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Speech Intelligibility as a Function of the Number of Channels of Stimulation for Normal-Hearing Listeners and Patients with Cochlear Implants

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Objective: One goal was to determine for normal-hearing listeners the number of channels of stimulation necessary to achieve a high level of speech understanding. The second goal was to determine whether patients with a six-channel cochlear implant could achieve the same level of speech understanding as normal-hearing subjects listening to speech processed through six channels.
Method: Speech signals were processed, for normal-hearing listeners, either in the manner of cochlear-implant processors with 2–9 fixed channels, or in the manner of a processor which picked, on each update cycle, 6 of 16 channels.
Results: For the most difficult test material eight fixed channels were necessary to achieve the level of performance achieved with the "n of m" processor. Some cochlear implant patients with a six-channel continuous interleaved sampling processor achieved the same level of performance as normal-hearing subjects listening to speech via six channels.
Conclusions: A signal processor for cochlear implants with eight channels should produce the same level of intelligibility as a processor with many more channels. Processors using continuous interleaved sampling technology can provide a signal which results in the same level of speech understanding as normal, acoustic stimulation. **Key Words:** Cochlear implants—Channels of stimulation.
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Shannon et al. (1) have shown that normal-hearing listeners can identify vowels, consonants, and sentences with high accuracy when the signals are processed into only three or four bands of stimulation. The aims of the current experiment were 1) to test the findings of Shannon et al. (1) with a different signal processor, one that outputs sine waves at the center frequencies of the filters instead of bands of noise; 2) to assess the number of fixed channels of stimulation that would give the same identification accuracy as a signal processor, which operated in the manner of the Cochlear Corporation's Spectra, cochlear-implant processor; and 3) to compare the results of normal-hearing patients listening to six bands of stimulation and the results of patients who received implants using a six-channel continuous interleaved sampling (CIS) processor.

METHODS

For the fixed-channel processors, the speech band was divided into two to nine equal logarithmic bands. Processing was conducted in the manner of the continuous interleaved sampling (CIS) processor of Wilson et al. (2). Sine waves were output at the center of each band. Processing for the "n of m" processor was similar to that of a 16-channel Spectra processor (i.e., on each up-

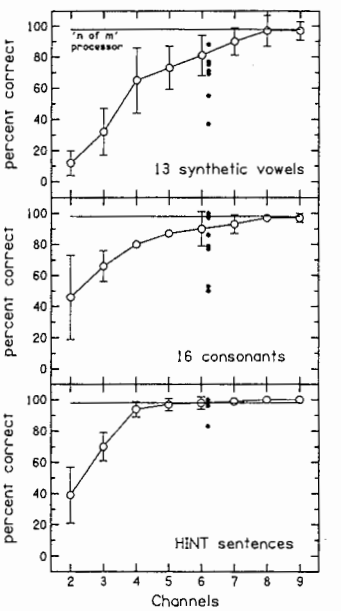

FIG. 1. Speech intelligibility as a function of the number of channels of stimulation.

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date cycle, the 6 (n) of 16 (m) channels with the highest root mean square (RMS) levels were output as sine waves).

RESULTS AND DISCUSSION

Performance with the "n of m" processor is shown by the solid line in the three panels of Figure 1. Identification scores are near 100% correct for each test. Performance with the fixed-channel processors is shown by the open circles. Eight channels allow the same level of performance as the "n of m" processor. This finding may be of interest to designers of cochlear implants. The performance of seven patients fit with six-channel CIS processors is shown by the filled circles. For the vowel and consonant tests, five of the seven patients achieved scores at the margin or within the range achieved by normal-hearing patients using processors with the same number of channels. For the sentence material, three of four patients scored within the range of normal subjects. The finding that some patients with implants achieved scores within the range of normal subjects listening to the same number of channels indicates that for these patients, the principal limitation on performance is the number of channels of stimulation and not other phenomena associated with electrical stimulation, such as reduced dynamic range, upward transposition of frequencies due to the location of the stimulating electrodes, or current spread.

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