; Dillon, Burkholder, Cleary, & Pisoni, in press). In addition, memory processes carried out during the digit span task, such as rehearsal speed, have been found to be directly related to nonword repetition in deaf children using cochlear implants (Dillon, Cleary, Pisoni, & Carter, 2004). By using overt speaking rate as a measure of subvocal verbal rehearsal speed, Dillon and colleagues found that children who were able to subvocally rehearse faster received higher nonword repetition ratings than children who rehearsed verbal information slowly.

These findings indicate that speech perception abilities and memory performance are intimately related to one another in this clinical population, especially when the tasks require the encoding and manipulation of auditory stimuli in tasks such as nonword repetition and digit span recall. Recently, the relationships between memory span and speech perception skills have also been examined in normal-hearing listeners under auditory conditions that are designed to simulate what deaf users of cochlear implants may hear (Burkholder, Pisoni, & Svirsky, this issue; Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000). Cochlear implant simulation studies provide a unique opportunity to investigate how memory and speech perception are affected when normal-hearing listeners are exposed to novel auditory stimuli.

Acoustic simulations of cochlear implants are able to emulate how speech is processed by the devices by filtering the speech signal into bands or adjacent frequency bins and then identifying the amount of spectral energy within bins that spans the entire range of speech sounds. The electrical pulses directed to the electrodes in a cochlear implant are modulated by the output of each of the adjacent frequency bins. This process is typically mimicked in acoustic models of cochlear implants through filtered noise band modulation carried out by the output of the simulator's frequency bins which corresponds to the spectral bands of the noise. However, in some acoustic models of cochlear implants, the frequency of the analysis filters creating the frequency bins that modulate the noise bands is exceeded by the frequency of the noise bands (Kaiser & Svirsky, 2000). This mismatch in frequencies causes an upward shift in the sound's frequency. This simulation technique is designed to mimic the natural basalward frequency shift that results when the cochlear implant's electrode placement is unable to reach tonotopic areas deep within the apical end that are tuned for low frequency sounds. This often causes a mismatch and a frequency shift between what sound is being detected through the implant and what sound is actually perceived.

Cochlear implant simulation studies have previously been used in normal-hearing listeners to investigate the effects of degraded auditory stimuli on digit span performance (Burkholder et al., this issue; Eisenberg et al., 2000). Results of these studies have shown that digit span significantly declines in both normal-hearing adults and children when the stimuli are presented in degraded auditory conditions meant to simulate a cochlear implant. In addition, cochlear implant simulation studies have provided a unique opportunity to determine whether speech perception abilities in degraded auditory conditions and performance on memory tasks conducted under degraded auditory conditions are related in normal-hearing listeners as they are in deaf children using cochlear implants. For instance, using models of 4- and 8-channel cochlear implants, Eisenberg and colleagues (2000) found modest correlations between normal-hearing adults' and children's performance on word and sentence recognition scores and their digit spans under cochlear implant simulation conditions. Their results are consistent with numerous studies showing a relationship between cochlear implant users' speech perception skills and memory spans.

In addition to demonstrating a link between perceptual abilities and cognitive performance, studies of cochlear implant simulations have also provided a unique opportunity to study perceptual learning and auditory adaptation to severely degraded auditory stimuli. Cochlear implant simulation studies have demonstrated rapid perceptual learning and auditory adaptation after listeners have been trained with a variety of auditory stimuli such as consonants, vowels, words, and sentences (Fu, Shannon, & Gavin, 2002; Rosen, Faulkner, & Wilkinson, 1999). The adaptation to spectrally shifted speech, designed to model a cochlear implant, was examined several years ago by Rosen and colleagues (1999). In their study, they determined that even though initial identification of spectrally shifted speech was very poor, participants' abilities to identify intervocalic consonants and vowels and to recognize words in sentences improved with training and exposure to the simulation.

However, when conducting a word identification task, especially using words embedded in sentences, speech perception performance is heavily influenced by sentence context and the listener's prior lexical knowledge (Miller, Heise, & Lichten, 1951). The identification of vowels and consonants may be relatively free of higher-level contextual influences, but vowels and consonants are not representative of the complexity that characterizes listening to connected speech in everyday circumstances. In order to evaluate perceptual learning for complex auditory patterns that are similar to English words, yet lack contextual or lexical influences, we examined normal-hearing participants' nonword repetition performance under conditions of degraded and spectrally shifted speech, focusing on the specific effects of training on nonword performance.

