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Cochlear Implant Program at The University of Iowa

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At The University of Iowa we are conducting an evaluation of patients with different types of cochlear implants. One of our goals is an in-depth evaluation of the benefits provided by different cochlear implants. We hope to learn about the kinds of sounds that can and cannot be coded with electrical stimulation, which should provide useful information for new implant design. In this paper we describe some preliminary results from a limited number of patients. We also discuss some examples where our patients show improvement in their performance over a 1-year period. We show results from a patient tested in a 1-channel and 21-channel configuration, and we present some preliminary comparisons between cochlear implants and vibrotactile aids.

Comparative Evaluation of Different Implants

We have tested four patients with the Los Angeles (LA) implant (House & Urban, 1973), three patients with the intracochlear Vienna (V) implant (Hochmair-Desoyer, Hochmair, Fischer, & Burian,1980) and two patients with the multichannel Melbourne (M) device (Tong et al., 1981). All patients were postlingually deafened adults who used their implants for at least three months before testing. All patients had a profound bilateral hearing loss, except LA2. (This subject had a progressive hearing loss but some residual hearing in the nonimplanted ear. All tests were performed without his hearing aid in the nonimplanted ear.) *Table 1* shows relevant biographical data. The patients were tested with some of the tests from the Minimal Auditory Capabilities (MAC) Battery (Owens, Kessler, Telleen, & Schubert, 1981) and the Iowa Cochlear Implant Battery (Tyler, Preece, & Lowder, 1983). The tests were presented at about 65 dB SPL in sound field. The subjects were instructed to adjust their devices so that the sounds were at a comfortable loudness.

Subject	Sex	Age (years)	Years of Profound Deafness	Experience with Implant when tested (months)
LA1	F	62	10	24
LA2	M	64	3	6
LA3	M	33	8	30
LA4	M	66	8	60
V1	F	53	9	12
V2	M	23	2	12
V3	M	56	9	12
M1	M	45	1	4
M2	M	33	7	4

Table 1. Biographical data from patients with the Los Angeles (LA), Vienna (V) and Melbourne (M) cochlear implants.

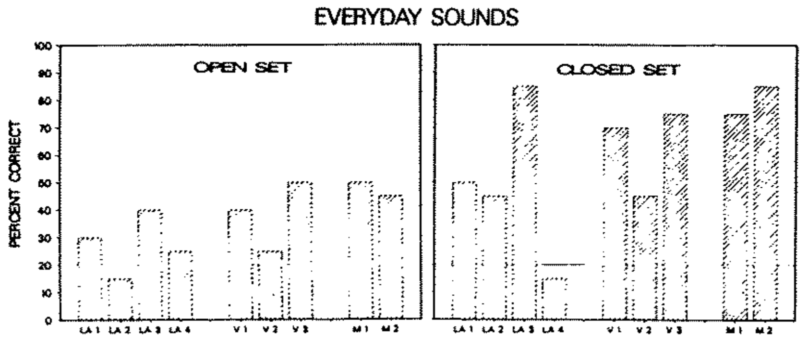

Figure 1. Results from the open-set (left) and closed-set (right) Iowa *Everyday Sound Recognition* tests. The same 20 items, which include sounds like a typewriter, cafeteria noise, footsteps, and a telephone ringing, are included in both tests. In the closed-set version the patient selects a response from five alternatives. Chance performance is 20% for the closed-set version (horizontal solid line).

Here we present results from only a few selected tests that show some areas where implants provide a great benefit and from some areas where they do not. A more complete description of our findings is found in Gantz and Tyler (1985), McCabe et al. (1984), Tyler et al. (1985), and Tyler, Lowder, et al. (1984).

Figure 1 shows the results when patients were presented with a single everyday sound and required to identify it. The left panel shows the results for an open-set response format, and the right panel shows results obtained when the patients could select their response from five alternatives. The open-set format was presented first, and feedback was not given. Five of the patients scored at or above 70% on the closed-set task (chance performance is 20%), and eight scored at or above 25% correct in the open-set format. We consider this an important benefit provided by the cochlear implant.

