40

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AUDIOLOGICAL RESULTS WITH TWO SINGLE CHANNEL COCHLEAR IMPLANTS

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We tested six patients with single channel cochlear implants on several tests from the Minimal Auditory Capabilities battery and the Iowa Cochlear Implant Tests. All patients were able to discriminate some everyday sounds and to identify the number of syllables in the words presented. Five patients were able to identify speaker sex reliably. Surprisingly, some patients had difficulty discriminating between a modulated noise and a voice or between a question and a statement or identifying the accented word in a sentence. On several audiovisual tests, an improvement was observed for the sound plus vision condition compared to the vision only condition. This was particularly true for sentence tests, but was not uniform across patients or across tests.

KEY WORDS — cochlear implants.

INTRODUCTION

While it is becoming clear that cochlear implants can provide some useful hearing to some profoundly hearing-impaired patients, few reports have assessed their performance on a variety of communication tasks. The Minimal Auditory Capabilities (MAC) battery[1,2] provides a useful initial attempt to quantify performance on several skills. We have developed some additional tests, the Iowa Cochlear Implant Tests,[3] to extend the range of abilities measured and to provide taped audiovisual tests. In this paper we describe the Iowa tests and report our initial results with patients wearing the Los Angeles[4] (LA) and the Vienna[5] (V) single channel cochlear implants.

It is inappropriate at this time to compare results between these two types of cochlear implants. First, the number of patients is small and other individual factors, like the number of surviving neurons and the ability to synthesize limited information, might account for differences that are observed. Furthermore, the amount of experience that these patients have had with the implant is probably crucial to their performance, and the V patients had much less experience than two of the three LA patients (LA1 and LA3).

METHODS

Patients. Patients were unselected in regard to which implant they received. Specifically, our first five patients received the LA device (Sigma model) and the next four received the V device as soon as that was available. Unfortunately, three of the patients who received that LA device are unsuitable for rigorous investigations because of either emotional problems (unrelated to the implant) or inability to understand and perform the tasks. Another patient with the LA device (Sigma model) was implanted elsewhere, but has moved into our area and is included in this report. One of the patients with the V device experienced pharyngeal pain to electrical stimulation after implantation and was unable to wear an implant. Thus, the results presented here are from three patients with the LA device and three with the V device. Table 1 shows relevant biographic data from our six test patients. All patients except LA2 had profound bilateral hearing loss and had not found a hearing aid useful. They were unable to identify spondees wearing a high-powered hearing aid in our clinic. Patient LA2 had some residual hearing but a progressive hearing loss in his nonimplanted ear; he routinely wore a hearing aid and was able to repeat several spondees presented at 85 dB hearing level but was unable to repeat any W-22 words at any level. Patient LA2 was tested in this study without his hearing aid.

All patients except LA2 and V2 wore their implants all day. Patient LA2 relied more on his hearing aid. Patient V2 drove a truck and removed his implant while driving because the noise level was disturbing. Electrical thresholds, uncomfortable loudness levels (ULLs), and dynamic ranges (without external processors) are shown in Table 2. Soundfield speech detection thresholds and audiometric data (with the processors) are shown in Table 3. The

TABLE 1. PATIENT CHARACTERISTICS

Patient	*Age (yr)*	*Etiology of Deafness*	*Duration of Hearing Loss (yr)*	*Duration of Profound Hearing Loss (yr)*	*Tinnitus*	*Time Since Implantation (mo)*
LA1	62	Otosclerosis	57	10	Crackling (B)	21
LA2	64	Otosclerosis	22	3	None	6
LA3	53	Skull fracture	8	8	Ringing, rumbling (B)	29
V1	53	Congenital syphilis	45	9	None	5
V2	23	Skull fracture	2	2	Buzzing (B)	5
V3	56	Otosclerosis	45	9	Buzzing (B)	3

B — bilateral.

