PRELIMINARY RESULTS WITH A MINIATURE SPEECH PROCESSOR FOR THE 22-ELECTRODE MELBOURNE/COCHLEAR HEARING PROSTHESIS

Richard C. Dowell, Lesley A. Whitford¹, Peter M. Seligman¹, Burkhard K-H Franz and Graeme M. Clark

University of Melbourne. Department of Otolaryngology, 32 Gisborne St, East Melbourne, Vic 3002; ¹Cochlear Pty Ltd, 14 Mars Road, Lane Cove, NSW 2066; Australia

Introduction

The 22-electrode cochlear prosthesis developed by the University of Melbourne in conjunction with Cochlear Pty Ltd has been used successfully by profoundly deaf patients since 1982 and is now a part of everyday life for some 2000 people in many countries around the world. The implanted part of the prosthesis has remained relatively unchanged in this time except for the alteration of the design in 1986 to incorporate an implanted magnet and reduce the overall thickness of the device. The implanted magnet eliminated the need for wire headsets which were difficult to fit and in some cases did not maintain the position of the external transmitter coil adequately. This was felt to be essential before the prosthesis could be used in young children.

The external speech processor which provides information and power to the implant has undergone significant change since 1982. The speech coding scheme used by the first patients was developed in 1979 at the University of Melbourne using a prototype multichannel implant. This scheme presented three acoustic features of speech to implant users. These were amplitude, presented as current level of electrical stimulation; fundamental frequency or voice pitch, presented as rate of pulsatile stimulation; and the second formant frequency, represented by the position of the stimulating electrode pair. This coding scheme (FOF2) provided enough information for profoundly, postlinguistically deafened adults to show substantial improvements in their perception of speech with and without lipreading. Most adults demonstrated the ability to understand open-set speech without lipreading within three months of implantation and mean results for open-set sentence testing were 15-20% correct.

A natural progression from this coding scheme was to present additional spectral information and this was implemented in 1985 when a second stimulating electrode pair was added representing the first formant of speech. This new scheme (FOF1F2) showed improved performance for adult patients in all areas of speech perception. There was a highly significant improvement in performance on open-set speech perception with mean scores for open-set sentences increasing to 30-40% within three months of implantation. The FOF1F2 scheme also showed significant improvements over FOF2 in moderate levels of background noise. Many patients using the FOF1F2 speech processor have been able to use the telephone for two-way conversations.

Despite the success of this speech processor (WSP III) over the last five years, a number of problems have been identified. Patients who perform well in quiet conditions can have significant problems when there is a moderate level of background noise. The size and weight of the device has been troublesome in certain situations, particularly for small children, and the external controls have not had the flexibility to cope with all acoustic environments. The FOF1F2 scheme codes frequencies up to 3500 Hz, however, many phonemes and environmental sounds have a high proportion of their energy above this range making them inaudible to the implant user in some cases. These considerations have prompted the continued research and development in speech processing at the University of Melbourne and Cochlear Pty Ltd which has led to the new Miniature Speech Processor (MSP) and MULTIPEAK speech coding scheme. This new external processor does not
require more sophisticated implanted hardware so existing and newly-implanted patients can benefit from the improved design. This paper will briefly describe the new speech processor and coding scheme and present some preliminary results obtained with adult patients.

Hardware

The MSP is approximately one-half the volume of the existing speech processor (WSP III), with dimensions of 9 cm x 6 cm x 1.65 cm (89 cubic cm) compared with 12 cm x 7.5 cm x 2 cm (180 cubic cm). The MSP weighs approximately one-third of the WSP III at 100 g compared with 265 g. It is powered by a single AA size, rechargeable lithium cell. The sensitivity control, which sets the gain of the pre-amplifier, is continuously variable in the new model compared with the coarse step-wise control in the WSP III. A new noise suppression algorithm has been designed for use in everyday environments and it is anticipated that patients will use the speech processor with the noise suppression activated most of the time. An LED monitors the battery supply level and input from the microphone or external audio input. Another LED enables testing of the transmitter coil by placing the coil adjacent to the speech processor case. An audio input selector allows direct connection to various audio sources with the option of activating a microphone for environmental sounds simultaneously.