The top of *Figure 2* shows the waveform and spectrogram of the sentence, "*Who* is your new neighbor?" with the word "who" stressed. We can see from the waveform that the voicing frequency, the rate at

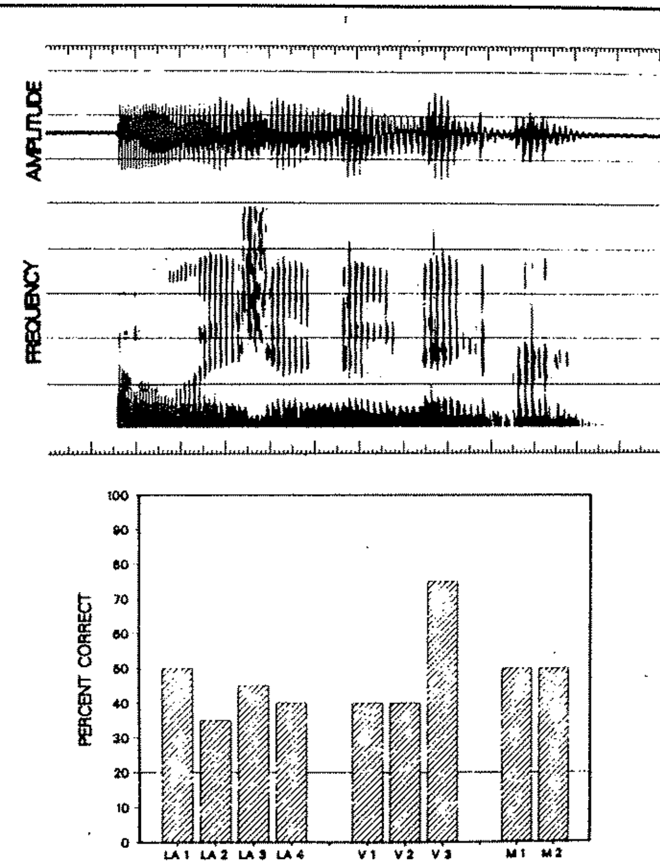

Figure 2. Top: Waveform and spectrogram for the sentence "*Who* is your new neighbor?", with the word "who" accented. The X-axis represents time, each division representing 10 ms. The Y-axis is amplitude (arbitrary units) for the waveform, and frequency (1000 Hz division) for the spectrogram. Bottom: Results obtained from the 20-sentence MAC *Accent* test. The patient is presented with a sentence, which is written in front of him/her, and the accented word must be selected. Chance performance is 20%.

which the vocal folds come together (demarcated by the appearance of vertical lines in the waveform), is higher for the word "who." If patients were able to reliably code voicing frequency, they should be able to select the accented word. The results from the MAC *Accent* test are shown at the bottom. All patients scored about 40 to 50% correct, except V3 who was able to score 75% correct. There is still great room for improvement. (We presented this test to five normal listeners and obtained scores of 100, 100, 100, 95 and 90% correct.) While the implant seems to provide some

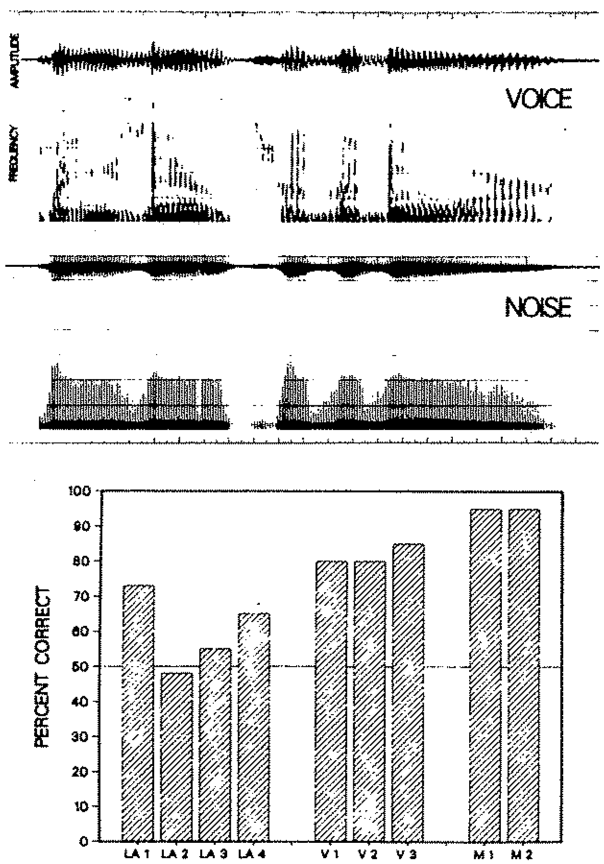

Figure 3. Top: Waveforms and spectrograms for the sentence "Please answer the door," and for noise whose amplitude is modulated by the envelope of the same sentence. Bottom: Results obtained from the 20-item MAC *Noise/Voice* test.

information about voicing frequency, patients do not perform as well as we would expect on this test.

