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The Identification of Speech in Noise by Cochlear Implant Patients and Normal-Hearing Listeners Using 6-Channel Signal Processors

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Abstract TOP

Objective: To compare the recognition of vowels and sentences in noise by cochlear implant patients using a 6-channel, continuous interleaved sampling (CIS) processor and by normal-hearing subjects listening to speech processed in the manner of the implant processor and output as six amplitude-modulated sine waves.

Design: Subjects, 11 normal-hearing listeners and 7 cochlear implant patients, were presented natural vowels produced by men, women, and girls in /hVd/ context and sentences from the Hearing In Noise Test (HINT) lists at +15, +10, and +5 dB signal to noise ratio (SNR) for identification. Stimuli for the normal-hearing subjects were preprocessed through a simulation of a 6-channel implant processor and were output as the sum of sinusoids at the center frequencies of the analysis filters.

Results: For the multitalker vowels, four of the seven patients achieved scores within +/-1 standard deviation of the mean for normal-hearing listeners at +15 and +10 dB SNR. At the +5 dB SNR three patients achieved scores within +/-1 standard deviation of the mean for the normal-hearing listeners. For the HINT sentences, four of seven patients achieved scores within +/-1 standard deviation of the mean for the normal-hearing listeners at +15 dB and at +10 dB SNR and two achieved scores within that range at +5 dB SNR.

Conclusion: Our results extend the range of stimulus conditions, from quiet to modest amounts of noise, in which the CIS strategy allows the best performing patients to extract most, if not all, of the information available to normal-hearing subjects listening to speech processed into six channels.

Article Outline

Dorman and Loizou (1998) have reported that some cochlear implant patients fitted with a 6-channel continuous interleaved sampling (CIS) processor (the CIS-link device by Med El Corporation) achieve scores on tests of speech identification that are within the range of scores achieved by normal-hearing individuals listening to speech processed through a 6-channel signal processor and presented as the sum of six fixed-frequency sine waves. **Dorman and Loizou (1998)** concluded that some fortunate patients receive most, if not all, of the information available from signals processed in the manner of a cochlear implant and output to six channels.

In **Dorman and Loizou (1998)** the subjects were tested with synthetic vowels, multitalker vowels, and consonants in medial position. All stimuli were presented in quiet. On the test least influenced by differences in experience with the test stimuli, i.e., multitalker vowels, four of seven patients achieved scores within the range of scores achieved by normal-hearing individuals.

Tests conducted in quiet, as those described above, may not be a good indicator of the performance of cochlear implant patients in real, noisy communicative situations. For that reason, in the present experiment, both normal-hearing individuals and cochlear implant patients were tested with sentence material processed into six channels and presented at +15, +10, and +5 dB signal to noise ratio (SNR). At issue was whether cochlear implant patients would achieve scores within the range of scores achieved by normal-hearing individuals when the speech material was presented against a background of noise.

Method TOP

Subjects TOP

Eleven normal-hearing students at Arizona State University, who ranged in age from 22 to 34 yr, and seven cochlear implant patients, who ranged in age from 38 to 74 yr, participated in the experiment. The implant patients had used an Ineraid cochlear implant for at least 5 yr before being fitted with the Med El Corporation's CIS-link signal processor. The patients had used the CIS-link processor for a minimum duration of 1 yr and a maximum duration of 4 yr. The patients were chosen for participation on the basis of availability for testing. Six of the seven patients had previously participated in **Dorman and (1998)** and are described in that report. One subject (S6) from that experiment was unavailable for testing. The new patient was 43 yr old, had used his Ineraid for 13 yr, and had used the CIS-link processor for 1 yr. The patient's hearing loss was detected at age 22 and a hearing aid had provided no benefit for 4 yr before he was fitted with the Ineraid. With the CIS-link processor the patient's HINT score in quiet was 100% correct and his Northwestern University Auditory Test No. 6 (NU-6) score was 70% correct (averaged over three NU6 lists).

Speech Materials TOP

The stimuli were 11 naturally produced vowels in /hVd/ context and the HINT sentences.* Three test conditions were constructed for both sets of stimuli: +15 dB SNR; +10 dB SNR; and +5 dB SNR.