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TABLE 2. ELECTRICAL THRESHOLDS, UNCOMFORTABLE LOUDNESS LEVELS, AND DYNAMIC RANGES OF IMPLANT USERS*

Patient	*62 Hz*	*98 Hz*	*125 Hz*	*177 Hz*	*250 Hz*	*500 Hz*	*1,000 Hz*	*2,000 Hz*	*16,000 Hz*
LA1	—	—	—	—	—	—	3.6 / >17.0 } >13.5	—	2.1 / 17.0 } >18.2
LA2	—	—	—	—	—	—	5.0 / 20.0 } 12.0	—	2.2 / 20.0 } 19.2
LA3	—	—	—	—	—	—	Not tested	—	3.5 / >22.0 } >16.0
V1	0.38 / 8.14 } 26.7	0.40 / 8.37 } 26.5	0.24 / 9.27 } 31.8	0.32 / 9.06 } 29.0	0.09 / 9.41 } 40.8	0.46 / 9.64 } 26.4	0.62 / 10.20 } 24.4	1.58 / 10.20 } 24.4	—
V2	0.97 / 8.96 } 19.4	1.01 / 8.85 } 18.8	1.83 / 8.63 } 13.5	2.96 / 9.73 } 10.4	4.02 / 10.20 } 8.0	4.36 / 10.20 } 7.4	4.07 / 10.11 } 7.9	4.18 / 10.20 } 7.3	—
V3	1.81 / 5.45 } 9.6	1.07 / 6.39 } 15.5	0.75 / 4.39 } 15.4	1.01 / 0.64 } 16.3	2.25 / 5.75 } 8.2	1.78 / 5.82 } 10.3	2.38 / 7.91 } 10.4	2.77 / 10.20 } 11.3	—

*Without external processors. In triads, electrical thresholds are top number, uncomfortable loudness levels bottom number, dynamic ranges (in decibels) number at right. For the Los Angeles patients, results are shown in volts, and reflect threshold and ULL to 16,000-Hz carrier. Results shown for 1,000 Hz are for condition where 16,000-Hz carrier is set to just below threshold and modulated by 1,000-Hz sinusoid. Measurements were made with House Ear Institute threshold tester, in which it is not possible to present modulator frequencies other than 1,000 Hz. For Vienna patients, results are shown in microvolts for direct sinusoidal stimulation. In both groups, voltage is reported at external coil, and many factors (external-internal coil interface characteristics, electrode impedance) influence current density at internal electrode.

soundfield thresholds for the LA patients are similar to the average of 65 LA patients reported by Thielemeir et al.[4] Our thresholds at 250 Hz are slightly better and at 1,000 Hz are poorer. Our results also fall within the range reported by Bilger and Hopkinson[7] from 12 patients with an early LA device.

Test Battery. In testing our patients we used portions of the MAC battery because we felt it tested some aspects of sound processing that were important to measure and because other investigators have published results using these tests. A description of the MAC tests and their administration has been published.[1,2] We also felt that it would be worthwhile to evaluate other abilities, for example, to determine if patients could recognize male versus female speakers, and to evaluate audiovisual perception with videotaped material. Therefore, we developed additional tests (the Iowa Cochlear Implant Tests), described in the Appendix.[8,9] We are continuing to revise and improve these tests, but feel they provide useful information in their current state and are making them available to interested parties. We also used the Monosyllable-Trochee-Spondee (MTS) test,[10] because MTS results have been reported for several LA patients.[6]

Procedure. We produced three randomizations of each of the Iowa tests and rerecorded three randomizations of the MAC tests. The order of presentation of the tests was randomized within and across subjects with three exceptions. The closed set Everyday Sound Recognition test always was presented after the open set Everyday Sound Recognition test, and several other tests were interspersed between the two. In the audiovisual tests, the sound only version was presented before either the vision or sound plus vision tests. All three modality versions of the audiovisual tests were separated by at least three hours of other testing.

All tests were presented at about 65 dB sound pressure level (SPL) and subjects were allowed to adjust their implants to a comfortable setting. This tends to maximize the amount of information falling above an individual's threshold. Subjects might not perform as well with lower presentation levels (such as might occur in typical listening environments).

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 audiovisual tests were presented in soundfield in a large, quiet (but not soundproof) room (background level 43 dBA). All other tests were recorded on Maxell UDBXL-II cassette tapes, played back on a Nakamichi LX-5 recorder (with Dolby on), and presented in a single-walled sound-treated room.

RESULTS

Everyday Sounds. Table 4 shows the results from the Everyday Sounds and the Warning Sounds tests. All patients were able to discriminate some everyday sounds. Even without alternatives, patients were able to identify some of the reference sounds. As expected, performance on the open set task was poorer.