In the MAC *Noise/Voice* test, the patient was presented with a sentence which was either a noise (whose amplitude is modulated by the speech waveform) or a voice. An example of this for the sentence, "Please answer the door," is shown in the upper half of *Figure 3.* The noise version contains no spectral information, but does represent the envelope accurately. Results, shown at the bottom, highlight the wide variation of patient scores on this task. Two patients could not distinguish between a noise and a voice, but two patients scored 95% correct.

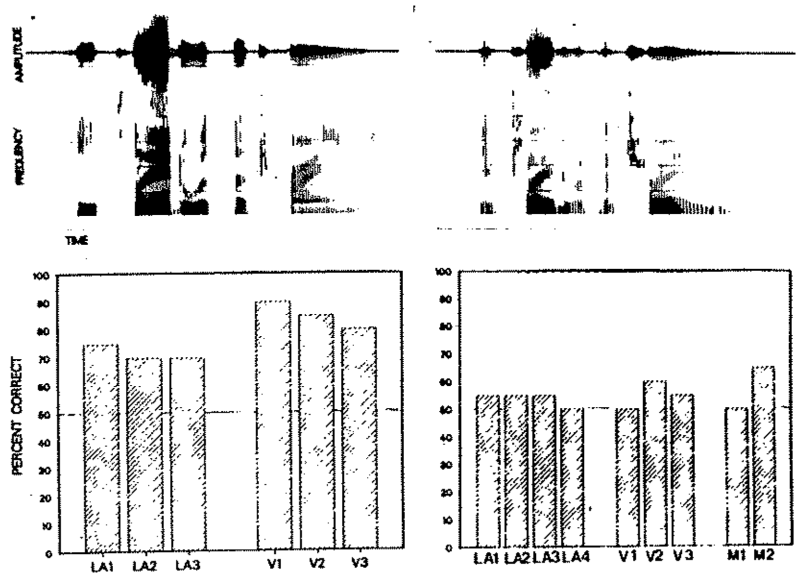

Figure 4. Top: Waveforms and spectrograms for the sentence "He played with the train" spoken by two different speakers. Bottom left: Results obtained from the Iowa *Speaker Discrimination: Same Sentence* test. Not all patients received this test. Bottom right: Results obtained from the Iowa *Speaker Discrimination: Different Sentence* test.

It has been claimed that cochlear implants provide sufficient information to help in recognizing different speakers. In one of our tests the patient hears two identical sentences which are either spoken by the same speaker or by two different speakers (of the same sex). The patient must select whether the pair of sentences was spoken by the same or different speakers. The upper half of *Figure 4* shows the waveforms and spectrograms for the sentence, "He played with the train," spoken by two different speakers. While there are obvious similarities in both waveform and spectrogram for the two utterances, there are also many differences. For example, speaker 1 takes longer to say the entire sentence than does speaker 2. Other differences involve the rate and duration of formant transitions, the voicing frequency, and the relative amplitude of adjacent speech segments. The results for the *Speaker Discrimination: Same Sentence* test, shown in the bottom left panel of *Figure 4*, indicate that performance is good. In another test, *Speaker Discrimination: Different Sentences*, two different sentences are used in the pair. Again the patient must decide whether the sentences were spoken by the same or different speakers. The bottom right panel shows that results are much poorer. Many of the cues that were available in the same-sentence task can no longer be used to make the distinction because the listener cannot compare identical words or phonemes. Performance decreases because patients must rely on finer quality differences, such as voicing frequency and formant locations.

Perhaps one of the most important benefits of cochlear implants is their ability to supplement lipreading. We have developed a number of word and sentence lipreading tests (Tyler et al., 1983). In the *Sentence Recognition With Context* test, a picture of one of the words in the sentence is presented before each sentence. The sentences are based on those used by Bench and Bamford (1979), which were designed from the grammar and vocabulary of children (aged 8 to 15 years) in British schools for the hearing impaired. In the sound-only condition the patient sees the picture providing some context, but does not see the talker. *Figure 5* (top) shows that, in sound alone, seven of the nine patients are able to understand some of the words in the sentences, provided they are given the contextual information. There is a wide range of performance in the vision-only condition, but in all cases sound-plus-vision scores are higher than the scores in the vision-only condition. The *Sentence Recognition Without Context* test uses similar sentences but without any contextual cues. Results for this test are shown at the bottom of *Figure 5*. Without context, only M2 understands some of the words in the sound-alone condition. Again there is a consistent improvement in the sound-plus-vision condition over the vision-only condition for all subjects.

