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Consonant Recognition as a Function of the Number of Channels of Stimulation by Patients Who Use the Symbion Cochlear Implant*

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ABSTRACT

The intelligibility of a 16-item consonant set was assessed for 10 patients who use the Symbion four-channel cochlear implant. The patients were selected on the basis of "good" speech recognition scores. For each patient, consonant intelligibility was assessed when his/her processor was configured to pass from one to four channels of information. The results suggest, most generally, that two channels, one low frequency and one high frequency, provide most of the information about consonant identity.

One of the central issues in the design of cochlear implants is the number of channels of stimulation that are necessary to achieve open set speech understanding without lipreading. The data which bear on the issue are the speech identification scores of patients fitted with single and multiple channel implants.

Patients who use the 3M/House single-channel implant obtain little or no open set speech understanding (Edgerton et al, 1983) but may, if fitted with the "optimized" 3M/House processor, achieve relatively good scores on tests of consonant identification (Edgerton, 1985). Tyler et al (1989) report that "good" patients who use the 3M/Vienna single-channel implant can perform as well on tests of isolated word recognition as good patients who use multichannel implants (Hochmair & Hochmair-Desoyer, 1983; Hochmair-Desoyer et al, 1985). Tyler and colleagues also report for good 3M/Vienna patients that (1) word recognition scores on a sentence level task average approximately half that of good multichannel patients, (2) vowel recognition scores average about half that of multichannel patients (Tyler et al, 1989a), and (3) consonant recognition scores are slightly lower than those of patients with multichannel implants (Tyler et al, 1989b). The consonant, vowel, and word recognition results for single-channel implant patients do not fall into an easily understood pattern and more studies are in order if we are to understand the constraint on speech understanding imposed by a single channel of stimulation.

The data on speech understanding by patients who use the four-channel Symbion implant and the 22-channel Nucleus implant are less problematic. In an experiment in which both Symbion and Nucleus patients were tested with the same, taped test materials, Tyler and colleagues report, for 9 good users of the four-channel implant, mean scores of 36% correct for words in sentences, 13% correct for words in isolation, 85% correct for vowels, and 46% correct for consonants. Ten good users of the 22-channel implant achieved scores of 30% correct for words in sentences, 11% correct for words in isolation, 94% correct for vowels, and 41% correct for consonants. These data suggest that a small number of channels can allow a level of speech recognition equivalent to that of a large number of channels.

Any comparison between the number of channels used and the speech recognition scores of patients who use the Symbion four-channel device and the Nucleus 22-channel device is confounded by the different speech processing strategies and different electrode designs for the two devices. If we are to compare the effects of the number of channels on speech recognition, the best design is within subjects (see Tyler et al, 1986, for a review and critique of studies which have used a within-subject design to assess the effect of the number of channels of stimulation on speech recognition).

In the research reported here, we examined the issue of the number of channels of stimulation needed for conso-

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nant recognition by patients who use the Symbion implant. The patients were presented tests of consonant recognition when their signal processors were configured to pass from one to four channels of stimulation. Our aim was to determine the contribution of the channels to consonant recognition and, in so doing, to provide an answer to the question of whether, for consonant recognition, the Symbion device functions as a four-channel system or as a device with fewer than four functional channels.

METHOD

Subjects

Ten adults served as subjects. The patients were chosen on the basis of good speech recognition scores and availability for testing. The age of the patients ranged from 20 to 58 years. The length of deafness ranged from 1 to 28 years. The presumed etiologies of profound deafness included "unknown" (n = 7), trauma (n = 1), Menieres Disease (n = 1), and drug ototoxicity (n = 1).

The patients' word recognition scores in sentence context (the CID Everyday Sentences administered "live voice") ranged from 84% correct to 100% correct; spondee recognition scores ranged from 66% correct to 100% correct; and the isolated word recognition (NU 6) scores ranged from 26% correct to 52% correct. The spondee and word recognition tests were administered via tape recordings.

Stimuli

The stimuli were 16 aCa disyllables produced by the first author. The consonant set included /b d g p t k s θ tʃ m n z y r l/. The stimuli were filtered at 9.7 kHz, digitized at a 20 kHz sampling rate, and stored in computer memory. The vocalic portions of the 16 disyllables were edited to have similar amplitude and duration characteristics. The consonantal portions differed in amplitude, duration, and spectral content.

Eight tokens of each stimulus were created. The stimuli were randomized with a 3 sec interstimulus interval and, after filtering at 9.7 kHz, were recorded on audio tape. Six different randomizations of the test sequence were generated.

Implant design

The Symbion implant consists of (1) 6 monopolar electrodes implanted in the scala tympani with remote reference; (2) a percutaneous pedestal to which the electrode wires are attached; and (3) a portable speech processing and electrode stimulation system (Eddington, 1980, 1983). The most apical electrode is located about 22 mm from the round window. The electrodes are spaced at 4 mm intervals. Given the depth of insertion of the electrodes and their spacing, we suppose that the most apical electrode No. 1 is near the 1 kHz place in the cochlea, that electrode No. 2 is near the 2 kHz place, that electrode No. 3 is near the 4 kHz place, and that electrode No. 4 is near the 8 kHz place. In most patients, the four most apical electrodes are activated. Each electrode is driven by a signal derived from the input signal after bandpass filtering. The center frequencies of the filters for channels 1 to 4 (most apical to most basal electrodes) are 0.5, 1, 2, and 3.4 kHz. The filters roll off at 6 dB/octave.