Three patients (LA3, V1, and V2) were aware of some of the warning sounds and three patients (LA1, LA3, and V2) were able to identify some. The results for LA1 are misleading; on the awareness portion of the test he nearly always guessed that there was a warning sound and therefore scored at chance. However, he was then allowed an opportunity to identify all the warning sounds, and was able to identify some sounds at better than chance performance. Other subjects, however, were only allowed to identify sounds when they indicated a warning sound was present.

Prosody Tests. Table 5 shows the results from the

TABLE 3. SOUNDFIELD AUDIOGRAMS WITH IMPLANT*

Patient	*Speech Detection Threshold*†	*Hearing Level in Decibels*							
		125 Hz	*250 Hz*	*500 Hz*	*1,000 Hz*	*2,000 Hz*	*3,000 Hz*	*4,000 Hz*	*8,000 Hz*
LA1	45	>40	35	30	70	50	65	60	>60
LA2	48	>40	50	60	70	55	60	65	70
LA3	44	>40	30	50	55	50	65	>60	>60
V1	36	20	25	30	40	35	40	40	>60
V2	30	40	35	45	45	45	50	60	>60
V3	30	25	30	30	45	50	70	>60	>60

Sensitivity for sounds (particularly above 500 Hz) does not imply that these sounds elicit different pitches.

*Obtained with frequency modulated tones, 10% modulation at 5/s.

†Speech detection thresholds were obtained live-voice by female speaker (except V2 - male speaker) with spondees.

TABLE 4. EVERYDAY SOUNDS AND WARNING SOUND TESTS

	Percent Correct			
	Everyday Sounds		*Warning Sounds*	
Patient	*Closed Set*	*Open Set*	*Awareness*	*Identification*
LA1	50*	30*	56	33*
LA2	45*	15*	50	0
LA3	85*	40*	78*	6*
V1	70*	40*	72*	0
V2	45*	25*	72*	11*
V3	75*	50*	50	0
Chance	20%	0%	50%	0%
Number of items	20	20	18	18

*$p > .05$. Here and in the following tables we have defined significantly better than chance by using standard scores suggested by Owens et al.[4]

four prosody tests. Only three patients scored above chance on the Question/Statement test, and only two scored above chance on the Accent test. However, all 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. Four of the patients scored above chance on the MTS/Stress test. The three LA patients had performed the test several times as part of the rehabilitation protocol for users of the LA device coinvestigation. It is noteworthy that several patients were not able to recognize a one syllable word as such. The one syllable words on the MTS test all end with plosives. It is possible that the offset noise-burst from the plosive release is perceived as a second syllable. More trochee than spondee substitutions were made for one syllable words.

Spondee Tests. Table 6 shows the results of the four tests that utilize spondee words. Five of the patients can discriminate same/different with spondees and four scored above chance on the spondee four choice tests. The dramatic effect of adding noise is demonstrated by the observation that none scored above chance on the four choice in noise test. Three patients got one or two syllables correct on the Spondee Recognition test.

Speech-Related Tests. Table 7 shows the results of the speech-related tests. Four of the patients performed above chance on the Noise/Voice test, and five performed above chance on the female/male voice test. All the patients scored above chance on the speaker discrimination tests for the same sentence. However, no one scored above chance when the pair of sentences was different. No differences attributable to speaker sex were found on either test. Only patients V1 and V2 scored above chance on the closed set MTS word test.

Audiovisual Tests. Table 8 shows the results of the six audiovisual tests. On the medial vowel test, performance is near chance for the sound only condition. Although many of the vowels were easily discriminated in the vision only condition, no significant improvement was observed when sound was added to vision. Binomial confidence intervals applied to the different scores[11] were used to determine if the implant provided any additional benefit to speechreading (ie, vision plus sound compared to vision only).

On the initial consonant test, subjects LA1, LA2, and V2 scored above chance on sound only. Subjects LA2, V1, and V2 demonstrated a clear benefit from adding sound to the vision only condition.

On the final consonant test, all of the patients scored above chance on the sound only condition. Three (LA3, V1, and V3) showed improvement with the sound plus vision condition over the vision only condition.

In all three sentence tests, scoring was by the total correct words within a sentence. Key word scoring was not used. Each word had to be exactly correct, including tense and plurality markers. On the Sentence With Context test, the picture provides a cue to the context of the sentence. Since there are 30 pictures and 157 words, guessing the picture words only would produce a score of 30 out of 157, or 19%. However, none of the patients adopted the strategy of guessing the picture word.