We can conclude that cochlear implants are beneficial in many ways, particularly in providing information about environmental sounds and as an aid to speechreading. We have seen very limited open-set speech understanding, but we consider these preliminary findings very encouraging.

Patient Performance Over Time

We have results on three of our patients who were tested on three different occasions with the same tests. In the top panel of *Figure 6* we see the results for the *Everyday Sound Recognition* tests, both in the closed-set and in the open-set conditions. All three patients show an increase in performance since the initial connection. In two patients, the results obtained at 4 to 6 months are similar to those obtained at about 1 year. But M1 demonstrates continued learning up to 10 months in the open-set task.

In the middle panel we see the results for the *Speaker Discrimination: Different Sentence* test. Here the effect of learning is not as great. Nevertheless, M1 and V2 do show higher scores after about 1 year compared to their scores at initial connection.

In the bottom left we show results obtained with the *Sentence Recognition With Context* test (sound only). Patients are shown a picture of an object which represents a word in the following sentence. All subjects show improvement over time. The right panel shows results for the *Sentence Recognition Without Context* test. V1 was tested on the three occasions, but could not recognize any words. The other two patients, M1 and M2, however, show improved performance between 4 and 10 months.

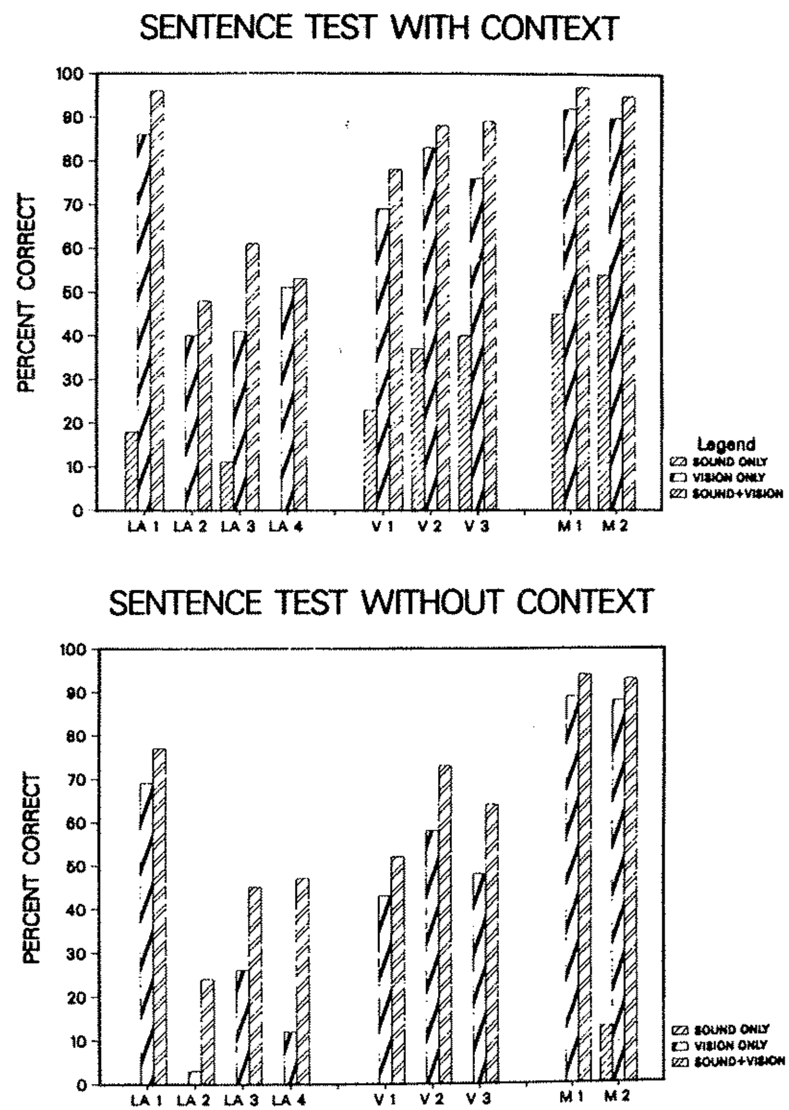

Figure 5. Top: Results obtained with the Iowa *Sentence Recognition With Context* test. A picture of an object, representing a word within the sentence, precedes the talker. This visual. contextual cue is provided even in the sound-alone condition. There are 30 sentences with a total of 157 words. Scoring was based on total words correct. Bottom: Results obtained with the Iowa *Sentence Recognition Without Context* test. There are 30 sentences with a total of 153 words.

