Speech Understanding by Cochlear-Implant Patients with Different Left- and Right-Ear Electrode Arrays

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Electrode-pitch rankings and monaural and binaural speech perception scores were obtained from two patients fit with a Med El CIS-Link processor and Ineraid electrode array in one ear and a Clarion processor and Hi-Focus electrode array in the other ear. The results of the electrode-ranking task indicated that current from the Hi-Focus electrodes extended more apically than current from the Ineraid array, i.e., the two most apical Hi-Focus electrodes were ranked lower in pitch than the most apical Ineraid electrode. Because of this and because of the different number of active electrodes in the two arrays, it is likely that the two cochleae presented different representations of the same signal to more central stages of information processing. In spite of this, both patients achieved better scores when both implants were activated than when the implants were activated one at a time.

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Binaural cochlear implants are likely to provide better speech understanding than a monaural implant in two conditions: (i) when the electrodes in the two ears are inserted to the same depth and, as a consequence, the outputs of the two auditory peripheries are frequency matched, or (ii) when the electrodes in the two ears are inserted to different depths and the information from the two electrode arrays is complementary (Lawson, Wolford, Brill, Schatzer, & Wilson, Reference Note 1; Long, Eddington, Colburn, & Rabinowitz, 2003). From this point of view it is of interest to investigate the performance of binaural patients in whom the electrode arrays differ in terms of place of stimulation and number of electrodes. At issue is whether central processing for speech perception can accommodate mismatched signals from the auditory periphery and provide an advantage for two ears versus a single ear. To find out, monaural and binaural speech perception tests were carried out on two patients fit with a four- or five-electrode Ineraid array in one cochlea and an eight-electrode Clarion Hi-Focus array in the other.

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Methods

Subjects and Devices

Patient U-1 acquired a severe hearing loss following meningitis at age 6. The loss progressed suddenly to profound hearing loss in his left ear at age 10 and in his right ear by age 15. He was fit with the four-channel Ineraid processor and six-electrode array in his left ear at age 21. He received a Med El CIS-Link processor for his left ear at age 25. The processor was programmed to output to the five most apical electrodes because stimulation on electrode 6 was described as unpleasant. Pulse duration was 40 μs/phase and pulse rate was 833 pulses/sec/channel. At age 31, Patient U-1 was fitted with the Clarion implant and eight-electrode Hi-Focus array in his right ear. The Clarion device was programmed in continuous interleaved sampling (CIS) mode to output to all 8 electrodes. Pulse duration was 75 μs/phase and pulse rate was 813 pulses/sec/channel. At the time of testing, Patient U-1 had used the two processors together for a period of approximately 3 wk.

Patient U-2 had a progressive hearing loss of unknown origin. Her hearing loss was detected at age 9 and progressed to profound at age 33. Patient U-2 was fitted with the Ineraid device and electrodes in her right ear at age 55. Only electrodes 1, 2, 3, and 5 were functional. She received a Med El CIS-Link processor for the right ear at age 70. The processor was programmed to output to the four functional electrodes. Pulse duration was 40 μs/phase and pulse rate was 3030 pulses/sec/channel. Patient U-2 was fit with the Clarion C1 device and Hi-Focus electrode array in her left ear at age 71. The Clarion device was programmed to output to all eight electrodes using a MPS strategy. Pulse duration was 70 μs/phase and pulse rate was 1414 pulses/sec/channel. At the time of testing, Patient U-2 had used the two processors for a period of approximately 1 mo.

Filter-to-Electrode Mapping

For the Clarion devices, the center frequencies of the bandpass filters for electrodes 1–8 were 418 Hz, 604Hz, 861 Hz, 1213 Hz, 1703Hz, 2280 Hz, 3143 Hz, and 44572 Hz, respectively. For Patient U-1, the center frequencies of the CIS-Link bandpass filters

