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OPEN-SET WORD RECOGNITION WITH THE DUREN/COLOGNE EXTRACOCHLEAR IMPLANT*†

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ABSTRACT

The author visited Duren, West Germany and evaluated the performance of five patients implanted with the extracochlear Duren/Cologne implant who achieved better word recognition levels. Word and sentence speech reception tests were presented live-voice by a familiar German speaker. Performance ranged from 1% to 80% correct word recognition with sentence material, 0% to 63% correct word recognition with word lists, and 13% to 86% correct recognition for phonemes in words. One patient achieved high-level, open-set word recognition without visual cues, using single-channel, extracochlear stimulation. Preimplant auditory thresholds in her implanted ear were 60, 65, 90, and 105 dB HL at octave frequencies from 125 to 1,000 Hz, respectively. There was no measurable hearing at higher audiometric frequencies.

Patients throughout the world now benefit from a cochlear implant. Some implants allow patients to recognize words using no visual cues.[1-3] The purpose of the present investigation was to provide an independent speech recognition evaluation of five of the better patients implanted with the Duren/Cologne extracochlear implant at St. Marien Hospital.[4] In the present paper, live-voice tests with a familiar speaker were performed to demonstrate word recognition abilities under favorable conditions (such as in real-life situations, where the speaker is usually familiar to the implant patient). The Duren/Cologne implant is unique in that it has the ability to provide multichannel extracochlear stimulation.

Description of the Duren / Cologne Cochlear Implant

The electrode carrier is a plate on which 14 different electrodes are located. This plate is fixed to the labyrinth capsule on the medial wall of the middle-ear cavity adjacent to different turns of the cochlea.[4] Two other electrodes are included, one in the round window niche and one anterior to the ascending portion of the basal coil.

Incoming stimuli are filtered by 16 bandpass filters with center frequencies from 200 to 6,300 Hz (18 dB/octave filter skirts). Filter outputs are scanned progressively from high to low frequency to determine peaks in the spectrum. A biphasic pulse is then sent to the electrode whose center frequency corresponds to the filter with the peak in the spectrum. Low-frequency filters stimulate electrodes adjacent to higher turns in the cochlea, while high-frequency filters stimulate electrodes adjacent to lower turns in the cochlea. This strategy attempts to simulate "frequency by place" coding in the cochlea.

The speech processor then determines the next lower spectral peak in frequency, and sends a pulse to the corresponding electrode. The speech processor continues searching for lower-frequency peaks and stimulating lower-frequency electrodes. The identified energy peaks must exceed a certain threshold or they will not be coded, in order to avoid the coding of spurious spectral peaks.

Once the lowest peak has been determined, the speech processor begins the cycle again, searching for the highest-frequency peak.

The succession of pulses sent to different electrodes is sequential and nonsimultaneous. When the peak is in a high-frequency filter, a short delay (from the beginning of the scan) is used. When the peak is in a low-frequency filter, a long delay is used. This is an attempt to simulate the delay time of the traveling wave along the cochlear partition. The interpulse time interval is determined by the location of the filters identified as having the peak.

The bipolar pulse duration is fixed at 2 msec. The range of interpulse intervals is 4.3 to 16 msec. Pulse amplitude is fixed.

It should be noted that the minimum cycle time (to return to the same electrode) is limited to 6.3 msec (2 msec pulse duration plus 4.3 msec delay for a single spectral peak of energy), which corresponds to a maximum frequency of 233 Hz.

Four of the five patients tested were functioning with a single electrode pair, which was typically chosen as the pair with the largest electrical dynamic range. The speech processor in this configuration still uses the 16 filters, but results in a stimulation of only one electrode pair. Interpulse interval becomes the only apparent cue to the patient for extracting spectral information. These four patients reported that the sound of speech through the im-

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TABLE I.
Preimplant Audiograms of Patients in Implanted Ear (dB HL).

Patient	125	250	500	1,000	2,000	4,000	8,000 Hz
D1	+	+	95	100	+	+	+
D2	60	65	90	105	+	+	+
D3	80	90	115	+	+	+	+
D4	+	+	+	+	+	+	+
D5	75	75	90	100	+	+	+

+ = no measurable hearing to the limits of the audiometer (80, 90, 115, 115, 115, 110, 100 dB from 125 to 8,000 Hz, respectively).

plant was not very different when stimulated through the 1-electrode version than when all 16 electrodes were stimulated. This suggests that the multiple electrode template was not effective in stimulating different nerve fibers in these four patients. Note that these four patients were implanted with 16 electrodes, and the most favorable pair (largest dynamic range) was determined postimplant. If they had been implanted with a single-electrode pair, then the most favorable position might not have been available.

