Telephone use by a multi-channel cochlear implant patient
An evaluation using open-set CID sentences

by
A. M. Brown, G. M. Clark, R. C. Dowell, L. F. A. Martin, and P. M. Seligman (Melbourne, Australia)

Abstract
A totally deaf person with a multiple-channel cochlear prosthesis obtained open-set speech discrimination using the telephone. CID Everyday Sentences were presented by telephone to the patient, who repeated an average of 21 per cent of key words correctly on the first presentation, and 47 per cent when a repeat of the sentences was permitted. This result is consistent with the patient's reports of telephone usage.

Introduction
Electrical stimulation of the auditory nerve is a means of providing hearing sensations to the profoundly deaf. The hearing sensations have been shown to enhance communication by supplementing lipreading (Bilger and Hopkinson, 1977; Fourcin, 1983; Martin et al., 1981) and to provide awareness of and recognition of environmental sounds (Thielemeyer, 1982). In addition, in recent years, a number of groups have reported subjects able to discriminate speech presented as an open-set (that is, completely unknown and untrained material) by electrical stimulation alone. This has been achieved by subjects with multiple-channel cochlear implant systems (Clark et al., 1981; Clark et al. (in press); Dowell et al., 1983; Chouard et al., 1983; Eddington, 1983) and with single-channel cochlear implant systems (Hochmair-Desoyer et al., 1981; Michelson and Schindler, 1981; Owens et al., 1982).

In 1978, surgeons at the University of Melbourne implanted a totally deaf patient with a prototype multiple electrode cochlear prosthesis. Results obtained from psycho-physical testing of this and a subsequently-implanted subject were used to develop a speech processing strategy, to determine the parameters and pattern of electrode stimulation (Tong et al., 1980). Speech discrimination results for the two subjects using this strategy were encouraging (Tong et al., 1981). This led to an association between the University of Melbourne and a medical electronics company, Nucleus Limited, from which a multiple-channel cochlear prosthesis and portable speech processor were developed. Late in 1982, a clinical trial of this system was undertaken with an initial group of six totally deaf subjects, all of whom were post-lingually deaf. Following psychophysical testing and programming of the speech processor, each subject underwent training with the system for a period of approximately two-to-three months. The training programme included both auditory and audio-visual training, and counselling in the optimal use of the cochlear prosthesis system (Martin et al., 1983). Each subject was also counselled and received training in the use of the telephone in a restricted way. That is, the detection and
recognition of the telephone signals, the use of 'yes—yes/no' codes (Castle, 1977) and message matrices (McLeod and Guenther, 1977) which are based on detection of different numbers of beats/syllables. These do not permit two-way conversations, in the general sense. They do, however, enable the person to transmit information and receive simple messages over the telephone. At this stage, several subjects reported understanding some words spoken to them over the telephone. For instance, one subject could understand 'Hello, son' and 'How are you?' but very little else. Thus, he was understanding speech which was largely determined by the context. However, another subject (Patient 4) reported having telephone conversations regularly with relatives and friends.

After completion of the training programme, each subject's performance was assessed using a number of speech and non-speech tests. The results indicated that all six subjects were capable of open-set speech discrimination using the cochlear prosthesis system alone, although there was large variation in the scores. Notably, Patient 4 scored 38 per cent on the CID Everyday Sentences test (Dowell et al., 1983). Refer to Table I for the 'free field' thresholds obtained with cochlear prosthesis for Patient 4.

This study investigated the ability of Patient 4 to discriminate speech when presented over the telephone.

<table>
<thead>
<tr>
<th>Warble tone centre frequency (Hz.)</th>
<th>Threshold (db. SPL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>71 (hearing)</td>
</tr>
<tr>
<td>250</td>
<td>56 (hearing)</td>
</tr>
<tr>
<td>500</td>
<td>51 (hearing)</td>
</tr>
<tr>
<td>750</td>
<td>38 (hearing)</td>
</tr>
<tr>
<td>1,000</td>
<td>35 (hearing)</td>
</tr>
<tr>
<td>1,500</td>
<td>33 (hearing)</td>
</tr>
<tr>
<td>2,000</td>
<td>35 (hearing)</td>
</tr>
<tr>
<td>3,000</td>
<td>39 (hearing)</td>
</tr>
<tr>
<td>4,000</td>
<td>34 (hearing)</td>
</tr>
<tr>
<td>6,000</td>
<td>42 (hearing)</td>
</tr>
<tr>
<td>8,000</td>
<td>43 (hearing)</td>
</tr>
</tbody>
</table>

The Cochlear Prosthesis and Speech Processor

The multiple-channel cochlear prosthesis and speech processor have been described elsewhere (Clark et al., 1983; Clark et al. (in press)). Briefly, the implanted cochlear prosthesis (shown in Fig. 1) comprises a receiver-stimulator electronic unit enclosed in a hermetically-sealed titanium container. An array of twenty-two electrodes emerges from this via a connector. The receiver-stimulator provides biphasic pulses to any of the twenty-two electrodes as either a bipolar or common ground stimulus. The external hardware (Fig. 2) comprises a speech processor, and a headband which houses the directional microphone and the transmitter coil.

