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INITIAL RESULTS WITH TWO SINGLE-CHANNEL COCHLEAR IMPLANTS

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Abstract

A uniform comprehensive clinical evaluation of different cochlear implant prostheses is ongoing at the University of Iowa. Preliminary results from seven patients with two different cochlear implants are presented. Early results indicate only minor differences among implants.

Introduction

Over the past ten years, cochlear implants have become a realistic alternative for the management of profoundly deaf patients. Debates concerning the clinical efficacy of the cochlear prosthesis are now being replaced by discussions regarding electrode design and coding strategies. In addition to the great number of design alternatives, individual patient differences must be considered before selecting a device for a specific patient. Because of these variables, it is likely that a universal device for all patients may not be realistic. Three to four implant designs will likely emerge as being the optimum for a specific patient when surviving neuron population and cost are taken into account. In order to determine the performance characteristics of the present generation of implants, comparison data is vital. As we became involved with cochlear implants, it was recognized that uniform evaluation methods were absent from the research reports from various centers. Comparisons among existing coding strategies and implant designs were difficult to assess. Our cochlear implant research has been directed, therefore, toward establishing an independent center where uniform comparisons of different cochlear implants can be performed. This report describes the audiologic assessment portion of our cochlear implant evaluation protocol and presents preliminary results obtained from patients with two different single-channel cochlear implants. Another report (8) describes the audiologic battery in more detail. The present study reports the results of three patients with six months of experience using the Vienna (2) intracochlear implant and four patients with six months or more experience with the Los Angeles (4) device.

Methods

Patients were not selected with regard to which implant they received. Specifically, our first five patients were implanted with the Los Angeles (LA) device and the next four received Vienna (V) implants. Unfortunately, three of the patients who received the LA device were later found to be unsuitable for rigorous investigations because of emotional problems or inability to understand the tasks. Two of the patients, LA3 and LA4, were implanted elsewhere but were geographically readily available for evaluation at our facility. One of the patients implanted with a Vienna device had fibrous overgrowth of the cochlea.

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The electrode was placed in a sulcus created adjacent to the scala tympani. Electrical stimulation resulted in otalgia and was accounted a surgical failure. Therefore, results presented here are from four Los Angeles single-channel implant patients and three Vienna patients.

Table I illustrates the relevant biographical data on the seven patients. All patients except LA2 had profound bilateral hearing loss and appropriate hearing aids were not useful. LA2 had some residual hearing in his non-implanted ear, routinely wore a hearing aid but was not able to repeat any W-22 words of spondees at any presentation level.

TABLE I. Biographical data on patient.

PATIENT	AGE (yrs)	ETIOLOGY OF DEAFNESS	DURATION OF HEARING LOSS (yrs)	DURATION OF PROFOUND HEARING LOSS (yrs)	TIME SINCE IMPLANTATION (months)
LA1	62	otosclerosis	57	10	21
LA2	64	otosclerosis	22.5	3	6
LA3	53	skull fracture	8	8	29
LA4	66	ototoxicity	4	4	60
V1	53	congenital syphilis	45	9	6
V2	23	skull fracture	2.5	2.5	6
V3	56	otosclerosis	45	9	6

The audiologic battery is a combination of selected tests from the Minimal Auditory Capabilities (MAC) battery (6) and 12 additional tests called the Iowa Cochlear Implant Tests (9). The tests are organized into five categories - everyday sounds, prosody tests, closed-set and speech related tests, open-set speech, and audiovisual tests.

A. Everyday sounds

Five additional items were added to the original MAC Everyday Sound test to make the 20-item Everyday Sound Identification Test. The patients hear a sound and are asked to describe it. No choices are provided. In a second test, Everyday Sound Discrimination, the same 20 items are presented but the patient has five written choices from which to select a response. A third test, Warning Sounds, contains eighteen 5-sec samples of a cafeteria noise. In nine of the samples, a warning sound occurs about two seconds after the noise onset at a signal-to-noise ratio (S/N) of +6dB. Patients are scored on their awareness of the presence of the warning sound. Patients are provided with 15 warning-sound alternatives.