The fifth patient (D4) used eight electrode pairs with the same 16-filter processing.

METHOD

Patients

Five patients participated in this study. These patients were chosen by Professor Banfai as representing some of the better patients in his group. Professor Banfai had implanted approximately 170 postlingually deafened adults, 57 prelingually deafened adults, and 113 prelingually deafened children between 4 and 10 years of age. As mentioned, four patients used a single-electrode device, and patient D4 used an 8-electrode device. Turkish was the native language of patient D4, which she speaks in her home in Turkey. Patient D5 was deafened prelingually. Preimplant audiograms for the test ear are shown in Table I. Audiograms from the opposite ear all show profound hearing loss. More complete biographical data for the patients will be published in a subsequent study by the author.[5]

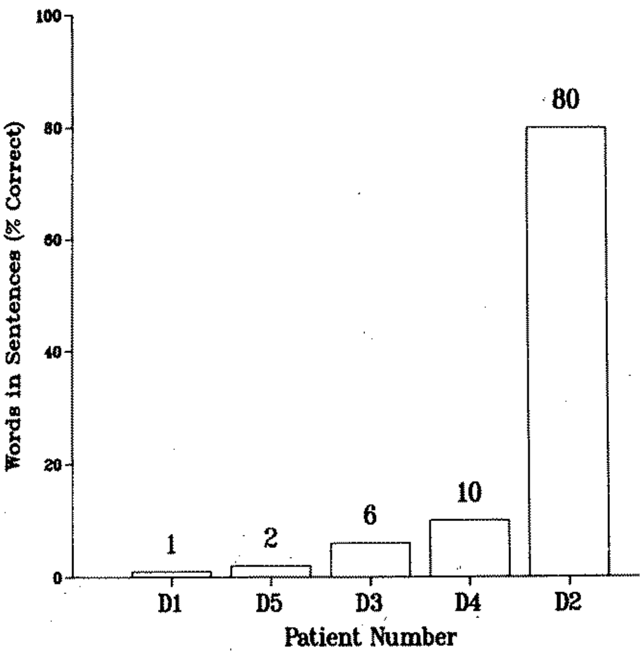

Fig. 1. Results for the sentence-level test, scored by words correct.

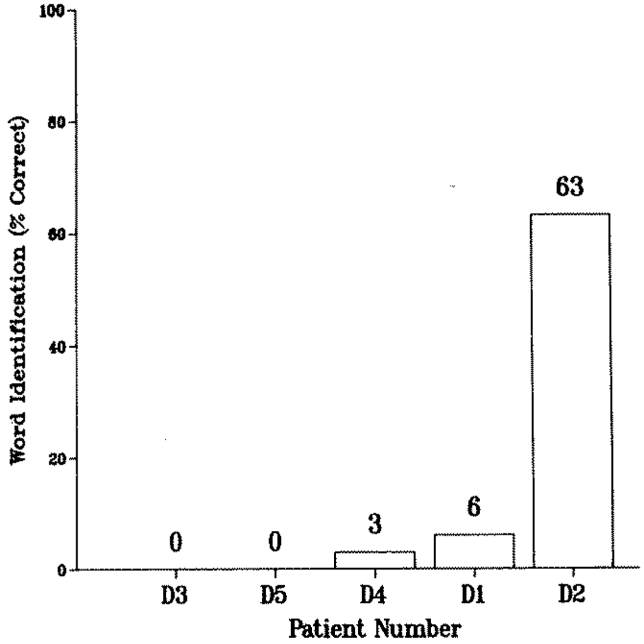

Fig. 2. Results for the word-level test, scored as percentage of words correct.

The duration of profound deafness ranged from 6 (D2) to 31 (D1) years. Experience with the implant was from 1.5 (D1) to 3.5 (D2, D4) years.

Tests

The tests were presented live-voice by a female speaker. The speaker had provided auditory training for the patients, and they were therefore quite familiar with her voice. Words and sentences were chosen by the author, and were unknown to the Duren/Cologne implant team and the patients. The words were simple, everyday words, one or two syllables in length. Test items were never repeated. The sentences were all statements, ranging from three to six words per sentence. The same stimuli were used previously by Tyler, *et al.*,[6] although different speakers were employed in that study. The speaker spoke at a fairly slow rate (as judged by the author), and at a level approximating 70 dB sound pressure level (SPL), measured at various locations close to the patients. The speaker was sitting behind the patients so that they could not see the speaker's face. Some found this situation irritating, and placed the microphone on their shoulder so that the microphone was facing the speaker. The patients wrote their responses on paper, and these were later scored by the Translation Laboratory at the University of Iowa.