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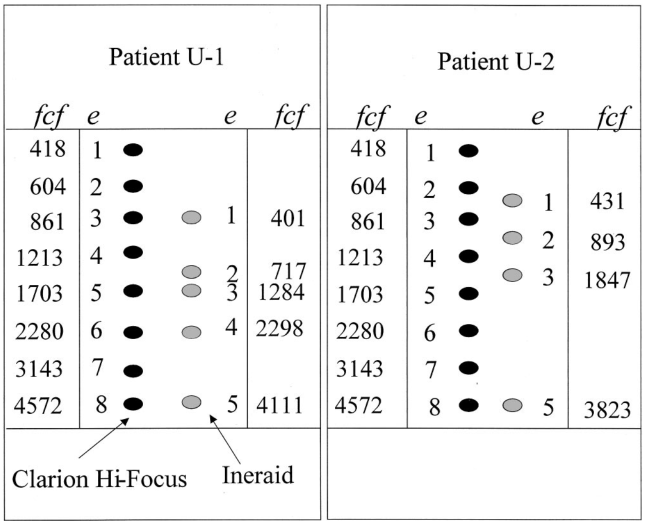

Figure 1. Relative pitch of stimulation at Clarion and Ineraid electrodes for two patients. Filter center frequency-to-electrode mappings are shown. Fcf: filter center frequency; e: electrode number.

were 401 Hz, 717 Hz, 1284 Hz, 2298 Hz, and 4111 Hz. For Patient U-2, the center frequencies of the CIS-Link bandpass filters were 431 Hz, 893 Hz, 1847 Hz, and 3823 Hz. The filter center frequency-to-electrode mappings for both patients are shown in Figure 1.

Stimulus Materials

Patient U-1 was tested with consonant-nucleus-consonant (CNC) words (50 word lists), synthetic vowels in /bVt/ environment (Dorman, Dankowski, Smith, & McCandless, 1989) and Hearing in Noise Test (HINT) sentences (Nilsson, Soli, & Sullivan, 1994) presented at a +5 dB signal-to-noise ratio (SNR). This SNR was chosen because it brought the patient's sentence scores off of the ceiling. Patient U-2 was tested with CNC words and with HINT sentences in quiet. The HINT sentences were scored in the standard manner, i.e., by key words. Patient U-2 was not tested with the synthetic vowels or in noise because she could not perform these tasks at an above-chance level. In all test conditions, the signals were presented via a loudspeaker in an audiometric test booth. The patients sat facing the loudspeaker during testing. The signal level was 70 dB SPL.

Pitch Ranking of Electrodes

The relative pitch of stimulation directed to electrodes in the left and right ears was established. Using the clinical fitting software, pulse trains were delivered to electrodes in the left and right ears and, after loudness balancing, the patients were asked to indicate the relative pitch of the signals. Each judgment was based on stimulation of three electrodes—two from the same ear and one from the other ear. For example, for the first stimulus set, the stimulation order was: Clarion electrode 1, Ineraid electrode 1, and Clarion electrode 2. The patients were instructed to rank the pitch of the Ineraid electrode relative to the two Clarion electrodes, i.e., lower than both, equal to the lowest, between the two Clarion electrodes, equal to the highest, or higher than both. Each stimulus set was presented twice. For Paient U-1, the rankings from both sets were identical. For Patient U-2, the first two sets of rankings differed in the ranking of Ineraid electrode 5. A third set of rankings was conducted and the rankings were identical to the second set. Those rankings are shown for Patient U-2 in Figure 1. All tests were conducted on the same day.

RESULTS

The results of the pitch-ranking experiment are shown in Figure 1. For both patients, stimulation at Hi-Focus electrodes 1 and 2 was ranked lower in pitch than stimulation at Ineraid electrode 1. For both patients, stimulation at Hi-Focus electrode 8 was ranked equal in pitch to stimulation at Ineraid electrode 5. In between these extremes, pitch ranking by the two patients varied at most by one electrode location (electrode 4 was not functional for Patient U-2).

The results from the tests of speech understanding are shown in Figure 2. Patient U-1 evidenced no advantage for binaural stimulation when the test material was CNC words. A small (86% versus 76%) and marginally significant advantage was seen for binaural stimulation versus the best single ear for synthetic vowels ($t = 2.00$; $p = 0.0509$). A large (94% versus 60%) and significant advantage was seen for binaural stimulation versus the best single ear for HINT sentences at +5 dB SNR ($p < 0.05$, binominal expansion). Patient U-2 achieved significantly better CNC scores when using binaural stimulation versus the best single ear (34% versus 14%; $p < 0.05$, binominal expansion) and achieved significantly better HINT scores in quiet when using binaural stimulation versus the best single ear (61% versus 29%, $p < 0.05$, binomial expansion).