B. Prosody tests

The MAC Question/Statement test, and the MAC Accent test, are used to study the perception of prosody. In addition, we developed the Number of Syllables test, which presents one to four syllable words. All syllabic boundaries in a given word are marked by either stops, fricatives, or continuants (glides or nasals). Patients are told the words will be either one, two, three or four syllables in length, and they select the appropriate number of syllables.

C. Closed-set speech-related tests

The Spondee Recognition test from the MAC Battery is considered to be a relatively closed-set word test in that many subjects have been tested with spondees previously, and they may have seen the written choices on the other spondee tests. A correct response is scored for each syllable repeated. A Four-Choice Spondee in Noise test was added, which contains the same target and foil spondees (different randomizations) as in Four-Choice Spondee test, but in a background of multitalker noise with a +10 dB S/N. Thus, these latter two tests can be directly compared to yield a measure of the effect of noise on spondee discrimination.

The speech related tests included the MAC Noise/Voice Discrimination, and two Iowa tests: Female/Male Discrimination and Different-Sentence Speaker Discrimination. The Female/Male Discrimination test contains 20 different sentences, each spoken by a different speaker (10 female, 10 male). The subject is asked to identify the gender of the speaker. The speaker discrimination test contains two sentences per test item and the patient is asked whether the sentences were produced by the same or different speakers. The sentences are always different. Each test has 10 male and 10 female speakers, but the speaker sex is always the same within the test pair.

D. Open-set speech understanding

This category includes the MAC Words in Context test (the high predictability items from the SPIN test; 5) and the Iowa sentence audiovisual tests when presented with sound only.

E. Audiovisual tests

Two videotaped sentence speechreading tests are used: Sentence Recognition With Context and Sentence Recognition Without Context. These utilized 30, five or six word sentences with simple vocabulary and grammar. Several of the sentences, grammatical structure, and vocabulary were borrowed from the Bench, Knowles and Bamford sentences (1). The 'with Context' version presents a picture of an object which represents one word of the sentence before the sentence is spoken in order to give contextual cues.

A live-voice test, Speechreading of Companion, is used to assess the subject's ability to speechread someone with whom they have a great deal of communication experience, a spouse for example. This test has 30 sentences each containing two to six words.

In all three sentences tests, scoring is by correct words. Each word must be reproduced perfectly by the subject, including tense or plurality markers. For the Sentence With Context test, we added the additional requirement that the picture word had to be located in the appropriate portion of the sentence. For example, if "Something that a kitchen clock" was repeated for the sentence "The clock is on the wall", the picture word "clock" would be scored as incorrect. All audiovisual tests were presented with sound only, vision only, and sound plus vision, each time in a different random order.

Test Procedure

Three randomizations of each of the Iowa tests were produced and three randomizations were re-recorded from the MAC tests. The order of presentation of the tests was randomized within and across subjects. In the audiovisual tests, the sound only version was presented before either the vision or sound plus vision tests. All three modality versions of audiovisual tests were separated by at least three hous of testing with other tests.

All tests were presented at about 65-70 dB SPL, and subjects were allowed to adjust their implant to a comfortable setting. This tends to maximize the amount of information falling above an individual's thresholds. Subjects might not perform as well with lower presentation levels.

The audiovisual tests were presented via a Sony U-matic VP-5000 on Scotch UCA videotape, with the sound presented through the video monitor (Sony Trinitron). The audovisual tests were presented in sound field in a large, quiet (but not soundproof) room (background level 43 dBA). All other tests were recorded on Maxell UDXL-II cassette tapes, played back on a Nakamichi LX-5 tape recorder (with Dolby on) and presented in a single-walled sound treated room.

Results

A. Everyday sounds

The results from the Everyday Sounds and the Warning Sounds tests are seen in Table 2. All patients are able to discriminate some everyday sounds. As expected, performance on the identification task was poorer. Patient V3 was able to identify 50% of the sounds, but identified only 15% correct. Three patients (LA3, V1 and V2) were aware of some of the warning sounds.

TABLE 2. Percent correct on the Everyday Sounds and Warning Sound tests. Here and in the following tables we have defined significantly better than chance by using standard scores (* = p > .05) as suggested by Owens et al (6). (DNT = Did Not Test).