The nonword repetition task has been used previously to examine speech perception and phonological working memory in deaf children with cochlear implants (see Carter, Dillon, & Pisoni, 2002; Cleary et al., 2002; Dillon et al. in press) as well as phonological working memory in normal-hearing children (Gathercole, Willis, Baddeley, & Emslie, 1994) and adults (Gupta, 2003; Papagno & Vallar, 1995; Service & Craik, 1993). Several recent studies from our laboratory examining the nonword repetition accuracy of deaf children using cochlear implants have shown that nonword repetition is a challenging task for deaf children to complete accurately (Carter et al., 2002; Cleary et al., 2002; Dillon et al., in press). The difficulty of the nonword repetition task renders it appropriate for use in normal-hearing adults listening to a cochlear implant simulation as well. By examining nonword repetition in normal-hearing adults exposed to an acoustic simulation of a cochlear implant, it may be possible to determine the extent of nonword repetition impairment that is the result of degraded auditory input and to estimate the degree of improvement that can be gained through a brief training period.

Performance on the nonword repetition task by deaf children with cochlear implants has been found to be strongly related to a number of other cognitive measures such as digit span, speaking rate, and spoken word recognition (see Cleary et al., 2002; Dillon et al., in press). Similarity, digit span and speech perception are related in normal-hearing adults and children listening to a cochlear implant simulation. Based on these previous results (Eisenberg et al., 2000) and other perceptual learning studies (Burkholder et al., this issue), we would expect that training on word recognition tasks should improve nonword repetition performance in normal-hearing adults listening to a cochlear implant simulation. In addition, we expect that performance in the training tasks would correlate with or predict performance on the nonword repetition task. Thus, the effects of short periods of open- and closed-set word recognition training on nonword repetition accuracy were examined in this study to determine if the training would generalize to unfamiliar nonword stimuli and improve normal-hearing participants' performance on a perceptual-motor task.

Methods

Participants

Word recognition and nonword repetition data were collected from 25 normal-hearing adults. Five participants were excluded from the study because they were unable to repeat a sufficient number of nonwords in the nonword repetition task (< 40). The nonword responses of 17 females and 3 males were used in this study. An additional 80 participants were also used to make perceptual ratings of the nonword responses. All participants were undergraduate students at Indiana University who participated in the study to receive course credit for the Psychology class in which they were currently enrolled. Participants reported that they were monolingual native speakers of American English and had no history of language, speech, hearing, or attentional disorders at the time of testing. A brief hearing screening was administered by the first author to determine whether the participants' hearing was within normal limits. Using a standard, portable pure-tone audiometer (Maico Hearing Instruments, MA27) and headphones (TDH-39P), each participant was tested at 250, 500, 1000, 2000, and 4000 Hz at 20 dB first in the right ear and then in the left ear. None of the participants showed any evidence of a hearing loss.

Stimuli and Materials

Several well known nursery rhymes (i.e. *Twinkle, Twinkle Little Star*; *Jack and Jill*) were used for initial familiarization with the processed speech. The nursery rhymes included in the familiarization phase are included in the Appendix. While listening to these passages in the cochlear implant simulated speech, the participants were provided with the written text of the nursery rhymes so they could read along silently with them.

The training stimuli presented to participants included both open- and closed-set word recognition tasks. A subset of words chosen from the Lexical Neighborhood Test (LNT; Kirk, Eisenberg, Martinez, & Hay-McCutcheon, 1999) was used as the open-set stimuli. The LNT words were chosen from the LNT easy (LNTe), hard (LNTh) and multisyllabic (mLNT) word lists. In addition to the LNT words, words taken from the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997) and the Word Intelligibility by Picture Identification (WIPI; Ross & Lerman, 1979) task were used in a closed-set word identification task.

The closed-set word recognition tasks paired recorded words with visual stimuli. Visual materials for the closed-set word recognition task included 20 panels of pictures taken from the PPVT testing booklet that corresponded to the appropriate recorded word. On each panel there were four pictures. One picture was the correct response to the auditory stimulus and three others were foils. The use of this test in the present experiment was not intended to assess vocabulary but rather to provide a moderately challenging closed-set speech perception task.