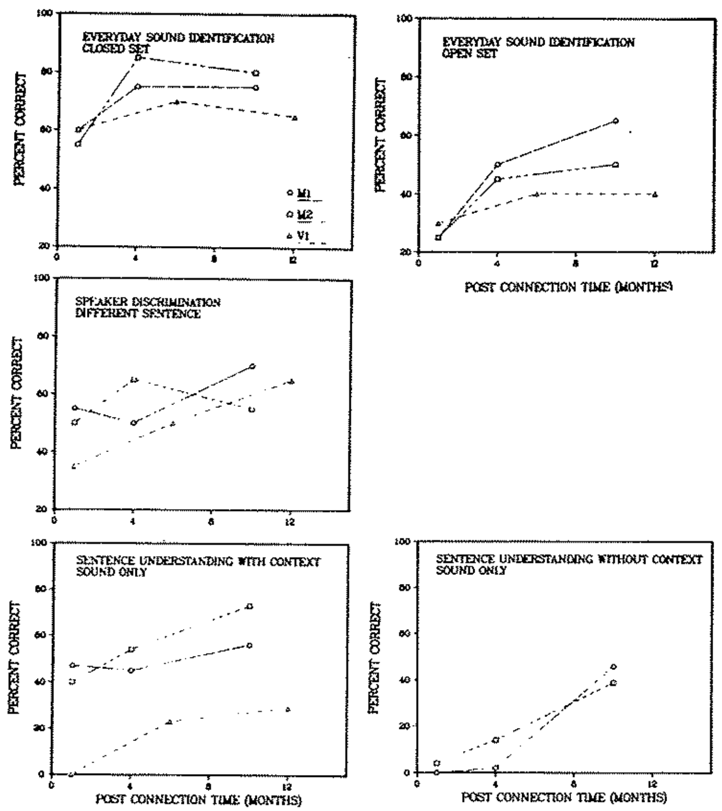

Figure 6. Performance of patients as a function of time after the initial connection of their implant. Only results from three patients (V1, M1, and M2) have been obtained to date. Top: Results from the closed-set (five alternative) and open-set Iowa *Everyday Sound Recognition* tests. Each test contains the same 20 everyday sounds. Middle: Results from the Iowa *Speaker Discrimination: Different Sentence* test. The patient hears two different sentences and must decide whether they were spoken by the same speaker or by two different speakers. Bottom: Results from the Iowa *Sentence Recognition With Context* and the Iowa *Sentence Recognition Without Context* tests for sound-only presentation. Patient V1 did not get any words correct on the latter test.

As might be expected, it appears that there is some learning over the first several months of implant use. This effect might be large for some tasks, like recognizing environmental sounds and understanding speech in context, but might not be as great for other tasks (particularly those on which the patient may be doing well immediately upon connection). Furthermore, in some tasks most of the learning might occur within the first 4 to 6 months. The influence of rehabilitation is unknown.

Single-channel versus Multichannel Processing

In one patient (M3) just recently implanted with the Melbourne multichannel cochlear implant, we have compared the processing of the device in its normal mode of 21-channels (bipolar configuration) to the same device set up to stimulate only 1 channel (bipolar). We chose the electrode (number 15) with the largest dynamic range. The 1 channel should therefore provide information about voicing (like the device by the London group; see Fourcin et al., 1979) plus amplitude. To compare the processing schemes we used our recently developed (videotaped) 14-choice nonsense syllable consonant confusion test (Tyler, Lansing, & Preece, 1984). The test can be presented for conditions of sound alone, vision alone, and sound plus vision. The test is presented in the /iCi/ format, with the consonants being /b, d, f, g, j, k, m, n, p, s, sh, t, v, z/, each being presented five times, for a total of 70 items. The vision and sound-plus-vision lists take about 30 minutes each to administer on videotapes (we are preparing laser videodiscs which should reduce the time for many patients), and the sound-only audiotape takes about 10-15 minutes per test.