PATIENT	EVERYDAY SOUNDS		WARNING SOUNDS
	Discrimination	Identification	Awareness
	%	%	%
LA1	50*	30*	56
LA2	45*	15*	50
LA3	85*	40*	78*
LA4	15	25*	DNT
V1	70*	40*	72*
V2	45*	25*	72*
V3	75*	50*	50
Chance (%)	20	0	50
Number of Items	20	20	18

B. Prosody tests

Table 3 shows the results from the three prosody tests. Only three patients scored above chance on the Question/Statement test. However, five patients scored above chance on the accent test and six patients scored above chance on the Number of Syllables test. There was a slight tendency to do better with plosive or fricative boundaries than with glide/nasal boundaries.

TABLE 3. Percent correct on the prosody tests. (*p > .05).

PATIENT	QUESTION/STATEMENT	ACCENT	# OF SYLLABLES
	%	%	%
LA1	80*	50*	67*
LA2	35	35	41*
LA3	60	45*	63*
LA4	60	40*	33
V1	75*	40*	58*
V2	60	35	71*
V3	95*	75*	71*
Chance (%)	50	20	25
Number of items	20	20	24

C. Closed-set speech tests and speech-related tests

Table 4 shows the results of the three tests that utilize spondee words. The four-choice (spondee) and four-choice in noise tests are closed set. Since the subjects are generally familiar with spondees, the Spondee Recognition test cannot strictly be considered open-set. Five of the patients scored above chance on the Spondee Four-Choice test. The dramatic effect of adding noise is demonstrated by the observation that only one patient scored above chance on the Four-Choice in Noise test. Three patients identified one or two syllables correct on the Spondee Recognition test.

TABLE 4. Percent correct on Closed-set Speech Tests (*p > .05).

PATIENT	4-CHOICE %	4-CHOICE IN NOISE %	RECOGNITION %
LA1	65*	20	0
LA2	20	30	2*
LA3	55*	35	0
LA4	10	10	0
V1	55*	25	1*
V2	55*	30	2*
V3	55*	40*	0
Chance (%)	25	25	0
Number of items	20	20	50

Table 5 demonstrates the results of the speech-related tests. Five of the patients performed above chance on the Noise/Voice test, and five performed above chance on the Female/Male Voice test. No one scored above chance when they were required to determine if two successive sentences were spoken by the same or different speakers.

TABLE 5. Percent correct on Speech Related tests (*p >.05).

PATIENT	NOISE/VOICE	FEMALE/MALE	SPEAKER DISCRIMINATION (DIFFERENT)
	%	%	%
LA1	73*	70*	55
LA2	48	55	55
LA3	55	90*	40
LA4	65*	40	50
V1	80*	85*	50
V2	75*	75*	65
V3	85*	95*	55
Chance (%)	50	50	50
Number of items	40	20	20

D. Open-set speech understanding

The sound-only conditions of the audiovisual tests provide opportunities for open-set speech understanding (Table 6) (7). Particularly on the Sentence with Context, five patients repeated some words correctly. Since there are 30 pictures and 157 words, guessing the picture words only would produce a score of 19%. However, none of the patients adopted a strategy to guess the picture word. As a further test we presented only the picture to five normal hearing subjects and asked them to make up 4 to 6 word sentences that would relate to the picture. The average score was 11 (s.d. = 5.4). With a picture of a clock, V2 and LA2 responded correctly to the spoken sentence "The clock is on the wall". With a picture of a ball, LA1 responded "The baby plays with a ball" to the sentence "The puppy plays with a ball". In addition, LA3 and V1 got the sentence "What time is it?" when it was spoken by their companion. V1 also repeated "Are you coming" correctly on this test.

TABLE 6. Percent correct on open-set speech understanding and the audiovisual tests. Results are shown for Sentence With and Without Context tests, and the Companion Sentence test. Results are shown for sound (S), and vision (V) and sound plus vision (S + V). The sound only presentation is considered open-set speech. Chance scores are shown along the bottom together with the number of items in each test (*p > .05). To test for significant differences between V and S+V, we adopted the binomial model suggested by Thornton and Raffin (7). In the sentence tests each word is not independent, and therefore this statistical test will be lenient. The '+' indicates a significant improvement of the S+V condition over the V condition. (DNT = Did Not Test).