Processor Configurations

For each patient, consonant intelligibility was assessed for at least four configurations of the processor: channel 1; channels 1,2; channels 1,2,3; and channels 1,2,3,4. In each configuration, the signals were filtered in the manner described above. For example, in the channel 1 condition the patients were presented with a bandpassed signal (center frequency of 500 Hz) on the most apical electrode.

Procedure

The listening tests were conducted in a sound attenuating booth. The patients sat approximately 1.5 m from a loudspeaker with the microphone of the sound processor oriented toward the loudspeaker. The signals were routed from the tape deck through an amplifier to the loudspeaker. Signal presentation level was 75 dB SPL (C-weighted).

To familiarize the patients with the speaker's voice, each listened first to three repetitions of the 16 stimuli. The identity of the signals was indicated on the printed answer sheet. For this phase of the experiment, the listeners' processors were configured in the normal four-channel configuration. Following the familiarization procedure, the patients' processors were changed to one of the four configurations described above. One of the test sequences was then presented. A practice list was not presented before the test sequence. The procedure of changing the processor and testing the patient with a new randomization of the test sequence was repeated as many times as there were processor configurations to be tested.

RESULTS

The results for each patient are shown in Table 1. Inspection of Table 1 reveals that the addition of higher frequency channels to channel 1 did not produce the same effect on consonant intelligibility for all patients. Accordingly, we have grouped the patients by response pattern and show the mean results, by subgroup, in Figures 1 and 2.

For the first six patients (Figure 1, *top*), the mean score for channel 1 was 23% correct; for channels 1,2 the mean score was 27% correct; for channels 1,2,3 the mean score was 49% correct; and for channels 1,2,3,4 the mean score

Table 1. Percent correct consonant identification as a function of channel stimulated.

	Channel			
Subject	1	1,2	1,2,3	1,2,3,4
Subgroup 1				
1	32	27	56	56
2	20	27	42	52
3	15	20	46	52
4	32	36	60	65
5	20	25	44	54
6	19	26	47	49
Subgroup 2				
7	36	36	36	65
8	25	24	24	50
....				
9	31	47	51	57
10	34	36	55	81

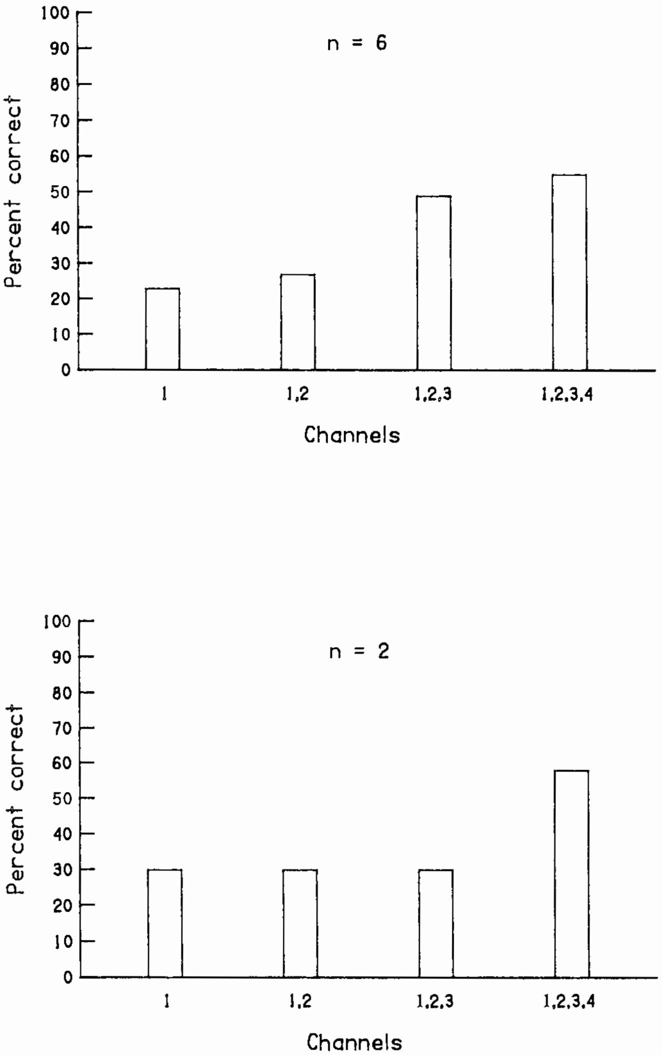

Figure 1. Averaged consonant recognition as a function of channel stimulated for patients No. 1 to 6 (*top*), and patients No. 7 and 8 (*bottom*).

was 55% correct. Although the number of subjects in this subgroup was too small to conduct a robust statistical analysis, we infer that the addition of channel 2 to channel 1 produced little or no benefit; that the addition of channel 3 to channels 1,2 produced a major benefit and that the addition of channel 4 to 1,2,3 produced relatively little benefit.