As a further test of chance performance we presented only the pictures (without sound) of this test to five normal-hearing subjects. They were asked to make up four- to six-word sentences that would relate to the picture. To be correct, the words had to be in the correct part of the sentence. For example, if the patient repeated, "Something that's a kitchen clock" for the sentence, "The clock is on the wall,"

TABLE 5. PROSODY TESTS

	Percent Correct			
Patient	*Question/Statement*	*Accent*	*No. of Syllables*	*MTS Stress*
LA1	80*	50*	67*	71*
LA2	35	35	41*	71*
LA3	60	45*	63*	83*
V1	75*	40	58*	50
V2	60	35	71*	88*
V3	70*	35	71*	42
Chance	50%	20%	25%	33%
Number of items	20	20	24	24

MTS — Monosyllable-Trochee-Spondee.

*$p > .05$. The results for the MTS test are shown for stress recognition.

TABLE 6. SPONDEE TESTS

Patient	Same Different	Percent Correct Four Choice	Four Choice in Noise	Recognition
LA1	80*	65*	20	0
LA2	65	20	30	2*
LA3	80*	55*	35	0
V1	80*	55*	25	1*
V2	85*	55*	30	2*
V3	75*	20	0	0
Chance	50%	25%	25%	0%
Number of items	20	20	20	50

*p > .05.

the picture word clock would be scored as incorrect. The average score for these normal subjects was 11 words correct (SD 5.4). Using this as a measure of chance, three patients scored above chance. Three patients showed significant improvement in the vision plus sound condition over the vision only condition.

On the Sentence Without Context test, no one perceived any words correctly on the sound only condition. However, three patients tested showed significant improvement in the sound plus vision condition compared to 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 same audiologist. Because different speakers are used for different patients, and because this is a live voice test, it is not appropriate to compare scores across patients. Four patients perceived some words correctly in the sound only condition. Four 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.

Open Set Speech Understanding. The sound only conditions of three of the speechreading tests provide opportunities for open set speech understanding. On the sentence with context test, three patients repeated some words correctly. With a picture of a clock, V1 and V2 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." As we noted previously, normal listeners were able to score 11% by guessing based on the pictures (without hearing anything). However, none of the normal listeners got entire sentences or phrases correct.

In addition, LA3 and V1 understood the sentence, "What time is it?" when it was spoken by their companion. Subject V1 also repeated, "Are you coming?" correctly on this test.

On two other tests of open speech understanding, the MAC Words in Context and the Iowa Monosyllabic Word Identification tests (rerecording of MAC XI [NU-6]), all patients scored zero correct.

DISCUSSION

Comparisons With Other Groups. Thielemeir et al[6] reported results with the MTS test with the LA device. Of the 18 patients tested, the average word scores were 27.5% correct after 1 to 3 months of experience and 35.4% after about 2 years' experience. The scores on the stress portion averaged 54.3% correct after 1 to 3 months and 63.3% correct after 2 years' experience. We have only one subject (V2) who performs this well on the word score. Four of our six subjects are performing similarly to Thielemeir's patients on the stress portion of this test.

Owens et al[2] reported scores on the MAC test

TABLE 7. SPEECH-RELATED TESTS

Patient	Noise Voice	Female Male Voice	Speaker Discrimination Same	Speaker Discrimination Different	MTS Word
LA1	73*	70*	75*	55	17
LA2	48	55	70*	55	21
LA3	55	90*	70*	40	11
V1	80*	85*	90*	50	29*
V2	75*	75*	85*	65	38*
V3	85*	90*	80*	65	21
Chance	50%	50%	50%	50%	17%†
Number of items	40	20	20	20	24

(Percent Correct)

*p > .05.

†For the MTS word test, we might assume that listeners can distinguish between one- and two-syllable words. This would mean that chance performance for one-syllable words would be 25% (1 out of 4), and for two-syllable words, 12.5% (1 out of 8). This results in a weighted average chance score of 17%.