Acoustic signals picked up by the microphone are analysed and coded according to the speech processing strategy. The voicing (or fundamental) frequency determines the rate of electrical stimulation. The dominant spectral peak in the mid-frequency range (750 to 4,000 Hz., encompassing the range of second formant frequencies of vowels) determines the electrode to be stimulated, and the amplitude of this spectral peak determines the stimulus amplitude. This coded information, along with the power necessary to drive the implant, is transmitted to the implanted receiver coil determining the electrical stimulation parameters and pattern.

The Subject

The subject, Patient 4, was a 24-year-old woman who, as a child, had multiple ear infections associated with chronic central perforations of the tympanic membranes of both ears. She had a number of operations on both ears, including myringoplasties and tympanoplasties. At 14 years of age, she was found to have total bilateral deafness.

Pre-operative audiometric testing showed no air-conducted hearing thresholds in either ear up to a maximum audiometer output of 130 db. SPL for the frequencies between 100 and 10,000 Hz. (These levels were obtained using an oscillator capable of producing sine waves of 100 to 10,000 Hz., inputting to the audiometer which outputted to the earphones
Fig. 1
The multiple-channel cochlear prosthesis.

Fig. 2
The wearable speech processor and headset.
via an audiometer booster. Measurements were obtained using a 6 cc. coupler prior to the subject testing session.) Bone conduction testing gave thresholds only at levels which elicit vibrotactile sensations (according to Boothroyd and Cawkwell, 1970). There was no speech discrimination in either ear at 115 db. SPL. Impedance audiometry showed Type A tympanograms in both ears, and acoustic reflexes were absent. Refer to Fig. 3 for the pre-operative audiogram.

The patient's aided performance was assessed using a powerful body-type hearing aid (maximum power output approximately 140 db. SPL). There were no hearing thresholds when the aid was fitted to either the left or the right ear. Vibrotactile sensations were reported for high-intensity, low frequency warble tones (refer to Table II). Comprehensive testing showed no significant open-set speech discrimination using the hearing aid and no improvement in aided over unaided communicative ability.

Polytome X-ray films revealed no gross changes in either cochlea. Furthermore, a positive result was obtained when the patient's right promontory was electrically stimulated. The procedure is used to ascertain whether residual auditory neurons are sufficient to produce hearing sensations when stimulated electrically. Biphasic current pulses were used (100 μsec. per phase) at pulse rates of 50, 100, and 200 pps. The patient reported hearing sensations for all pulse rates of threshold levels of 110 to 140 μA. with dynamic ranges (threshold to uncomfortably loud) ranging from 40 to

<table>
<thead>
<tr>
<th>Warble tone centre frequency (Hz.)</th>
<th>Threshold (db. SPL)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
</tr>
<tr>
<td>125</td>
<td>84 (vibrotactile)</td>
</tr>
<tr>
<td>250</td>
<td>84 (vibrotactile)</td>
</tr>
<tr>
<td>500</td>
<td>84 (vibrotactile)</td>
</tr>
<tr>
<td>750</td>
<td>84 (vibrotactile)</td>
</tr>
<tr>
<td>1,000</td>
<td>84 (vibrotactile)</td>
</tr>
<tr>
<td>1,500</td>
<td>N.R.</td>
</tr>
<tr>
<td>2,000</td>
<td>N.R.</td>
</tr>
<tr>
<td>3,000</td>
<td>N.R.</td>
</tr>
<tr>
<td>4,000</td>
<td>N.R.</td>
</tr>
<tr>
<td>6,000</td>
<td>N.R.</td>
</tr>
<tr>
<td>8,000</td>
<td>N.R.</td>
</tr>
</tbody>
</table>

N.R. indicates no response at 100 db. SPL.

Hearing aid specifications: maximum output 146 db. SPL: average gain (0.5, 1, 2 KHz.) 80 db. SPL.
90 μA. The patient was able to discriminate between 50 and 100 pps. stimuli, reporting pitch differences, but no pitch differences between 100 and 200 pps. stimuli were reported.