Another closed-set word recognition task, the WIPI test was also used in the training tasks. The WIPI was designed for use with hearing-impaired children. The WIPI is a more difficult test perceptually, because it contains six pictures instead of four, and the pictures depict phonetically similar minimal pairs of target words (i.e. *spoon* and *moon*; *fox* and *box*). One list of 25 WIPI words was used.

All stimuli used for familiarization and training were recorded digitally in a sound attenuated booth by the first author using an individualized version of a speech acquisition program (SAP; Dedina, 1987; Hernandez, 1995). The stimuli were sampled and digitized at 22,050 Hz with 16-bit resolution and then equated for amplitude using the Level16 software program (Tice & Carrell, 1998). All auditory stimuli were then batch processed using a personal computer equipped with DirectX 8.0, a Sound Blaster Audigy Platinum sound card, and Macro Magic. The signal processing procedure used for the cochlear implant simulation was adapted from the real-time signal processing methods designed by Kaiser and Svirsky (2000).

The signal processing strategy used bandpass filtering with a cutoff frequency of 1200 Hz. Eight filters were then used to simulate the speech processing capabilities of an 8-channel cochlear implant. The output of each filter modulated noise bands of a higher frequency range than the initial analysis filters. This mismatch was designed to model the natural frequency mismatch that occurs when the electrodes of a cochlear implant are shifted more basalward in the cochlea. The basalward shift used in this model was equivalent to a 6.5 mm shift within the cochlea.

The nonword stimuli used in this study were created and processed identically to the training stimuli with the exception that they were recorded by a different female speaker of American English. These nonword recordings were the same stimuli used in previous studies examining nonword repetition in NH children and deaf children using cochlear implants (see Carlson, Cleary, & Pisoni, 1998; Dillon et al., in press). The nonwords included in this study were all phonotactically permissible auditory patterns that could plausibly be real words in English. Forty nonwords originally developed by Gathercole and colleagues (1994) and 20 nonwords developed by Wagner and colleagues (1997) were used. The nonwords ranged in length from one to six syllables. There were ten nonwords used at each syllable length. Table 1 lists a sample of 20 of the nonwords used after training.

Number of Syllables	Target Nonword Orthography	Target Nonword Transcription
2	ballop	ˈbæ.ləp
	prindle	ˈpɹɪn.dl ¯
	rubid	ˈɹu.ˌbɪd
	sladding	ˈslæ.diŋ
	tafflist	ˈtæ.flɪst
3	bannifer	ˈbæ.nə.ˌfɚ
	berrizen	ˈbɛ.ɹə.ˌzɪn
	doppolate	ˈdɑ.pə.ˌle͡ɪt
	glistering	ˈglɪ.stɚ.iŋ
	skiticult	ˈskɪ.ɾə.ˌkʌlt
4	comisitate	kə.ˈmi.sə.ˌte͡ɪt
	contramponist	kən.ˈtɹæm.pə.ˌnɪst
	emplifervent	ɛmˈplɪ.fɚ.ˌvɛnt
	fennerizer	ˈfɛ.nɚ.ˌa͡ɪ.zɚ
	penneriful	pə.ˈnɛ.ɹə.ˌfʌl
5	altupatory	æl.ˈtu.pə.ˌtɔ.ɹi
	detratapillic	di.ˈtɹæ.ɾə.ˌpɪ.lɪk
	pristeractional	ˈpɹɪ.stɚ.ˌæk.ʃə.nl̩
	versatrationist	ˈvɚ.sə.ˌtɹe͡ɪ.ʃə.ˌnɪst
	voltularity	ˈvɑl.t͡ʃʊ.ˌlɛ.ɹəˌti

Table 1. Sample of nonwords used in the current study (adapted from Gathercole et al., 1994).

The stimuli used in a perceptual ratings portion of the experiment included the original unprocessed target nonwords and digital recordings of the participants' nonword repetition responses to the target stimuli. The nonword responses of the participants were sampled and digitized at 22,050 Hz with 16-bit resolution. Each nonword was segmented and stored individually in a digital file. All sound files were then equated for amplitude.