TABLE 8. AUDIOVISUAL TESTS

	Percent Correct																	
	Medial Vowel			*Initial Consonant*			*Final Consonant*			*Sentence Tests*								
										Context			*No Context*			*Companion*		
Patient	*S*	*V*	*S + V*	*S*	*V*	*S + V*	*S*	*V*	*S + V*	*S*	*V*	*S + V*	*S*	*V*	*S + V*	*S*	*V*	*S + V*
LA1	25	80*	80	42*	80*	88	54*	87*	90	18*	89*	96†	0	69*	77	6*	99*	99
LA2	23	63*	65	47*	67*	86†	48*	65*	69	0	40*	48	0	3*	24†	0	25*	50†
LA3	23	72*	82	33	77*	83	63*	77*	90†	11	41*	61†	0	26*	45†	4*	44*	78†
V1	32	83*	78	28	70*	89†	46*	73*	87†	23*	69*	78	0	43*	52	5*	73*	86†
V2	33	78*	80	50*	63*	86†	63*	87*	80	20*	82*	78	0	48*	59	0	67*	79†
V3	32	72*	72	30	81*	84	46*	67*	88†	10	53*	75†	0	36*	50†	1*	76*	72
Chance		25%			25%			25%			0%			0%			0%	
Number of items		60			64			52			157			153			135	

S — sound. V — vision. S + V — sound plus vision.

*p > .05.

†Significant improvement of the S + V condition over V condition (binomial model used for test[11]).

from six patients implanted with the San Francisco (SF) implant. This device had eight bipolar electrodes connected to a single channel processor. Their patients were tested after a healing period of at least 1 month, but it is unclear how much listening experience they had at the time of the tests. On the Spondee Same/Different test, their patients scored between 75% and 95% correct, slightly better than our range of 65% to 85%. On the Four Choice Spondee test, their patients' scores ranged between 10% and 80%. With the exception of their best patient, our own results ranging between 20% and 65% are comparable. Their best patient also scored 40% on the Spondee Recognition test, far superior to our own results.

On the Question/Statement test, their scores ranged from 60% to 95%, better than our scores, which ranged from 35% to 80%. On the Accent test, their scores ranged from 20% to 95%, with five of their patients scoring at 70% or above. Our patients' scores ranged from 35% to 50%, again inferior to the performance of Owens's group. On the Noise/Voice tests, their scores (only four patients tested) ranged from 52% to 82%, comparable to our range of 48% to 85%.

Our recordings of the four choice vowel and consonant tests are not directly comparable to those of Owens et al[2] (we rerecorded with a different speaker). On the vowel test, three of their patients scored 35%, 41%, and 42% correct, while the other three scored at chance. In contrast, none of our patients scored above chance performance. On the initial consonant test, their patients' scores ranged from 31% to 81% compared to the poorer performance of our patients, whose scores ranged from 28% to 42%. On the final consonant test, the scores from their patients ranged from 40% to 81%, again superior to our 46% to 63%.

Rosen et al[12] have recently reported administering the Question/Statement test to patients with their single channel implant that codes voicing frequency (F0). All three patients scored 100%, far better than our patients or the patients studied by Owens et al.[2]

Benefits and Limitations of Cochlear Implants. Cochlear implants provide information regarding everyday sounds and in some cases this information is sufficient for identification. The most frequently identified sounds were a telephone busy signal, a man talking, a man laughing, and a dog barking. Cafeteria noise, organ music, a person whistling, pouring water, a drum roll, and a typewriter were not identified by anyone.

Single channel cochlear implants should be able to convey information about F0 and the envelope of the speech waveform. On the prosody tests (Table 5), none of the patients performed well. The poor results on the Question/Statement and Accent tests were surprising. It may be that if the implant is severely clipping (LA) or compressing (V), then the coding of envelope changes would be restricted. Scores on the Noise/Voice tests and on the Female/Male Speaker Recognition tests were closely related across patients, except for LA3 who scored at chance on the Noise/Voice but got 90% correct on the female/male speaker test. It is encouraging that the implant can code male/female voice differences, which could be conveyed by F0 or formant frequency. However, it should be noted that none of the six patients scored 100% on this task.

On the spondee tests, performance was somewhat better. However, these tests do not provide insights into what information is being used by the patients to make their discriminations. The dramatic effect of the noise (at a speaker-to-noise ratio of + 10 dB) indicates a basic limitation of the single channel device. If the channel is "filled" by background noise, the effect on processing other information is drastic.

Patients were frequently able to tell whether two repetitions of the same sentences were spoken by the same speaker. This discrimination could have been made on a number of cues, including minor loudness differences or the duration of the sentence. This conclusion is supported by the chance performance on speaker discrimination when different sentences were used, where loudness and duration differences occurred between the two sentences whether the speaker was the same or different.