Patient M3 was a 52-year old female, who had been profoundly deaf for about 1 year when she received her implant. She was tested on three separate occasions after being connected to her implant. After 1 day of experience wearing the multichannel device, she scored 29% correct on vision alone, 39% correct on sound-plus-vision with 1 channel, and 39% correct on sound-plus-vision with 21 channels. She was then tested after 9 days of wearing the 21-channel device, and scored 23% correct on sound-alone with 1 channel, and 22% on sound-alone with 21 channels. At this time the patient commented that she much preferred the 21-channel configuration because the 1-channel mode sounded "dull." After 19 days of experience with the multichannel device, she scored 43% correct on the sound-plus-vision with 1 channel and 56% correct on the sound-plus-vision with 21 channels.

Figure 7 shows confusion matrices for the vision-only (day 1) and sound-plus-vision conditions (day 19). It can be seen that performance on the 21-channel device was characterized by notably improved recognition of /b/ and /s/. Visually, /b/ was identified as /m/, and this was not altered by the additional auditory information provided by 1-channel stimulation. Visually, /s/ was identified as /s, sh/ or /t/. With the addition of 1-channel stimulation, the responses changed to /k/, but were correctly reported as /s/ with the 21-channel stimulation. We have also computed an information transfer analysis (Miller & Nicely, 1955) on these confusion matrices, shown in the upper-right panel of *Figure 7*. It is interesting that slightly more voicing and nasality information is being processed through the 1-channel code, perhaps because there are fewer, potentially confusable cues than in the multichannel system. Most of the place information is being provided by vision alone. It is noteworthy that the two coding schemes provide about the same amount of information at the initial

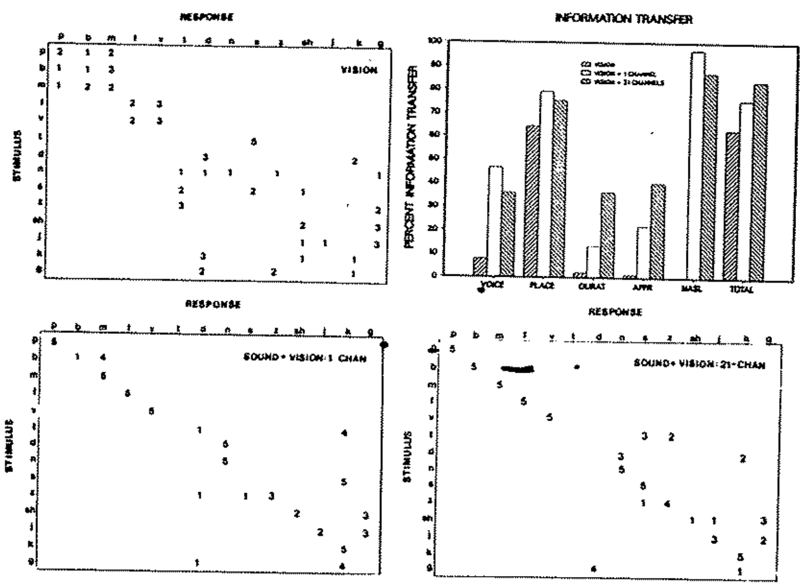

Figure 7. Results obtained on the 14-choice consonant confusion test comparing single versus multichannel stimulation modes in the same patient. The Melbourne multichannel implant was set to either 21-channel or 1-channel (the one with the largest dynamic range) stimulation. The upper-left panel shows the results from vision alone, and the lower-left and lower-right panels for 1-channel and 21-channel sound-plus-vision stimulation (obtained after 19 days of wearing the multichannel device). The upper-right panel shows the transformation analysis (Miller & Nicely, 1955) performed on these same data.

connection, but with experience (with the multichannel scheme) the scores obtained with the 21-channel device are higher.

Vibrotactile Aids and Cochlear Implants

Since cochlear implants do not restore normal hearing, it is reasonable to ask whether using vibrotactile aids is a viable alternative to implantation for persons with profound hearing loss. Our involvement in this area is just beginning. We have begun laboratory trials comparing normal listeners' performances using single-channel vibrotactile aids to that of cochlear implant patients wearing their cochlear implants. The results are seen in *Figure 8*. In all three panels, the worst and best results are shown for 8 normals using a single-channel vibrotactile aid, 2 patients using the Vienna implant, 1 using the Los Angeles single-channel implant, and 2 patients using the multichannel Melbourne cochlear implant. In the top panel, for tests that likely depend largely on voicing frequency or time-intensity information, the normals using the vibrotactile aid performed in the same range as did the patients using the implants. In the second panel, for tests that depend on a variety of speech cues, it appears