Procedure

Pretraining Nonword Repetition. Following a familiarization phase of listening to and silently reading along with a series of familiar nursery rhymes, participants were told that they would receive a nonword repetition task in which they would be asked to repeat the nonword that was presented using the same degraded format. The procedure for the nonword repetition was then demonstrated by having participants repeat two nonwords that were in unprocessed form. No participants experienced any difficulty repeating the intact nonwords. To further assist participants in completing the nonword repetition task, the effect of the signal processing on the nonwords was also explicitly demonstrated. Two nonwords were played back first in their unprocessed form and then immediately after under processed conditions.

After this sequence of nonword familiarization, participants completed nonword repetition of 30 different nonwords that were in processed form. Each nonword was played once in random order. The list of 30 nonwords included a combination of stimuli taken from the sets of both Wagner and Gathercole nonwords and included five nonwords at each of six different syllable lengths. All nonword responses were recorded onto digital audiotape (Sony Walkman TCD-D8) via a uni-directional headset cardioid condenser microphone (Audio-Technica ATM75). Because this was a difficult task, the participants were permitted to pass on items they were unable to provide a response to. However, participants were urged to repeat any portion of the nonword that they felt they could.

Training. After repeating the first set of nonwords, participants were administered the PPVT (Dunn & Dunn, 1997) and WIPI (Ross & Lerman, 1979) closed-set word recognition tasks. The easier closed-set task, the PPVT, was administered to the participants first in the training session followed by the WIPI. The visual and auditory stimuli used for closed-set word recognition training were presented in nonrandom order, in order to preserve the correct pairing between the picture panels in the testing booklets and the words. Following the presentation of each training word, participants either responded by pointing to the picture of the word they thought they heard or responded verbally. Auditory feedback was then given after each trial to indicate the correct response regardless of whether the correct response had been given or not. The auditory feedback was a repetition of the same utterance of the presented word in its unprocessed form.

After completing the closed-set speech perception tasks, participants were asked to identify words without the aid of any pictures from which to choose. The open-set training words were presented in random order to the participants. The sequence of open-set word recognition tasks began with the LNTe, followed by a combined list of words chosen from the LNTh and mLNT (Kirk et al., 1999). Auditory feedback was administered in the same manner as in the closed-set task. A total of 65 words taken from the LNTs were used for open-set word recognition training. Scoring of these training tasks was conducted online by the experimenter who was present during all sessions.

Post-training Nonword Repetition. Following the training sequence, which lasted approximately 35 minutes, participants completed a second nonword repetition task. Thirty different nonwords, 20 from the Gathercole set and 10 from the Wagner set were used. All nonwords ranged from one to six syllables, and there were five different nonwords at each syllable length. The 20 nonwords designed by Gathercole were specifically chosen for the post-training portion of nonword repetition task because they were the same nonwords used previously in the nonword repetition tasks completed by the deaf children with cochlear implants (Cleary et al., 2002). These 20 nonwords were originally selected for the testing of deaf children with cochlear implants, because when a group of normal-hearing children completed the entire nonword repetition task, their performance on these 20 words resulted in the most variation (Carlson et al., 1998).

Nonword Ratings. Each participant's nonword utterances were rated for imitation accuracy by a group of four different normal-hearing adults. Each listener first heard the unprocessed target nonword and then heard the nonword response spoken by the participant. A one-second interstimulus interval separated the target nonword stimulus and the participant's response. Both stimuli were presented to listeners through high quality, calibrated headphones (Beyer Dynamic, DT100) at 70dB SPL. All stimulus pairs were presented in two blocks with a different random order used within each block. Each listener rated each nonword repetition twice.

Ratings were made using a 7-point ordinal scale in which a score of "1" indicated that the listener believed the nonword utterance was "not accurate at all" and "totally failed to resemble the target utterance" whereas a score of "7" indicated that the listener believed the utterance was "perfectly accurate, ignoring differences in pitch." To record their perceptual similarity ratings, listeners used a response box with seven numbered buttons. The button box was interfaced to a PC which recorded all the nonword ratings entered by a listener into an identifiable output file.

Results

A summary of the participants' performance on the word recognition training tasks appears in Table 2. As expected, more words were identified correctly in the closed-set tasks than in the open-set tasks (*t*(18) = 40.56, *p* = .000). Within the closed-set and open-set tasks, differences were also found. Word identification on the WIPI was significantly worse than it was on the easier four-choice PPVT (*t*(18) = 6.33, *p* = .000). In addition, there was a main effect of word difficulty on word recognition accuracy in the open-set LNT tasks (*F*(1, 54) = 24.35, *p* = .000). As expected, words from denser lexical neighborhoods were more difficult to identify than words from sparser lexical neighborhoods.