The stimuli for the natural-vowel test were the words "heed, hid, hayed, head, had, hod, hud, hood, hoed, who'd, heard," each produced by three men, three women, and three girls. The multitalker stimuli were drawn from a set created by **Hillenbrand, Getty, Clark, and Wheeler (1995)**. The noise was spectrally shaped based on the averaged spectrum of all the vowel stimuli used in the experiment. Each stimulus appeared once in the randomized test sequence. The stimuli from all three conditions were randomized into a single test sequence.

The sentence material was taken from the HINT lists **(Nilsson, Soli, & Sullivan, 1994)**. Twenty sentences were used in each of the three test conditions. The noise was spectrally shaped based on the long-term average spectrum of speech. The stimuli from all four conditions were randomized into a single test sequence.

All test materials were stored on computer disk and were output via custom software routines using MATLAB (The MathWorks, Inc., Natick, MA) software and a 16 bit D/A converter.

Signal Processing for Cochlear Implant Patients TOP

The CIS-link signal processor was an implementation of the **Wilson, Finley, Lawson, Wolford, Eddington, and Rabinowitz (1991)** CIS processor fabricated by Med El Corporation **(Zierhofer, Peter, Bril, Pohl, Hochmair-Desoyer, & Hochmair, 1994)**. The processor was a 6-channel design with 6th order band-pass filters, 400 Hz first order smoother, and full wave rectification. Channel center frequencies were 393 Hz, 639 Hz, 1037 Hz, 1680 Hz, 2730 Hz, and 4440 Hz. The channels were of equal width on a logarithmic scale. Signals were pre-emphasized above 1200 Hz. Pulse duration and pulse rate were optimized for each patient.

Signal Processing for Normal-Hearing Listeners TOP

A software version of the Med El signal processor was implemented using the MATLAB signal-processing toolbox. After the operations of band-pass filtering, rectification, and smoothing, the root mean square energy of the envelope in each channel was computed every 4 msec, and sinusoids were generated with amplitudes equal to the root mean square levels and frequencies equal to the center frequencies of the band-pass filters (see **Dorman, Loizou, & Rainey, 1997**). The sinusoids were summed and presented to the listeners at a comfortable level through Sennheiser HMD 410 headphones.

Procedure TOP

Before the test with the multitalker vowels, the listeners were presented one token of each vowel produced by a man, a woman, and a girl (11 stimuli × 3 talkers = 33 stimuli) at +15 dB SNR, +10 dB SNR, and +5 dB SNR. The identity of the stimuli was indicated on a computer screen. Before the test with the HINT sentences the listeners were presented 10 sentences processed in the manner of each of the three test conditions. The words in each sentence were displayed on a computer screen during the presentation of the sentence.

Responses for the vowel tests were collected with custom software using a computer display of response alternatives and a mouse as a response key. The subjects were allowed to use a "repeat" key as many times as they wished. Feedback of correct answers was not provided during the test. Responses to the HINT sentences were collected by having the subject write on a response sheet. The repeat key was disabled for the sentence test. All tests were self paced.

Results and Discussion TOP

The results are shown in **Figure 1a and 1b**. The means and standard deviations of performance for the normal-hearing listeners are shown by open circles connected by solid lines. The error bars indicate ±1 standard deviation (for the scores in the present study, ±1 standard deviation was within a few percentage points of the interquartile range, or the middle 50% of the distribution of scores). The scores of the cochlear implant patients are shown by symbols not connected by lines. For the multitalker vowels, four of the seven patients achieved scores within ±1 standard deviation of the mean for the normal-hearing listeners at +15 and +10 dB SNR. at the +5 dB SNR three patients achieved scores within +1 standard deviation of the mean for the normal-hearing listeners. For the HINT sentences, four of seven patients achieved scores within ±1 standard deviation of the mean for the normal-hearing listeners at +15 dB and at +10 dB SNR and two achieved scores within that range at +5 dB SNR. These results demonstrate that in the presence of modest amounts of noise some patients fitted with 6-channel CIS processors and a monopolar electrode array are able to achieve scores within the range of performance of normal-hearing individuals listening to speech processed into six channels and presented as the sum of six sine waves.