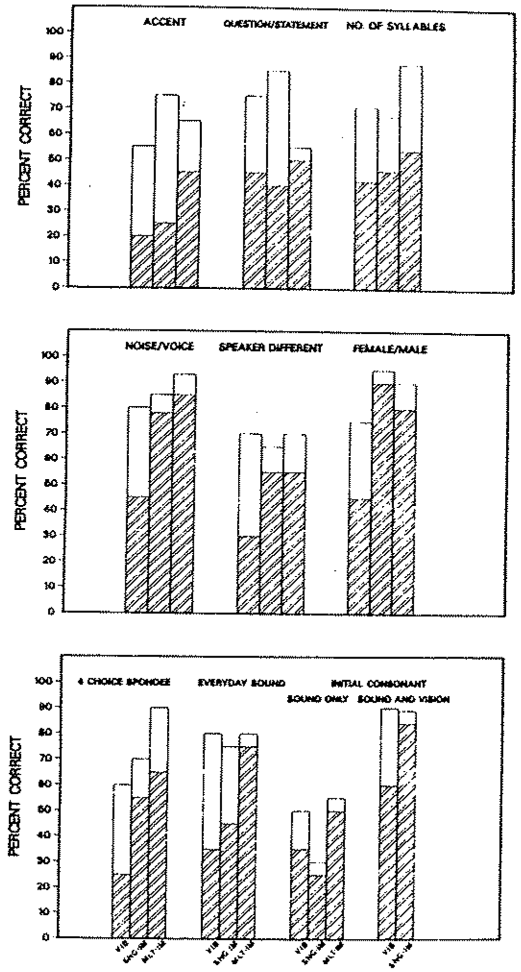

Figure 8. The lowest (hatched bars) and highest (open bars) scores obtained from eight normals using a single-channel vibrotactile (VIB) aid (Siemens Fonator), from two patients wearing the Vienna single-channel cochlear implant (SNG-IM) and from two patients wearing the Melbourne multichannel cochlear implant (MLT-IM). Top: Results from the MAC *Accent* and MAC *Question/Statement* tests and the Iowa *Number of Syllables* test. Middle: Results from the MAC *Noise/Voice* test, the Iowa *Speaker Discrimination: Different Sentences*, and the Iowa *Female/Male Speaker* tests. Bottom: Results from the MAC Four-alternative *Spondee* test, the Iowa five-alternative closed-set *Everyday Sound Recognition* test, and the four-alternative Iowa videotape recordings of the MAC *Initial Consonant* test. Neither of the Melbourne patients received the sound-plus-vision version of the latter test.

that the implant patients performed better at recognizing a female or a male speaker (Iowa *Female/Male Speaker* test). The bottom panel includes tasks of everyday sound recognition (five-alternative, closed-set) and speech. It is remarkable that the vibrotactile aids provided sufficient information to facilitate above-chance performance on spondees, everyday sounds, and initial consonants when in a closed set.

Another comparison that we are making is between cochlear implant patients using their implant and using a vibrotactile aid. Because the patients only received 1 hour of practice with the vibrotactile aid and had used their implant for at least 3 months, the comparison is biased. *Figure 9* shows some results for three different tests. The results from the *Accent* test show that the two patients with the multichannel implant performed as well with the vibrotactile aid as they did with their implants. In recognizing a female or male voice, however, all patients performed better with their implant. In selecting the one spondee from four alternatives, at least two patients (V3 and M1) did as well with the vibrotactile aids as they did with their implant. It appears that some of the information provided by cochlear implants could be provided by vibrotactile aids. However, no open-set speech understanding has yet been reported for vibrotactile stimulation only. It is likely that, given sufficient nerve-fiber survival, cochlear implants have the potential to provide more information about speech. While cochlear implants require surgery, vibrotactile aids may require more rehabilitation and may not have the same potential.

We have suggested previously (Gantz and Tyler, 1985) that cognitive and language top-down processing skills play an important role in the performance of patients using cochlear implants. Patients who were good at utilizing the limited cues available in lipreading also showed the highest scores on speech tests using the implant. Although we have insufficient numbers to make a strong case, *Figure 10* shows that there also seems to be a relationship between the ability to use the limited cues provided by the implant and those provided by the vibrotactile aid. The importance of this top-down processing ability emphasizes that we cannot make comparisons across implants without testing more patients.