Percent Correct Scores on Word Recognition Training Tasks

Closed-set Tasks	Mean	Standard Deviation
PPVT	85.35	8.29
WIPI	69.60	11.27
Open-set Tasks	**Mean**	**Standard Deviation**
LNT(easy)	19.15	9.78
LNT(hard)	9.20	4.42

Table 2. Mean percent correct and standard deviations of scores on closed-set and open-set word recognition tasks.

Prior to any analyses of the effects of training on nonword repetition, within-rater reliability was calculated using Cronbach's alpha reliability testing. The reliability of ratings made in the first and second block of trials was determined to be adequate. Alpha values ranged from .65 to .99, with 95% of the raters having reliability coefficients greater than .70. In addition, there was no effect of block number on the average nonword ratings recorded by all the raters (*F*(1, 8318) = .20, *p* = .657). Therefore, only ratings made in the first block were used in the data analyses.

Inter-rater reliability between each group of four listeners' first block of ratings was also assessed. Nineteen out of 20 groups had a reliability rating that exceeded .70, with most groups' alpha value approaching .90. One group of raters had a particularly low reliability rating of .26 and was therefore excluded from the final analysis. This exclusion meant that one of the 20 speakers originally receiving nonword ratings was excluded from the final analysis.

Figure 1 shows the average of all nonword ratings received by the participants. A univariate ANOVA revealed a main effect of the number of syllables in the nonwords on the average nonword rating assigned to each of the participants' utterances (*F*(5, 8318) = 20.645, *p* = .000). In general, nonwords with more syllables received lower ratings. The average nonword ratings received by the speakers for all syllable lengths were concentrated on the lower end of the ratings scale, indicating that this was a particularly difficult perceptual task for them to accomplish accurately.

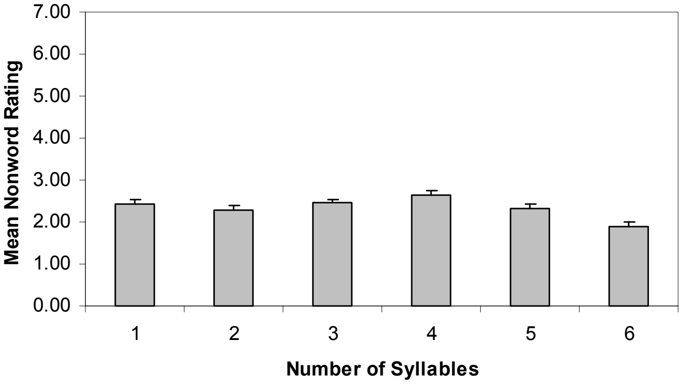

Figure 1. Mean nonword rating received by participants at all syllables both before and after training. Error bars represent standard error of the mean.

Several analyses were conducted to determine if there were any effects of training on nonword repetition ratings. An initial analysis including the average ratings of nonwords at all syllable lengths indicated no significant differences in the ratings received in the pre-training and post-training nonword repetition session ($t(18) = 2.31$, $p > .05$). However, when the one- and six-syllable nonwords were omitted from the analysis, post-training nonword ratings were significantly higher than the pre-training nonword ratings ($t(18) = 4.763$, $p = .000$). The six-syllable nonwords were excluded from the final analysis because these nonwords were omitted more frequently during the first block of the nonword repetition task than during the second block.

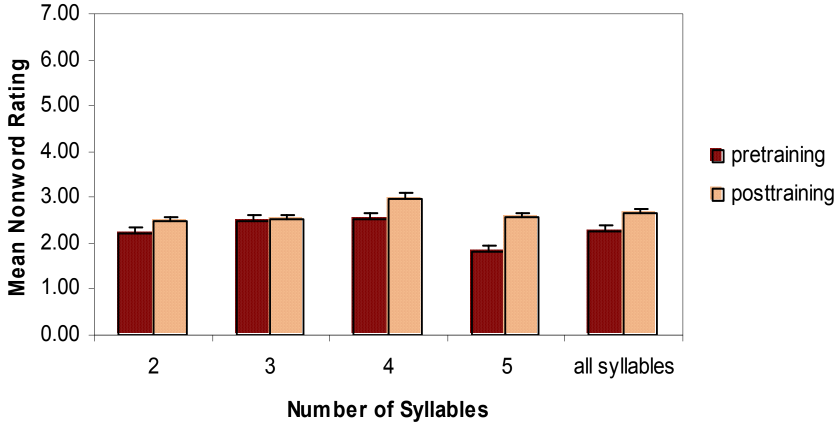

Figure 2. Mean nonword ratings received for nonwords repeated both before and after a short period of word recognition training.