Assessment of the ability of the implant to assist speechreading depended upon the test. For example, large improvements were seen in the final consonant test compared to the medial vowel or initial consonant test. In isolated words, many of the vowels and consonants in these tests are visible on the face, and the additional information provided by the implant does not supplement this information.

On the sentence tests, individual differences in speechreading ability are prominent. Patient LA1 seems to be the best speechreader, whereas LA2 seems to be the poorest. All of the patients showed significant improvement with the implant on at least one of the sentence tests.

Open Set Speech Understanding. Some groups[2,13,14] have reported some open set understanding of speech. This seems spectacular in light of the limited amount of information provided by cochlear implants compared to a normal ear. This is particularly true of single channel devices, such as the examples reported in this paper, where there is no place analysis. We have also observed some limited open set identification of speech, but only in context or with a familiar speaker. First, with the sentences in context, several phrases and even a few sentences were identified. This suggests that these patients are able to perform valuable top-down processing given minimal auditory information, and can synthesize some phrases in highly redundant sentences. Second, the identification of some speech produced by their companion without context and without speechreading suggests the role of familiarity with certain speakers and emphasizes the importance of experience and rehabilitation.

On most of our open set tests, the scores were zero or at chance. Therefore, it is misleading to suggest that these people can understand speech. This is further apparent when we examine their scores on the Noise Voice test. The three patients who understood some phrases on the companion sentence test (LA1, LA3, and V1) scored only 73%, 55%, and 80% (respectively) on the Noise Voice test. In this perspective we can see that these patients are not hearing speech as normal listeners do. It is remarkable and encouraging, nonetheless, that they are able to synthesize enough information to get any words correct at all. We should note that many of these patients had less than 6 months' experience with their implants, and that their performance is likely to improve.

Comparison With Results Obtained Using Vibrotactile Aids. While on the whole we consider the results obtained with cochlear implants encouraging, and certainly superior to receiving no sound whatsoever, it behooves us to examine results obtained from vibrotactile aids. Plant[15] recently reported results from four subjects with wearable single channel vibrotactile devices with from 6 months to 3 years of experience. He reported that their MTS word scores ranged from about 8% to 33% (about chance performance), and MTS stress scores ranged from about 66% to 82%. These results are not unlike those that we observed in the present study. These subjects were also able to discriminate some environmental sounds and recognize the stressed word in a sentence. Clearly a direct comparison of cochlear implants and vibrotactile aids would be informative.

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APPENDIX: IOWA COCHLEAR IMPLANT TESTS

All 15 of the Iowa Cochlear Implant Tests are available with the test items in three different random orders. Many of the tests have practice items (where the correct answer is given), but these items are never used as test items.

1. *Medial Vowel Recognition* — the MAC II Vowel Test adapted as a color taped audiovisual test. The 60 test items and foils are the same as in MAC II. First, the four choices are presented on the screen for 6 seconds. Second, a man (head and shoulders view) appears and says the test word once. Third, the four choices are presented again for 6 seconds and the subject is asked to make a choice. This is followed by a 2-second blank screen and a 2-second presentation of the next item. As in the MAC II test, there are six practice items. For the first two, the correct foil is flagged both before and after the speaker. For the remaining four practice items, the correct response is flagged after the speaker but not before. The test can be administered with sound alone, vision alone, or sound plus vision.

2. *Initial Consonant Recognition* — a version of the MAC VII Initial Consonant Test adapted as a color taped audiovisual test. It is presented exactly as in Iowa 1. There are three practice items.

3. *Open-Set Everyday Sound Recognition* — the MAC X test expanded from 15 to 20 items to reduce learning effects. The subject is presented with a sound and is asked to describe it precisely. No alternative choices are provided. All answers are recorded, but only specific responses (found on the score sheet) are accepted and scored correct. There are no practice items and no preceding warning sounds or words. This test should be administered before Iowa 7, Closed-Set Everyday Sound Recognition, which contains the same sounds but in different orders.

4. *Monosyllabic Word Identification (NU-6)* — identical to the MAC XI test except that it has been rerecorded. The original MAC tape contained several items which were unclear and were heard incorrectly by normal-hearing listeners. There are three practice words.

5. *Final Consonant Recognition* — a taped audiovisual version of MAC XIII, similar to the Iowa 1 and 2 tests; includes three practice items.