RESULTS

The results from the sentence test are shown in Figure 1. There were 129 words scored within the 30 sentences. The articles "a" and "the" and their derivations (*e.g.*, der, die, das, ein...) were not scored. The percentage of words correctly identified ranged from 1% (D1) to 80% (D2). Only patient D2 scored above 10% correct.

The percentages of words correctly identified on the word test are shown in Figure 2. There were 35 words and 134 phonemes. Scores ranged from 0%

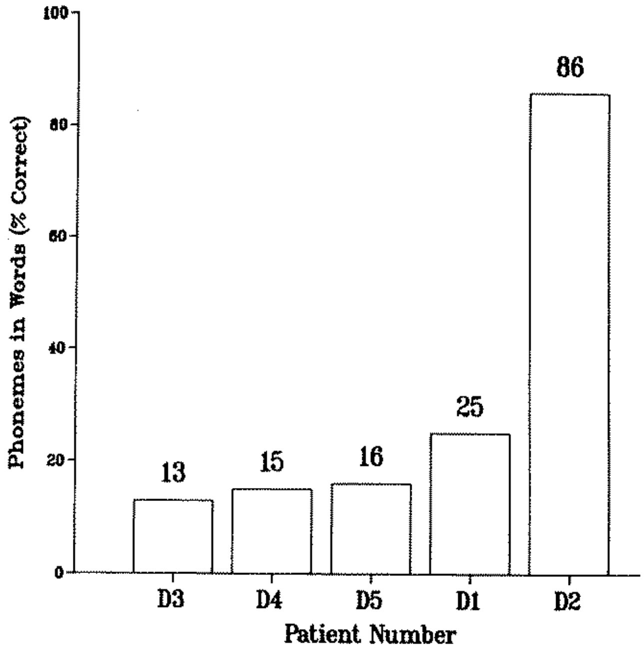

Fig. 3. Results for the word-level test, scored as percentage of phonemes correct.

(D3) to 63% (D2) correct, with only patient D2 scoring above 6% correct.

The percentage of phonemes correctly identified on the word test are shown in Figure 3. Scores ranged from 13% (D3) to 86% (D2) correct, with only patient D2 scoring above 25% correct.

CONCLUSION

It is important to realize that these word and sentence recognition tests were open-set tasks. Material of this type is very difficult for profoundly hearing-impaired subjects. Although the present results show limited open-set recognition, except in one patient, cochlear implants can aid communication in many other ways. It is likely that all these patients benefited from their implant in their lipreading ability[7] and their recognition of everyday sounds.[5]

Clearly, patient D2 is exceptional. However, three other patients scored above chance. Patient D1 achieved a score of 6% correct word recognition, D3 scored 6% correct, and D4 scored 10% word recognition in sentences. It would be interesting to note how D2 differed from the other patients. The engineers from this group indicated that there was no difference in how her processor was set. Patient D2 was deafened by a car accident at the age of 46, was 52 years old when tested, and had worn the implant for 3.5 years. These characteristics, however, do not distinguish her from the other patients.

Her preimplant auditory thresholds were 60, 65, 90, and 105 dB HL at 125, 250, 500, and 1,000 Hz in the implanted ear. No measurable hearing was obtained at higher frequencies.

Patient D4 had hearing thresholds that were better than those normally considered for implantation. Her superior performance suggests a difficult dilemma regarding what degree of hearing loss a patient should demonstrate before receiving a cochlear implant. This particular individual performs very well with her implant. However, there is a risk that patients with usable residual hearing will have a worse performance with a cochlear implant than they did with a hearing aid before receiving the implant. Until more data are available, a conservative approach should be followed. One such approach would be not to implant anyone who receives any significant open-set word recognition with hearing aids.

The Duren/Cologne group is currently attempting to miniaturize their speech processor to produce a behind-the-ear version. The new device, which is being manufactured by the Fraunhofer Institute, can vary pulse amplitude and has steeper filter skirts.

In summary, one patient implanted with the Duren/Cologne cochlear implant has achieved very high levels of word recognition. Three other patients have also obtained some limited open-set word recognition. It is remarkable that this level of performance can be achieved with any cochlear implant, let alone single-electrode extracochlear stimulation. About 40% of Professor Banfai's patients are now using single-channel stimulation. Extracochlear devices have an important application, particularly for young children, where the precise degree of deafness and benefit that would be derived from alternative devices is often difficult to determine.[8,9]

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