Coding scheme

The new MULTipeak speech coding scheme provides all of the information available in the FO/F1/F2 scheme while providing additional information from three high frequency band pass filters. These filters cover the following frequency ranges: 2000 to 2800 Hz, 2800 to 4000 Hz and 4000 to 8000 Hz. The energy within these ranges controls the amplitude of electrical stimulation of three fixed electrode pairs in the basal end of the electrode array. Thus, additional information about high frequency sounds is presented at a tonotopically appropriate place within the cochlear.

The overall stimulation rate remains as FO (fundamental frequency or voice pitch) but in the new scheme four electrical stimulation pulses occur for each glottal pulse. This compares with the FO/F1/F2 strategy in which only two pulses occur per voice pitch period. In the new coding scheme, for voiced speech sounds, the two pulses representing the first and second formant are still provided and additional stimulation pulses occur representing energy in the 2000-2800 Hz and the 2800-4000 Hz ranges.

For unvoiced phonemes, yet another pulse representing energy above 4000 Hz is provided while no stimulation for the first formant is provided, since there is no energy in this frequency range. Stimulation occurs at a random pulse rate of approximately 260 Hz which is about double that used in the earlier strategy.

The new noise suppression algorithm operates in a continuous manner, rather than as a voice activated switch as has previously been used. This removes the perceptually annoying switching on and off of the earlier system. In the new algorithm the noise floor is continuously assessed in each frequency band over a period of ten seconds. The lowest level over this period is assumed to be background noise and is subtracted from the amplitude relevant to that frequency band. Thus any increase in signal amplitude above the noise level is presented to the patient while the ambient noise level itself is reduced to near threshold.

Subjects

Due to the difficulty for experienced implant users in changing from one speech processing scheme to another on a short term basis, two groups of subjects were evaluated in this study. In pilot studies, it became clear that subjects given a smaller, lighter, subjectively better processor which was easier to operate were unwilling to return to the use of the old processor at home for the purposes of testing. Without home experience with the processor to be evaluated, test results become biased as implant users will tend to perform better with
Preliminary results with a miniature speech processor

Two groups of four subjects were tested in this study. These subjects were not selected using any special criteria except availability and willingness to participate in research studies. All eight subjects were using 15 or more stimulation channels of their cochlear prosthesis. Group A subjects were assessed using the WSP III with the FOFIF2 coding scheme and Group B subjects were assessed using the new MSP with the MULTIPEAK coding scheme. The two groups of subjects were matched as far as possible based on age, implant experience, and post-operative speech perception results (using the FOFIF2 coding scheme).

Table 1 summarizes the results for the two groups of subjects on three month postoperative clinical evaluations. Also included, for comparison, are the mean scores for all adult implant users on the same evaluations. It is evident from the Table that the two groups are well matched on all parameters except for consonant recognition results, for which Group A subjects performed significantly better overall than Group B ($t = 3.38, df = 6, p < 0.01$). It is also worth noting that both groups performed significantly better than the average for all adult patients on open-set testing. It is reasonable to assume that successful implant users are more likely to be interested in participating in such studies and that this may explain such a result.

Method

The two groups of subjects were first tested in quiet conditions using vowel recognition, consonant recognition and the BKB open-set sentence tests. The vowel recognition test consisted of the 11 pure vowels of Australian English in an /h-vowel-d/ context presented four times in random order at each test session. For each item, the subject was required to select from a list of the 11 vowels. The consonant recognition test consisted of 12 consonants in an /a-consonant-a/ context presented four times in random order at each test session. For each item, the subject was required to select from a list of the 12 consonants. The BKB open-set sentence test consists of lists of 16 sentences of five to six words in length with vocabulary restricted to words familiar to school age hearing impaired children. In each list, 50 words are designated as key scoring words. This test is slightly more difficult than the more commonly used CID open-set sentences and produces scores between 10% and 30% less than the CID test in the same subjects. The subjects listened to the sentences once and were required to repeat what they heard. No repeated presentation was allowed, no contextual information was provided, and different test lists were used for each test session.