For patients No. 7 and No. 8 (Fig. 1, *bottom*), the mean scores for the first three channel configurations (1; 1,2; 1,2,3) were identical: 30% correct. The mean score for channels 1,2,3,4 was 58% correct. Clearly, the addition of channel 4 produced a major increment in performance.

For patient No. 9, the pattern of results was not similar to that of either the first or second subgroup of patients. The addition of channel 2 to channel 1 produced the largest change in recognition accuracy.

Patient No. 10 (described as SS in Dorman et al, 1988) presented yet another pattern of results (Fig. 2). As was

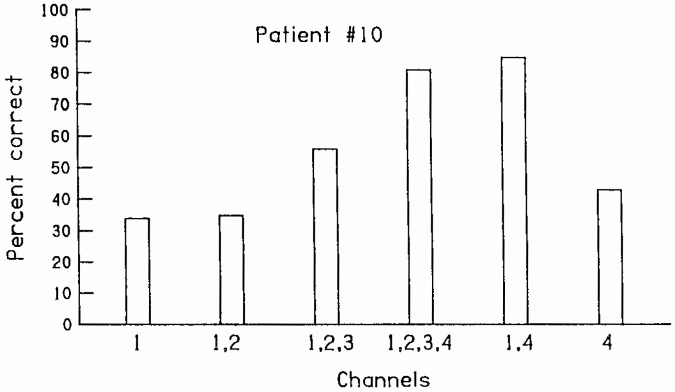

Figure 2. Consonant identification as a function of channel stimulated for patient No. 10.

the case for the first two subgroups, the addition of channel 2 to channel 1 produced no benefit (36% correct versus 34% correct) and the addition of channel 3 to channels 1,2 produced a major gain in intelligibility (55% correct versus 36% correct). However, the addition of channel 4 to channels 1,2,3 also produced a large gain in intelligibility (from 55% correct to 81% correct). Indeed, with the addition of channel 4, patient No. 10 became the best performing patient.

Because two channels of information (one low frequency (channel 1) and one high frequency (either channel 3 or 4)] appeared to carry most of the information for 8 of the 9 patients, patient No. 10 was tested in two additional conditions: channels 1,4 and channel 4 alone. Channels 1,4 allowed recognition scores equal to that of channels 1,2,3,4 (83% correct). Channel 4 alone allowed a score of 43% correct.

DISCUSSION

The aim of the research reported here was to determine the contribution of the four channels of stimulation provided by the Symbion processor to consonant recognition. Our conclusion is that, for most "good" patients, most consonant information is carried by one low frequency channel and one high frequency channel. We base our conclusion on the outcomes (1) that the addition of channel 2 to channel 1 produced little or no gain in intelligibility for 9 of the 10 patients and (2) that either channel 3 or channel 4, but usually not both, added greatly to the intelligibility allowed by channels 1 and 2.

We have also found that two channels of stimulation can support a high level of consonant recognition. Patient No. 10 recognized 83% of the test items when his processor was configured in the channel 1,4 mode. This finding—that two channels of information can support relatively good scores on tests of consonant recognition—is not unique. Wilson et al (1987) report results similar in kind for five patients who use the four-channel, UCSF/Stortz cochlear prosthesis. A mean score of 62% correct was obtained for a test set of eight consonants when the patients' processors were configured in a two channel mode. Although we can not directly compare these results with ours, due to differences in processor and electrode design, the two studies demonstrate that relatively good consonant recognition can be obtained with two channels of stimulation. This outcome suggests, as Wilson et al (1987) have noted, that patients who can distinguish between only a limited number of channels could receive a great deal of benefit from a cochlear implant.

Tyler et al (1986) have argued that most, if not all, studies which have used a within-subject design to assess the effects of the number of channels of stimulation on speech recognition confound channels of stimulation with the amount of practice a patient has had with different channel configurations. This is also the case in our study. However, we note, for 8 of the 10 patients, that performance in a nonpracticed condition, that is, channels 1, 2, 3 for 7 patients and channels 1,4 for 1 patient, allowed performance within, most generally, 10 percentage points of the highly practiced condition, that is, channels 1,2,3,4. If we had provided additional experience with the unfamiliar conditions of stimulation, we would have had, most likely, additional evidence for our conclusion that most consonant information is carried by fewer than four channels.

The number of channels activated alters the amount of current delivered to the patient and, thus, the loudness of the signal. To assess in an informal manner whether loudness, per se, was responsible for the differences in performance among test conditions, three patients were asked to rate loudness and intelligibility in the four test conditions. All indicated a small change in loudness but a large change in intelligibility as the number of channels was increased from one to four.

The results of our study and the results of Tyler and colleagues suggest (1) that a small number of channels can support relatively high levels of consonant recognition and (2) that a small number of channels can allow performance equal to that allowed by a large number of channels.

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