6. *Number of Syllables* — test in which the subject is presented with a single word and asked to report the number of syllables that it contains. The subjects are told not to try to identify the words. Of the 24 test words, six have one syllable, six have two syllables, six have three syllables, and six have four syllables. The test items can be further divided by manner of phonemic syllable boundary. Syllabic boundaries can be plosive, fricative, or nasal-liquid, with eight words in each category. Patients are told the words will be one, two, three or four syllables in length. There are three practice words.

7. *Closed-Set Everyday Sound Recognition* — subject is presented with one of the 20 environmental sounds in the Iowa 3 test and asked to identify it by selecting one among five alternatives.

8. *Sentence Understanding Without Context* — a taped audiovisual test utilizing 30 sentences, each containing five or six words. The sentences have simple vocabulary and grammar and, in several sentences, the grammatical structures and vocabulary were borrowed from the Bamford-Kowel-Bench (BKB)[8] sentences. The subject is given three practice sentences with feedback. Scoring is by total words (153) and by key or content words (88). Words must be reproduced (oral or written) perfectly, including tense and plurality markers.

9. *Sentence Understanding With Context* — a taped audiovisual sentence test that presents pictures before the test items. The picture represents one of the key words within the sentence. Some of the 30 sentences are taken from the BKB lists, but are different from those in Iowa 8. The picture is on the screen for 3 seconds. There are three practice sentences with feedback. The test can be scored by total words (157), key words (90), and picture words (30). A separate videotape is available for sound only presentation. Here the picture is presented, but the speaker is not visible.

10. *Female Male Speaker Recognition* — 20 sentences are presented, half spoken by women and half spoken by men, and the subject asked to indicate the gender of the speaker. The subject is provided with a list of the sentences taken from or modeled after those of the BKB lists, but none are duplicates of sentences in the Iowa 8 and 9 tests. Each sentence was recorded by a different speaker, all having a general American dialect. There are three practice sentences.

11. *Warning Sounds* — a test evaluating the ability to detect and label a warning sound presented in a background noise. There are 18 presentations of these 5-second samples of cafeteria noise (locally recorded), and in half of these presentations a warning sound occurs (2 seconds into the noise) at a signal-to-noise ratio of +6 dB. The test consists of 18 presentations of the noise, half of which also contain a warning sound. The test is scored in two ways, first for awareness (warning no warning) and second for correct identification. The subject is given a list of all the warning sounds in the test plus six others, for a total of 15 alternatives.

12. *Speaker Discrimination: Same Sentence* — two presentations of the same sentence which patient is asked to identify as being produced by the same speaker (the same token) or by two different speakers. The sentences are the same as in Iowa 10 and 13 (but are not the same speakers). In each pair of sentences, the speaker's sex is always the same, with ten trials men and ten women. The subject is given a list of the sentences so that he or she does not have to attend to meaning. In recording the sentences, no attempt at controlling rate or inflection was made, but all speakers used a general American dialect. The test can be scored for the number correct with female speakers, with male speakers, and total correct. There are three practice sentences.

13. *Speaker Discrimination: Different Sentence* — similar to Iowa 12, except that each pair of sentences contains two different sentences. The patient must decide whether the pair of sentences was spoken by the same speaker or by two different speakers. Again, ten pairs of sentences are produced by men and ten by women. The subject is given a list of the sentences. Scores can be reported for the number correct with female speakers, with male speakers, and total correct. There are three practice items.

14. *Audiovisual Perception of Companion* — a live voice audiovisual test with 30 sentences containing from two to six words each. The sentences, which are adapted from the Manchester Speechreading Test,[7] are to be read by the patient's spouse or someone who is familiar and close to the patient. If no one else is available, the audiologist can perform the test. Scoring is total number of words correct. The speaker should be seated at a distance of 1 m from the patient. In the sound only condition, the patient faces away from the speaker and is unable to see any gestures or facial expressions. With this test, we wish to assess the patient's ability to speechread someone with whom they are familiar.

15. *Closed Set Spondee Recognition in Noise* — a four choice spondee test with 20 test and three practice items. Each word is presented in multitalker babble at +10 dB signal-to-noise ratio. This test is directly comparable to MAC XII, since it uses the same test items and foils, yielding a measure of the effect of noise on recognition. There are three practice items.