In order to balance the data set with respect to difficulty of the nonwords included in the analysis, the one syllable nonwords were also omitted. These exclusions were also desirable because it left the post-training data set with ratings made on the 20 original nonwords that were used previously in samples of pediatric cochlear implant users. Figure 2 shows the average nonword ratings of the 2-, 3-, 4-, and 5-syllable nonwords both before and after training. After the brief period of training, all but three participants received a higher average nonword rating for the remaining nonwords. In addition to the participants' overall performance on the nonword repetition task and response to word recognition tests used during training, we were also interested in determining whether the normal-hearing adults' nonword ratings were related to their word recognition performance and digit spans. Only the identification of processed digits in isolation was correlated to the nonword repetition ratings received by the participants ($r = .49$, $p < .05$). The failure to obtain the expected pattern of correlations between word recognition scores, and nonword repetition may have resulted from the lack of variance in the nonword ratings received by the speakers.

Discussion

Accuracy of nonword repetition increased significantly after only a short period of training with the speech processed through a cochlear implant simulation. These results are especially interesting because the nonwords were spoken in a different female voice than the training stimuli. This suggests that not only was the perceptual learning generalizable to novel nonwords but that the training was robust enough to extend to novel stimuli spoken in a voice different from the voice speaking the training stimuli. Specific information regarding the generalizability and potency of training with an acoustic simulation of a cochlear implant was also obtained in this study by showing that nonword repetition performance improved after a short period of training on word identification tasks. Effects of such a brief period of training on the ability to perform a perceptual-motor task using novel, nonword stimuli have not been documented previously in the literature.

However, it is important to note that effects of brief periods of training have not been documented in the same way using words either. A potential drawback to the present study is that spoken *word* recognition has not been tested both before or after such short periods of training with an acoustic model used to simulate a cochlear implant. Any evidence of such rapid effects of training on isolated word identification would provide preliminary support for the idea that improvements in nonword repetition performance could be due to the brief training. Given this lack of comparison data and support, it may be plausible that the improvements that were observed in nonword repetition were partly due to participants' practice in generating a verbal nonword response rather than to improvements in perceiving the auditory input. That is, participants may have performed better on this task due to procedural rather than perceptual learning. To determine more conclusively whether improvements in nonword repetition by these participants were actually due to training, additional nonword repetition data should be collected from a second group of listeners who do not receive any training.

If we accept the finding that the increase in nonword ratings was due to improvements in the participants' skills in accurately perceiving auditory stimuli transformed by the simulation, we do not necessarily know what specific aspect of the processed stimuli they are adapting to most proficiently. It is plausible that the participants were learning and retaining a broad representation about how the cochlear implant simulation alters speech rather than learning representations specific to the indexical properties of one speaker or more precise acoustic-phonetic representations of familiar words. However, both an improvement in phoneme identification and suprasegmental or prosodic knowledge are likely to help participants in the nonword repetition task.

It is difficult to discern exactly what attributes of the cochlear implant simulated speech the normal-hearing listeners were attending to through the current methods of analysis or what properties of the speech signal were most easily learned and reproduced during the nonword repetition task. More detailed analyses such as measuring suprasegmental and segmental accuracy in the nonword repetitions would be useful to help determine more precisely what acoustic-phonetic characteristics of the nonwords the normal-hearing adults were able to perceive and reproduce. Suprasegmental and segmental analyses have previously been conducted on the nonword repetitions of deaf children with cochlear implants (Carter et al., 2002; Dillon et al., 2004). Obtaining these same measures from normal-hearing listeners exposed to a cochlear implant simulation would enable useful comparisons between nonword repetition responses elicited from normal-hearing listeners exposed to an acoustic simulation of a cochlear implant and from deaf children using a cochlear implant. Such comparisons may have implications for how accurately an acoustic simulation of a cochlear implant can model the auditory input from a cochlear implant.