DISCUSSION

The two most apical Hi-focus electrodes were ranked lower in pitch than the most apical electrode in the Ineraid array. Long et al. (2003) have reported a similar result. A reasonable interpretation of these

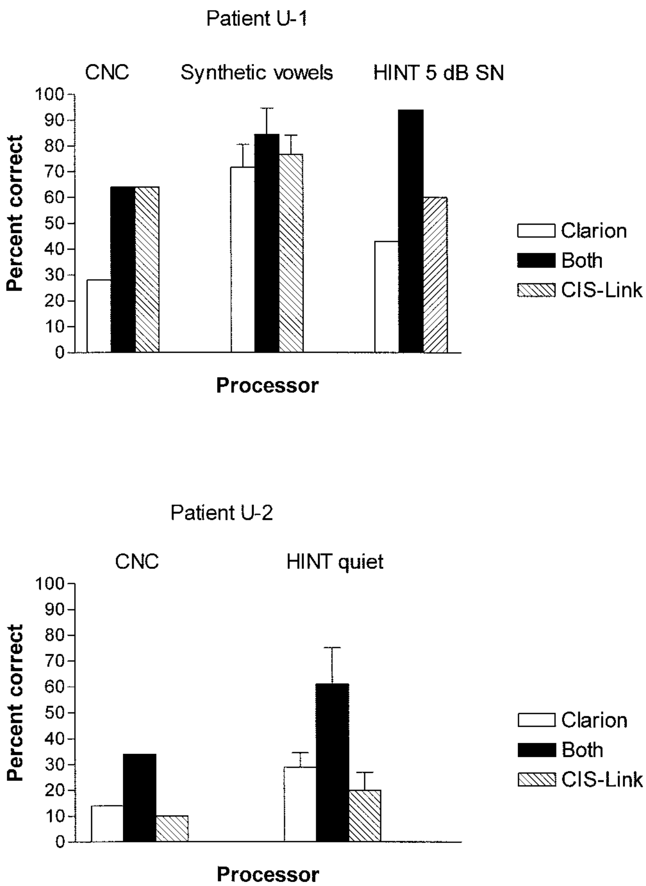

Figure 2. Speech understanding as a function of monaural or binaural stimulation for two patients.

data is that the electrodes in the Hi-Focus array were placed more apically into the scala tympani than the Ineraid electrodes, and that current from the deepest Hi-Focus electrodes extended more apically into the spiral ganglion than the current from the deepest Ineraid electrode. Because of this and because of the different number of active electrodes in the two cochleae, it is probable that the two cochleae presented different representations of the same signal to more central stages of information processing. This inference rests, at least partially, on the assumption that each electrode functioned as a channel. That assumption is unlikely to be true. The number of functional channels of stimulation is, most generally, smaller than the number of electrodes (Fishman, Shannon, & Slattery, 1997; Wilson, 1997). For that reason, it is possible that the number of functional channels of stimulation was similar for the two ears. It is also possible that, because of current spread, the neural populations stimulated in the two ears were similar even if the electrodes were in different locations in the scala tympani. However, it seems unlikely that both of the possibilities were realized in both of the patients. In the end, it is more parsimonious to assume that the representations of the signals were different than to assume that they were alike. This assumption is supported by the outcome of different levels of performance for the two devices. The degree to which the representations differed cannot be determined from the data collected for this project.

The patients enjoyed very different levels of speech understanding through their implants. Patient U-1 achieved relatively high (65% correct) CNC scores with his CIS-Link system. In contrast, Patient U-2 achieved very low (10%) CNC scores. Yet both patients enjoyed significant increases in sentence understanding when a second processor was activated. Better binaural performance was achieved even though one ear had experienced years of stimulation while the other ear had experienced less than 1 mo of stimulation. Thus, both "good" and "poor" performers can benefit from binaural input.

The factors that underlie the binaural advantage found in this experiment are not clear. Given the differences in electrode arrays and the differences in details of stimulation, it seems unlikely that the special mechanisms underlying binaural advantages in normal-hearing listeners were involved. Moreover, it is difficult to see in Figure 1 how the output from one cochlea added information complementary to information missing from the output of the other cochlea. More research needs to be conducted to understand how binaural stimulation combines to improve speech recognition for patients fit with a different implant in each ear.

Acknowledgments

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