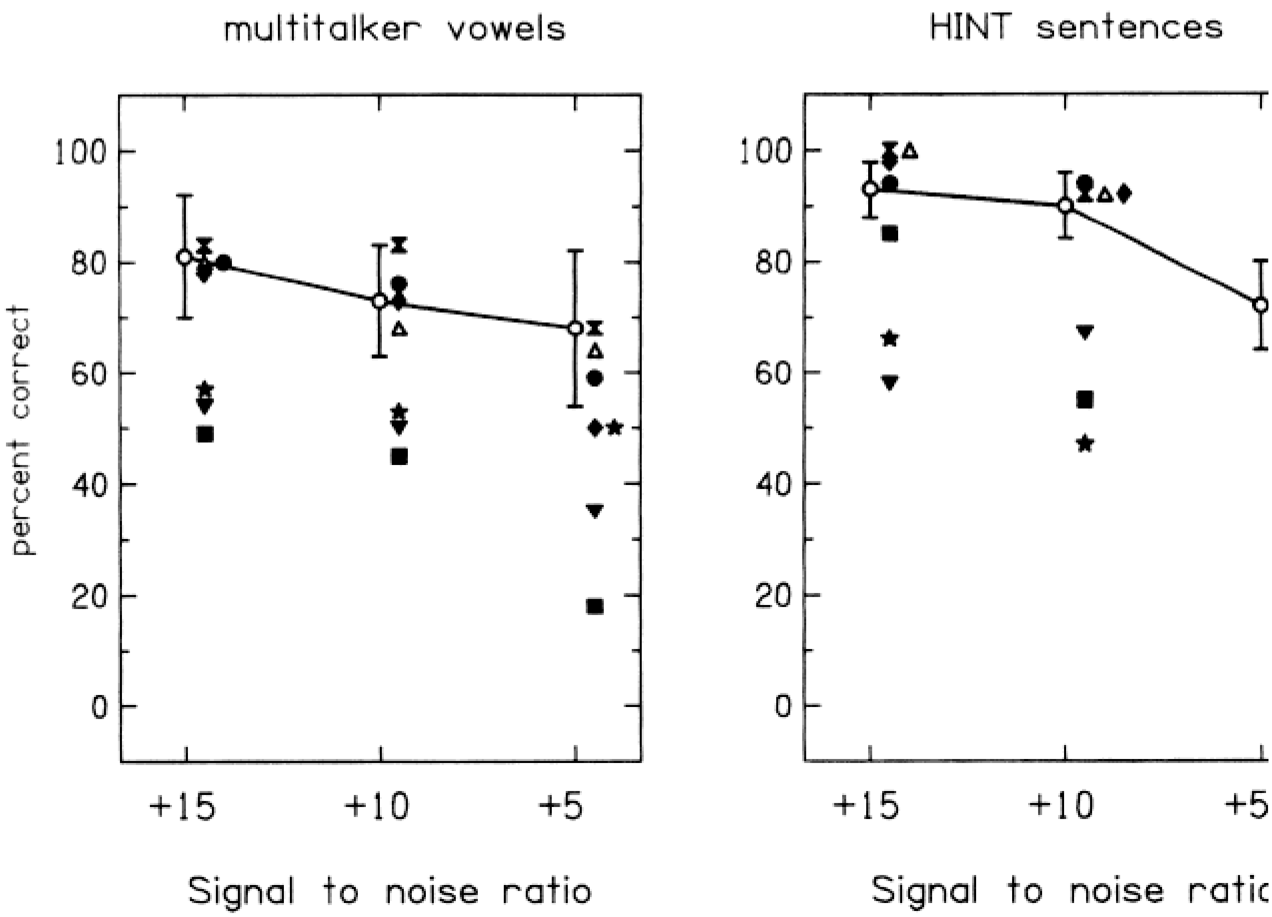

Figure 1. Test scores as a function of signal to noise ratio. The scores for normal-hearing listeners are shown by open circles connected by solid lines. The scores for cochlear implant patients are shown by symbols not connected by lines. The error bars indicate ±1 standard deviation. HINT = Hearing In Noise Test.

