OUTCOME MEASUREMENTS

Effects of auditory training on adult cochlear implant patients: a preliminary report

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ABSTRACT *The process of learning new electrically stimulated speech patterns can be difficult for many cochlear implant users, especially congenitally deafened patients. Some implant users receive little benefit from the device, even after long-term experience. While many factors may influence individual patient outcomes, the paucity of auditory rehabilitation resources, especially for adult users, may contribute to some implant patients' poorer performance. The present study examined whether moderate auditory training, using speech stimuli, can improve the speech-recognition performance of adult cochlear implant patients. Ten cochlear implant patients with limited speech-recognition capabilities used a recently developed computer-based auditory rehabilitation tool to train at home for a period of one month or longer. Before training began, baseline speech-recognition performance was measured for each patient; baseline performance was measured for at least two weeks, until performance asymptoted. After baseline measures were complete, subjects were instructed to train themselves at home using novel monosyllable words one hour per day, five days per week. Subjects then returned to the lab every two weeks for retesting with the baseline speech materials. Preliminary results showed that there was significant improvement in all patients' speech perception performance after moderate training. While most patients did improve, the amount and time course of improvement was highly variable. Moderate training using a computer-based auditory rehabilitation tool can be an effective approach to improve cochlear implant patients' speech recognition, especially for poorer-performing implant users.*

Introduction

The cochlear implant is an electronic device that provides hearing sensation to patients with profound hearing loss. In general, the speech-recognition performance of cochlear implant patients has steadily improved in recent years; however, considerable variability remains in individual cochlear implant patient outcomes. Even with the latest speech processing technology, some cochlear implant patients receive little benefit from the device after years of daily use. This outcome variability is likely due to a number of factors. Some factors may be patient-related, such as the placement, number and geometric relationships of the implanted electrodes, the location and condition of surviving neural elements in the vicinity of the electrodes, and the duration of deafness and implantation; other factors may be speech-processor-related. The cochlear implant speech processor determines how acoustic sounds are transformed into electric signals delivered by the implanted electrodes. Some cochlear implant users' poor speech-recognition skills might be caused by a less-than-optimal acoustic-to-electric amplitude mapping (Fu and Shannon, 1998), and/or a mismatch between the acoustic frequency and electrode location because of a shallow electrode insertion depth (Fu and Shannon, 1999a,b). However, some cochlear implant users' poorer performance may be related to difficulties in learning the speech patterns provided by electrical stimulation of the cochlea. In these cases, training cochlear implant users to identify speech patterns may be integral to successful use of the device.

Some studies have assessed the effects of limited training on the speech-recognition skills of poorer-performing cochlear implant users. Busby et al. (1991) examined the effects of ten 1-hour speech perception and production training sessions, conducted one or two times per week. Three prelingually deafened multichannel cochlear implant users (two adolescents and one adult) participated in the training sessions. After the training period, there were only minimal changes in these individuals' perceptual abilities. The authors noted that the subject who improved the most was implanted at an earlier age than the other two subjects and therefore had a shorter period of deafness. Dawson and Clark (1997) reported more encouraging results with vowel-recognition training assessed for five cochlear implant users. Each subject had been deaf for at least four years prior to implantation, and none had achieved open-set speech recognition. Training consisted of one 50-minute training session per week for 10 weeks. Following training, four of the five subjects showed some measure of improvement that was retained on subsequent testing 3 weeks after the training was completed.

The effects of speech training have also been evaluated in normal-hearing subjects listening to spectrally shifted speech. Rosen et al. (1999) assessed the effects of training on normal-hearing listeners' ability to recognize spectrally shifted speech, using a four-channel speech processor that simulated a shallow insertion of the electrode array. Pre-training results with the shifted speech showed very poor speech recognition. However, after only nine 20-minute training sessions using connected discourse tracking with the shifted speech, performance improved significantly for the identification of intervocalic consonants, medial vowels in monosyllables and words in sentences. As indicated previously, some cochlear implant users' poor speech recognition may be caused by a mismatch between the spectral content of the acoustic signal and the spectral representation delivered by the implant array due the limited extent and insertion of the electrode array. Fu and Galvin (2003) also examined the effects of short-term learning on normal-hearing listeners' ability to accommodate spectrally altered speech patterns. Results showed that speech recognition with 20-channel noise-band processors was acutely affected by severe spectral mismatch. Initially, subjects could tolerate only a small amount of spectral mismatch. However, after short-term training with severely shifted speech, subjects were able to significantly improve their recognition of spectrally shifted speech. However, the improvement was restricted to the trained spectral shift, and did not generalize to other spectral shifts distant from the location where the training had occurred.