Any comparisons drawn between normal-hearing adults and deaf children completing a nonword repetition task must be considered with some caution at this time because the two populations likely differ in their speech production skills. Normal-hearing adults with no previous history of speech or language disorders are assumed to have normal speech production skills. However, deaf children with cochlear implants often have poor speech intelligibility (Miyamoto, Kirk, Robbins, Todd, Riley et al., 1997; Osberger, Robbins, Todd, & Riley, 1994), which makes it difficult to attribute nonword repetition errors exclusively to poor speech perception abilities. Therefore, it may be difficult to compare the segmental nonword repetition errors of deaf children using cochlear implants and normal-hearing listeners.

However, the results of this study do share some similarities between the nonword repetition results obtained from normal-hearing adults exposed to a cochlear implant simulation and hearing-impaired children using a cochlear implant that are unconfounded by differences in speech production. One common result found between the studies examining nonword repetition in normal-hearing adults exposed to transformed speech and deaf children using a cochlear implant was that nonword repetition accuracy was related to the number of syllables in the nonwords in both groups. Both deaf children using cochlear implants and normal-hearing adults listening to transformed speech were more accurate in repeating nonwords with fewer syllables. These results suggest that adults and children are utilizing similar cognitive processes to complete the nonword repetition task. In addition, under normal listening conditions, both adults and children demonstrate an effect of syllable number on nonword repetition accuracy (Gupta, 2003). The carryover of this effect to nonword repetition under severely degraded auditory conditions may indicate that the basic processes or strategies used to complete the task are retained despite the unusual circumstances in which they are being used.

Although the effect of syllable length on nonword repetition accuracy was found in these adult participants, their nonword ratings showed no relationship to the key speech perception training tasks as the nonword ratings of deaf children with cochlear implants typically have (Cleary et al., 2002; Dillon et al., in press). However, the rating data obtained from normal-hearing adults' nonword repetitions were collected using a different procedure than the rating data previously collected on the deaf children with cochlear implants. One difference was that in this study each listener heard the responses from only one speaker whereas in the studies with deaf children, the listeners heard nonword responses from many children over the entire test block.

In addition, in the studies using pediatric cochlear implant users, the raters were exposed to a combination of multiple speakers based on predetermined speech intelligibility (Cleary et al., 2002; Dillon et al., in press). The speech intelligibility measures ensured that the listeners were exposed to children with a varying range of speech quality. Thus, the methods used to collect ratings in the current study may have failed to appropriately detect a relationship between nonword ratings and performance on the speech perception tasks because of a more restricted range and variance in the ratings and a near floor performance by the normal-hearing adults. To more accurately assess the relations between the nonword repetition ratings and word recognition, a ratings procedure in which different speakers' utterances could be compared to one another should be conducted.

Finally, an additional improvement upon this study would be to conduct it using normal-hearing children rather than adults. Normal-hearing peers of the deaf children using cochlear implants would be a more appropriate control than normal-hearing adults because of the large developmental differences that have been previously shown in speech and memory tasks (Cowan, Saults, Nugent, & Elliot, 1999). We do plan to collect immediate memory span and nonword repetition data from normal-hearing children while listening to an acoustic simulation of a cochlear implant. Such data would be an appropriate comparison to carry out in order to examine how memory processes and perceptual skills are differentially affected by profound deafness and by the unique sensory simulation provided by a cochlear implant which requires a period of auditory adaptation and perceptual learning after implantation.

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Appendix

Stimulus materials used for familiarization with the acoustic model of a cochlear implant.

Hickory, Dickory, Dock
Hickory, dickory, dock,
The mouse ran up the clock.
The clock struck one,
The mouse ran down.
Hickory, dickory, dock!

One, Two, Buckle My Shoe
One, two, buckle my shoe,
Three, four, knock at the door.
Five, six, pick up sticks,
Seven, eight, lay them straight.
Nine, ten, big fat hen.

Twinkle, Twinkle
Twinkle, twinkle, little star,
How I wonder what you are!
Up above the world so high,
Like a diamond in the sky.
Twinkle, twinkle, little star,
How I wonder what you are!

Jack and Jill
Jack and Jill went up the hill
To fetch a pail of water
Jack fell down and broke his crown,
And Jill came tumbling after

Star Light
Star light, star bright
First star I see tonight
I wish I may, I wish I might
Have the wish I wish tonight