In November 1982, an electrode array 20 mm. in length was inserted into the scala tympani (of the right cochlea) via the round window. A receiver-stimulator unit was placed in a bed drilled in the mastoid bone, and the wound closed in layers.

Following a two-week healing period, the patient’s prosthesis was tested (using the microcomputer and interface unit shown in Fig. 4). All electrodes were found to elicit hearing sensations, and the pitch ranking of these sensations was consistent with the tonotopic organization of the cochlea.

Procedure

The present study was conducted approximately eight months post-operatively. The patient sat in an office with one of the authors (who recorded the responses). The patient held a hand microphone (which inputs to the speech processor through the external input socket) to the telephone handpiece (Fig. 5). She was informed that a speaker would say a sentence over the telephone and that she was required to repeat, word-for-word, what she heard.

The speaker was a woman with whom the patient was acquainted, but who had not participated in any testing or training sessions with the subject. The speaker sat in a separate office. There was no direct acoustic transmission between the two rooms.

The test material consisted of two lists of CID Everyday Sentences (Davis and Silverman, 1970), modified for Australian use by the National Acoustic Laboratories and the University of Melbourne). Lists H and I were used, as these had not previously been administered to the patient. The modifications consisted of the substitution of ‘lollies’ for ‘candy’ (List H) and ‘chocolate’ for ‘candy’ and ‘autumn’ for ‘fall’ (List I). The test is scored by
FIG. 5
Multiple-channel cochlear prosthesis patient using telephone. In this instance, using pick-up attached to telephone and inputting directly to the speech processor via the external input socket.

FIG. 6
Frequency response of the telephone.
TABLE III

SPEECH DISCRIMINATION: KEY WORDS SCORE

<table>
<thead>
<tr>
<th>CID Everyday Sentences</th>
<th>1st Presentation (per cent)</th>
<th>2nd Presentation (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>List I</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td>List II</td>
<td>16</td>
<td>58</td>
</tr>
<tr>
<td>Average score</td>
<td>21</td>
<td>47</td>
</tr>
</tbody>
</table>

b. Modified for Australian use.
Score is expressed as a percentage of key words (50 key words per sentence list).

the number of key words correctly repeated (50 key words per list of 10 sentences).

The lists of sentences were read aloud by the speaker over the telephone to the patient, one sentence at a time. The patient was required to repeat what was said. If the response was not correct, the speaker repeated the sentence (once only).

The telephone frequency response was measured using a Fourier Analysis of low frequency square waves. An acoustic square wave was presented to the telephone mouthpiece at 90 db. SPL in an anechoic environment. The receiving telephone's earphone was coupled to a Brüel and Kjaer earphone coupler and measuring amplifier. The resulting signal from the amplifier was analysed using a Fast Fourier Transform to obtain the overall frequency response (Fig. 6).

Results

Referring to Table III, the subject correctly repeated an average of 21 per cent of keywords when each sentence was presented once only. When a single repeat was allowed, the subject repeated an average of 47 per cent of keywords correctly.

Discussion

The telephone presents a major problem to many hearing impaired people. In general, as the severity of hearing impairment increases, the ability to use the telephone decreases. For some, telephone devices (such as amplified phones, telecoils which link the phone and the hearing aid electromagnetically, flashing lights to indicate the ringing of the phone) can help to overcome this problem. However, for the vast majority of profoundly deaf people, use of the telephone is restricted to special codes or teletype printers (which use keyboards in conjunction with each phone).

According to Johnson and Rubenstein (cited by Sims, 1978), hearing-impaired people with speech discrimination of 50 per cent or greater (as assessed by the CID Everyday Sentences Test) and intelligible speech have potentially sufficient oral-aural communication skills to be able to use the telephone for two-way conversation. Using these criteria, the subject of the present study, having intelligible speech and average speech discrimination (with repeats) of 47 per cent, has borderline discrimination skills for such telephone use.

In considering the reasons for the subject's ability to use the telephone, it is pertinent to point out the large increase in speech discrimination when a repeat was permitted. This is consistent with telephone conversations between the subject and one of the authors. Conversations proceed at a slower rate than normal, and words and phrases may need to be repeated or rephrased in order for the subject to understand what has been said. In addition to this, many everyday situations involving the use of the telephone contain more contextual cues (e.g., knowledge of the topic) and more interaction than the CID Everyday Sentences Test.

Summary

A totally deaf woman with a multiple-channel cochlear prosthesis reported telephone conversations with friends and relatives. This is consistent with her ability to discriminate an average of 47 per cent of keywords in the CID Everyday Sentences Test over the telephone.

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References


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