Previous attempts to improve the speech-recognition abilities of poor-to-moderate cochlear implant users have shown only minimal success (e.g. Busby et al., 1991; Dawson and Clark, 1997). However, these efforts have been extremely limited in terms of the amount of training provided. In normal-hearing populations, training has been successfully used to improve speech segment discrimination and identification (Tremblay et al., 1997, 1998), and recognition of spectrally shifted speech (Rosen et al., 1999; Fu and Galvin, 2003). These improvements typically occurred only after the completion of much more intensive training, as compared to the training used in studies with cochlear implant listeners. Cochlear implant users' auditory rehabilitation may require many more hours of perceptual training. For pre- or perilingually deafened patients, the time course of training may be even longer, on the order of months or years. Unfortunately, most adult cochlear implant listeners have limited access to speech rehabilitation services, and most speech pathologists do not have time to work with individual patients on a daily basis.

These previous training studies suggest that the mixed results obtained with cochlear implant users may be partly due to the amount and type of training employed. The speech patterns evoked by electric stimulation may be very different from those evoked by the normal acoustic stimulation; learning these electrically stimulated speech patterns and associating these patterns to corresponding words may be a difficult challenge for many cochlear implant users, especially congenitally deafened patients. A more extensive and intensive approach to speech pattern-recognition training might yield better results. This preliminary investigation of perceptual training for cochlear implant subjects focused on two hypotheses. First, poor speech performance by individual cochlear implant users can be improved by intensive auditory training. Second, the training can be self-administered by cochlear implant patients in their own home, using a computer and training software that requires minimal monitoring on the part of the researcher or speech therapist.

Methods

Subjects

Ten CI patients with poor-to-moderate speech-recognition ability were recruited to participate in a training program. Table 1 contains relevant information for the ten subjects.

Table 1: Relevant information for cochlear implant subjects

Subject	Age	Gender	Pre/post lingual	Duration of use	Implant device	Strategy	Vowels (%)		Consonants	
							Pre-	Post	Pre-	Post
S1	46	F	Pre	2	N-24	SPEA	9.60	26.90		
S2	51	M	Pre	3	C-II	CIS	10.00	18.60		
S3	25	F	Pre	1	C-II	PPS	11.80	27.80	6.00	11.30
S4	40	F	Post	2	C-II	MPSHiRe	14.10	27.20	15.00	27.80
S5	40	F	Pre	1	N-24	ACE	24.50	35.90	16.10	24.00
S6	48	M	Pre	1	C-II	CIS	26.00	37.50		
S7	40	F	Pre	1	C-II	SASHiRe	32.70	56.67	27.50	57.00
S8	36	F	Post	1	C-II	HiRe	33.13	55.00	46.50	64.50
S9	60	M	Post	6	N-22	SPEA	34.00	47.70	34.00	41.70
S10	38	M	Pre	1	N-24	SPEA	41.50	56.60	30.40	40.00

Testing and training materials

For most subjects, speech-recognition tests were conducted using four sets of test materials, including three closed-set identification tasks and one open-set recognition task. The three closed-set identification tasks included multi-talker vowel recognition, multi-talker consonant recognition and voice gender discrimination. Vowel recognition was measured in a 12-alternative identification paradigm. The vowel set included ten monophthongs and two diphthongs, presented in a /h/-vowel-/d/ context. The tokens for vowel-recognition test were digitized natural productions from five men and five women drawn from speech samples collected by Hillenbrand et al. (1995). Consonant recognition was measured in a 20-alternative identification paradigm. The consonant set included /b d g p t k m n l r y w f s v z t d/, presented in an /a/-consonant-/a/ context. Consonant tokens consisted of digitized natural productions from five men and five women, for a total of 200 tokens. All consonant tokens were recorded at the House Ear Institute. Voice gender recognition was measured in a two-alternative identification paradigm. The tokens for voice gender discrimination were the same as those used in the vowel recognition. Recognition of words in sentences was measured using the Hearing in Noise Test (HINT) sentences recorded at the House Ear Institute (Nilsson et al., 1994). For all subjects, baseline vowel recognition was measured before training began; baseline consonant recognition and voice gender recognition was measured for seven of the ten subjects, and baseline HINT sentence recognition was measured for only three of the ten subjects.