Summary

Our preliminary findings suggest that cochlear implants have great potential for improving the communication skills of profoundly, postlingually hearing-impaired adults. Cochlear implants can provide useful information about speech and non-speech sounds, and can be used to supplement lipreading. On some tests we can observe improved performance as the patient gains experience using the device. On one patient that we have tested with the Melbourne device there seems to be little difference between 1-channel and 21-channel stimulation for the first few days of use. After several weeks of experience wearing the multichannel device, the results with the 21-channel stimulation were superior.

Vibrotactile aids can convey some of the information provided by cochlear implants. Thus, if we can determine from pre-operative evaluation that the patient will not be a good candidate for implant or hearing-aid use, then a vibrotactile aid may be desirable. These pre-operative tests might include promontory psychophysical tests, electrically recorded auditory potentials, and a test of top-down cognitive processing abilities. Further evaluation is required to examine the potential of more sophisticated multichannel vibrotactile aids.

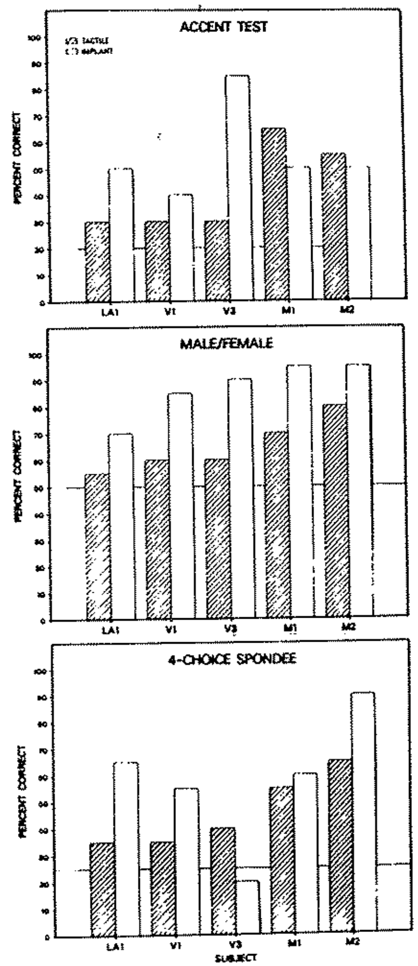

Figure 9. Results obtained from cochlear implant patients using either their cochlear implants (hatched bars) or using a single-channel vibrotactile aid for (Top:) the MAC *Accent* test, (Middle:) Iowa *Female/Male Speaker* test, and (Bottom:) MAC four-choice *Spondee* test. The solid horizontal line measures chance performance.

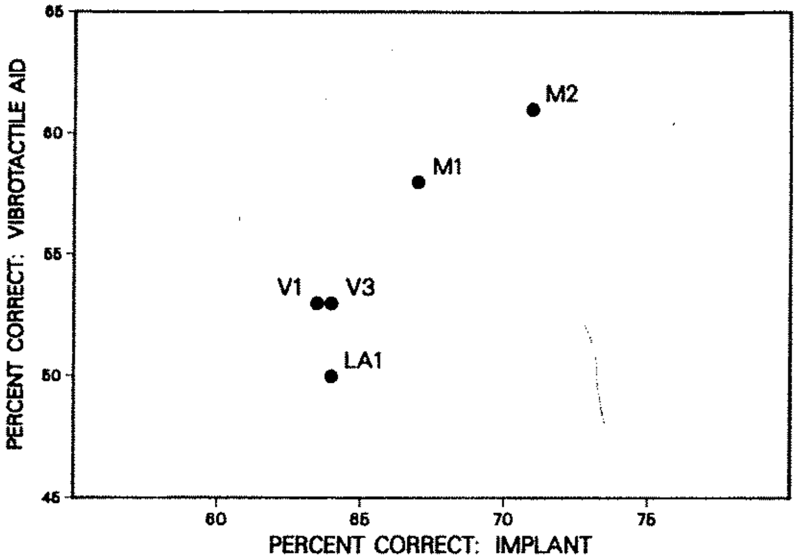

Figure 10. The average scores of five patients using cochlear implants and the same five patients using a single-channel vibrotactile aid on eight different tests. These tests included the MAC *Question/Statement* test, the MAC *Noise/Voice* test, the MAC *Accent* test, the Iowa closed-set *Everyday Sound Recognition* test, the Iowa *Number of Syllables* test, the MAC four-alternative *Spondee* test, the Iowa *Female/Male Speaker* test, and the Iowa *Speaker Discrimination: Different Sentence* test.

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