For both multitalker vowels and sentences fewer patients' scores fell within ±1 standard deviation of the scores for normal-hearing listeners in the +5 dB condition than in the +10 dB condition. This outcome could be interpreted to mean that there is a residual deficit in spectral resolution for implant patients that is not found normal-hearing listeners and that comes to light only at poor SNRs where spectral information is masked by noise. On the other hand, the scores in the multitalker vowel condition, for three of the best performing patients, drop about 10 percentage points from +15 to +5 dB and that drop in score is about the mean drop in percent correct for the normal-hearing subjects. Moreover, others have found results similar to those reported here. **Eddington, Rabinowitz, Tierney, Noel, and Whearty (Reference Note 1)** report that three implant patients, one using a 6-channel processor and two using 8-channel processors, achieved scores on a 24 consonant test in noise and on a sentence test in noise (at SNRs of +16 to 0 dB) that were similar to the scores of a normal-hearing subject listening to speech processed into six and eight channels. **Fu, Shannon, and Wang (in press)** report one 4-channel CIS patient whose scores on tests of consonants and vowels in noise were similar to the scores of normal-hearing subjects listening to speech processed into four channels. Thus, in noise, as in quiet, some implant patients using 4-, 6-, and 8-channel CIS processors extract most, if not all, of the information available from signals processed into four, six, and eight channels.

Although some patients achieve scores within the range of scores achieved by normal-hearing listeners, others do not. There is a long list of reasons why patients would not be able to extract the same amount of information from the speech signal as a normal-hearing subject listening to speech band passed into *n* channels. Among the most probable are nonuniform survival of spiral ganglion cells and current interactions among electrodes. Other possibilities include an abnormal representation of frequency caused by relatively shallow electrode insertions (if we assume that implant patients cannot adjust completely to the shallow insertion), poor resolution of the temporal waveform, and poor resolution of intensity differences in the speech signal. Any of the foregoing would limit the amount of information available to an implant patient.

The comparison of performance between normal-hearing listeners and implant patients in this study and others of similar design (e.g., **Eddington et al., Reference Note 1; Fu, Reference Note 2**) is of interest only if the performance of the normal-hearing listeners sets a reasonable benchmark for performance. If the standard of performance set by the normal-hearing listeners is unreasonably low because of, for hearing listeners, it is of little interest that implant patients fall within the range of performance for the normal-hearing listeners. At issue, then, is whether the performance of normal-hearing listeners is a reasonable benchmark.

On our view, the benchmark is a reasonable but conservative one. Signals are processed in the same way for normal-hearing listeners and implant patients and similar results are obtained for normal-hearing listeners when the signals are output as sine waves or noise bands **(Dorman et al., 1997; Fu, Reference Note 2)**. However, the normal-hearing listeners in our experiments have not had the same amount of experience listening to signals processed into *n* channels as the implant patients. For normal-hearing subjects listening to speech processed into *n* channels experience is measured in hours; for implant patients, experience is measured in years. However, the single normal-hearing listener in **Eddington et al. (Reference Note 1)** had many hours of listening experience (more than 4000 trials with feedback of results) with speech processed into *n* channels and his performance had reached asymptote. Thus, in this instance, the similarity in levels of performance for the implant patients and the normal-hearing listener was not due to lack of experience on the part of the normal-hearing listener.

Conclusion TOP

The results reported here extend the range of listening conditions from quiet to modest amounts of noise in which some patients fitted with 6-channel CIS processors and monopolar electrodes are able to understand speech with the same level of accuracy as normal-hearing subjects listening to speech processed into six channels. We infer from these results that monopolar electrodes and the CIS stimulation strategy are sufficient in a variety of stimulus situations to encode most, If not all, of the information available in speech signals band passed into six channels.

Acknowledgments: TOP

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2 Fu, Q-J. (1997). Speech perception in acoustic and electric hearing, Ph.D. Dissertation. University of Southern California, Los Angeles, CA.
[Context Link]

* Consonants were not used in the tests of speech understanding because the implant patients had been tested in quiet with the 16 Iowa consonants many times and the normal-hearing listeners had not. Neither the implant patients nor the normal-hearing listeners had extensive experience with the multitalker vowels or the HINT sentences in quiet. [Context Link]