Speech training was conducted by using more than 1000 monosyllable words and 200 nonsense words. The training tokens were digitized natural productions from two men and two women, recorded at the House Ear Institute. Monosyllable words were primarily used for phonetic (vowel and consonant contrast) training. None of the speech testing materials or talkers were included in the speech training material set.

Procedure

For vowel recognition, each test block included 120 tokens (12 vowels × 10 talkers). On each trial, a stimulus token was chosen randomly, without replacement, and presented to the subject; the subject responded by pressing one of 12 response buttons (labelled 'heed', 'had', 'head', etc.). For consonant recognition, each test block included 200 tokens (20 consonants × 10 talkers). On each trial, a stimulus token was chosen randomly, without replacement, and presented to the subject; the subject responded by pressing one of 20 response buttons (labelled 'aba', 'ada', 'aga', etc.). For voice gender recognition, each test block included 120 tokens (12 vowels × 10 talkers). On each trial, a stimulus token was chosen randomly, without replacement, and presented to the subject; the subject responded by pressing one of two response buttons (labelled 'male' and 'female'). For the vowel, consonant and voice gender-recognition tests, no feedback was provided to the subjects. For HINT sentence recognition, a list was chosen pseudo-randomly from among 26 lists; sentences were chosen randomly, without replacement, from the ten sentences within that list. The subject responded by repeating the sentence as accurately as possible; word-in-sentence recognition was scored by the tester. No feedback was provided for the sentence-recognition tests.

Before training began, baseline speech-recognition performance (vowel, consonant, voice gender and HINT sentence recognition) was collected for each patient. Baseline performance was measured for a minimum of two weeks, or until performance asymptoted. After baseline measures were complete, subjects were trained at home in specific training tasks based on their phoneme-recognition scores. Subjects returned to the lab every 2 weeks for retesting with the baseline speech materials.

Training tool

Software developed at House Ear Institute was used as a testing and training tool. Cochlear implant patients installed the software on their home computers or were loaned a laptop computer to use during the training period. The training software includes many features that are suitable for auditory training. First, the software contains a large database of speech materials that can be organized within a training session to encourage listeners' perception of phonemic contrasts; depending on the listeners' needs, weak or strong phonemic contrasts can be paired for comparison. Second, discrimination and identification tasks can be conducted with any audio materials and real-time signal processing modules can be used to mimic many everyday listening situations (noisy backgrounds, reverberant rooms, etc.); auditory resolution (frequency/amplitude/gap discrimination) can also be measured training. Third, the software includes many adaptable training protocols, e.g. 3AFC, ABX, preview, auditory/visual feedback etc.; training can be adapted to the acoustic differences between speech patterns and /or subjects' performance (differences in speech pattern according to subjects' responses). Fourth, the software is very user-friendly and provides online help files; based on subjects' test scores and training progress, the software automatically updates the training protocols, providing highly targeted training with minimal oversight by clinicians and/or researchers. Finally, the software has very powerful database administration, including user management, training time recording, report generation and progress monitoring.

Results

Figure 1 shows the vowel and consonant-recognition scores for the individual cochlear implant patients before and after training. Note that baseline consonant-recognition scores were not measured for subjects S1, S2 and S6 and therefore their post-training performance is not included in the figure. The filled bars show the asymptotic performance levels before training was begun and the open bars show performance at the end of the training period. For all subjects, there was significant improvement in vowel and consonant-recognition performance. Mean vowel-recognition scores increased from 22.10 to 36.47% correct; mean consonant-recognition scores increased from 25.07 to 38.04 % correct. For the seven cochlear implant patients who were tested in voice gender identification, performance was not significantly affected by training, improving only from 69.5 to 69.84% correct. For the three cochlear implant patients who were tested in HINT sentence recognition, mean word-in-sentence recognition improved from 27.89 to 55.82% correct. A paired student t-test revealed a significant