PATIENT	SENTENCE TESTS								
	CONTEXT			NO CONTEXT			COMPANION		
	S	V	S+V	S	V	S+V	S	V	S+V
LA1	18*	89*	96+	0	69*	77	6*	99*	99
LA2	0	40*	48	0	3*	24+	0	25*	50+
LA3	11	41*	61+	0	26*	45+	4*	44*	78+
LA4	0	51*	53	0	11*	47+	0	DNT	71
V1	23*	69*	78	0	43*	52	5*	73*	86+
V2	20*	82*	78	0	48*	59	0	67*	79+
V3	40*	76*	89+	0	48*	64+	17*	71*	83+
Chance (%)		0			0			0	
Number of items		157			153			135	

E. Audiovisual tests

Table 6 shows the results of the audiovisual tests. Binomial confidence intervals applied to the different scores (7) were used to determine if the implant provided statistically significant benefit to speech-reading (i.e., vision plus sound compared to vision only).

On the Sentence with Context test, the object provides a cue to the context of the sentence. Three patients showed large improvement in the vision-plus-sound condition over the vision-only condition.

On the Companion Speechreading test, three of the patients (LA3, V2, and V3) did not have a companion, and were therefore tested by the audiologist with whom they were most familiar. Four patients recognized some words in the sound-only condition. Five showed improvement in the sound-plus-vision condition over the vision-only condition. Note that LA1 scored 99% with vision only, and therefore could not show an improvement in the sound-plus vision condition.

Discussion

Loss of the awareness of environmental sounds and warning signals is a major handicap to the profoundly deaf patient, especially in our mechanized society. The cochlear implants evaluated in this study provide information regarding everyday sounds that in some instances is sufficient for identification of the sound. The most frequent sounds identified were a telephone busy signal, a man talking, a man laughing, and a dog barking.

It is discouraging that the patients did not perform better on prosody tasks. The single-channel implants should be able to convey information about the voicing frequency (Fo) and the envelope of the speech wave form. The Number of Syllables test was the only prosody task in which most of the patients performed significantly better than chance. It may be that the implants were severely clipping (LA) or compressing (V) and coding of envelope changes may be restricted. It does appear, however, that some voicing frequency information is being conveyed as evidenced by results on the Female/Male Voice test (Table 5), but this information is not sufficient to discriminate between speakers of the same gender. This is demonstrated by the results of the different speaker test where no one performed above chance (Table 5).

Some groups (3 and 10) have reported open-set speech understanding with their patients. This seems spectacular in light of the limited amount of information supplied by cochlear implants. This is especially astonishing considering that some of these results were obtained with single-channel cochlear implants where no place information is provided. We have also observed some limited open-set identification of speech (Table 6). None of the patients have identified any words on the open-set sentence if they were unfamiliar with the speaker, but if the patient was very familiar with the speaker, four of the patients made some discriminations. When contextual information is available to the listener, however, a dramatic improvement was noted. Several phrases and even complete sentences were identified. This emphasizes the importances of experience and familiarity with the speaker. Individual speechreading differences are prominent among the patients, but most of the patients display improvement with their devices on.

It is obvious from the results that there are large differences among the patients. There is also great variability in the rank-ordering among the patients on different tests. Because of these differences, it is premature to make comparisons between the two single-channel cochlear implants evaluated in the present study.

Furthermore, the number of patients is small and the amount of experience that these patients had with their devices, which is probably crucial to their performance, is not equivalent. Factors such as number of surviving neurons and the individual ability to synthesize limited information is exaggerated when dealing with such small numbers of patients. The above measures are being studied, but conclusive results have not been collected to date. As these measurements become available, more meaningful comparisons will be provided in the future.

The overall impression from the preliminary data is that most patients receive significant information from single-channel cochlear implants to aid them in communication. Individual patient differences, i.e., neuron survival and ability to synthesize limited information, may affect patient performance more than single-channel implant design, but it is inappropriate to make this conclusion based on the preliminary data presented here. The significance of individual patient differences will become more apparent as multi-channel implants are evaluated and reliable tests designed to measure neuron survival become available.

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