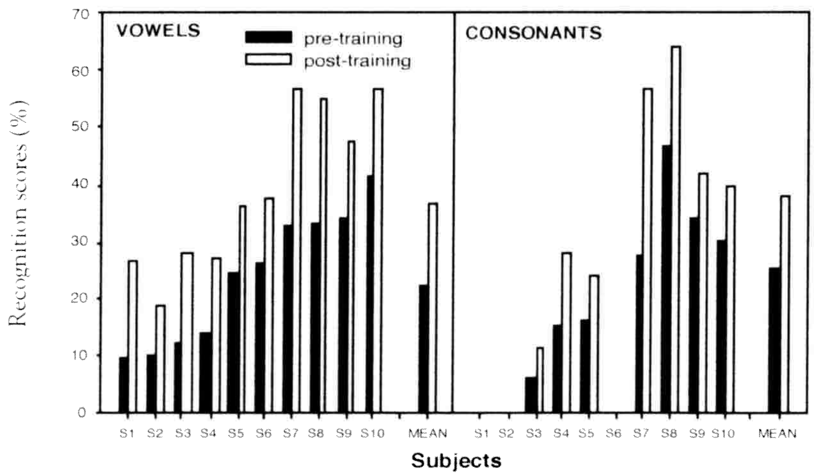

Figure 1: Individual cochlear implant subjects' vowel- and consonant-recognition scores, before and after training. Group mean scores are shown in the right of each panel.

improvement for both vowel recognition [t(10) = 8.83, $p < 0.001$], consonant recognition [t(7) = 4.09, $p < 0.01$], as well as HINT sentence recognition [t(2) = 14.59, $p < 0.01$] but no significant improvement for gender discrimination [t(6) = 0.62, $p = 0.56$].

Discussion and conclusion

Results showed that there was significant improvement in all patients' speech-perception performance after an extended period of moderate training. The amount and time course of improvement was highly variable among subjects, suggesting that individual cochlear implant patients may need different types and duration of training. Some subjects improved rapidly, even after only a few hours of training (comparable to the results of Rosen et. al., 1999), while others needed several weeks of moderate daily training to achieve and significant improvement. However, there was no significant correlation between the amount of training time and the amount of improvement. Also, there was no significant difference among implant devices.

Previous studies' failure to show significant benefits from training may reflect the limitations of the training programmes, rather than the potential abilities of the cochlear implant users. In most of these studies, training has been limited to infrequent (one per week), short-duration (1 hour) sessions. More intensive training programmes may result in larger and more consistent improvements in cochlear implant users' speech-recognition abilities. The design and implementation of the training procedure may be crucial to the success of that training.

These preliminary results suggest that moderate amounts of daily training (1–2 hours per day/5 days per week) can be an effective approach in improving cochlear implant patients' speech-recognition performance, especially for poorer-performing patients. The improved phoneme recognition through moderate training also generalized to recognition of words in sentences. The computer-based auditory training tools and methods used in this study may be a useful alternative or complement to auditory rehabilitation provided by clinical speech pathologists.

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Environmental sound perception in adult patients with cochlear implants: a comparison with central auditory disorders

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ABSTRACT *The aim of this study is to investigate the perception mechanism of environmental sounds in postlingual patients with cochlear implants compared with that in patients with central auditory disorders. Seventeen postlingual patients with cochlear implants were studied; six patients with auditory nerve disease (auditory neuropathy) and ten patients with cortical deafness were selected for the comparison. A tape-recorded environmental sound perception test of 24 environmental sounds was carried out. This test is divided into two categories: the category of voice includes human voice, animal and bird sounds, and the category of non-voice includes musical instrument sound, natural sound and artificial sound. The percentage of correct perception of environmental sounds in postlingually deaf patients with cochlear implants was markedly higher than that in patients with cortical deafness, but was similar to that in patients with auditory nerve disease (auditory neuropathy).*

Keywords: environmental sounds, postlingual deafness, cochlear implant, auditory neuropathy, cortical deafness

Introduction

The perception of environmental sounds in cochlear implantees with postlingual deafness appears to be better. However, its perception mechanism is not studied well compared with speech sound perception. The aim of this study was to investigate the perception, mechanism of environmental sounds in cochlear implantees compared with that in patients with auditory nerve disease (auditory neuropathy) and cortical deafness.