The Group A subjects were tested with the WSP III using the FOFIF2 coding scheme over four test sessions. The Group B subjects were tested over three test sessions, due to time constraints, using the MSP and MULTIPEAK coding scheme. All testing was carried out at 70 dB SPL using recorded material.

The two groups were also tested in competing noise using the Four Choice Spondee Test from the MAC battery and the BKB open-set sentence test, described above. The competing noise used was four-talker babble. The Four Choice Spondee Test is a closed-set test which involves the correct identification of a spondee word from a set of four alternatives. This test has been used previously to assess implant users’ performance in competing noise. During each test session, the spondee test was presented in quiet and at signal-to-noise ratios (SNRs) of +10 dB, +5 dB and 0 dB. The presentation level was again set to 70 dB SPL. The BKB sentences were presented at SNRs of +20 dB, +15 dB and +10 dB. Presentation of this test in quiet was not necessary due to the results already obtained in previous test sessions. Each subject was evaluated over two test sessions for the competing noise studies.

Results

The results of the speech perception studies in quiet are shown in Fig. 1. For the vowel recognition study, Group B subjects performed significantly better than Group A ($F = 7.78, p < 0.01$).
Fig. 1. Mean scores for two matched groups of multichannel cochlear implant subjects on vowel recognition, consonant recognition and open-set BKB sentences in quiet conditions. The darker bars represent the scores for the group using the new miniature speech processor (MSP) with the MULTIPEAK coding scheme and the lighter bars, the scores for the group using the wearable speech processor (WSP III) with the F0F1F2 coding scheme.

Fig. 2. Mean scores for two matched groups of multichannel cochlear implant subjects on the Four-Choice Spondee Test in quiet conditions and at signal-to-noise ratios of +10 dB, +5 dB and 0 dB. The competing noise used was four-talker babble. The darker bars represent the scores for the group using the new miniature speech processor (MSP) with the MULTIPEAK coding scheme and the lighter bars, the scores for the group using the wearable speech processor (WSP III) with the F0F1F2 coding scheme.
MSP AND WSP-III COMPARISON
BKB sentences in competing noise

Fig. 3. Mean scores for two matched groups of multichannel cochlear implant subjects on the open-set BKB sentence test in quiet conditions and at signal-to-noise ratios of +20 dB, +15 dB and 10 dB. The competing noise used was four-talker babble. The darker bars represent the scores for the group using the new miniature speech processor (MSP) with the MULTIPEAK coding scheme and the lighter bars, the scores for the group using the wearable speech processor (WSP III) with the F0F1F2 coding scheme.

The overall mean score for Group A using the WSP III with the F0F1F2 coding scheme was 77.6% and for Group B using the MSP with the MULTIPEAK scheme, 87.7%. For the consonant study, the mean result was also higher for Group B (61.9% compared with 56.2%), however, this difference was not statistically significant. The open-set sentence testing showed a large difference between the two groups with an overall mean for Group B of 88.0% and for Group A, 54.8%. This difference was highly significant (F = 43.7, df 1, 26; p < 0.001). The closed-set spondee test results with different levels of competing noise are shown in Fig. 2. A problem that is immediately evident is that this test is very easy for these subjects, particularly in quiet conditions, and it is difficult to demonstrate any differences in performance between the two groups. Nonetheless, a significant difference is evident with Group B subjects performing better than Group A (F = 4.00, df 1, 56; p < 0.05). The open-set sentence results with competing noise are shown in Fig. 3 and demonstrate a substantial benefit for Group B compared with Group A (F = 22.4, df 42,1 ; p < 0.001). The subjects using the new speech processor and coding scheme perform significantly better at all SNRs evaluated.

Discussion

The results of this study show that a group of subjects using the new speech processor and coding scheme performed significantly better on a range of speech perception tests in quiet and in noise than a matched group of subjects using the old speech processor and coding scheme. The mean open-set sentence score for the subjects using the new system (88.0%) indicated that they could expect to understand a substantial amount of connected speech without lipreading in quiet conditions. As shown in Table I, both groups of subjects in this study perform above the average level for all adult implant users. Thus, it would not be justified to expect this level of performance from all patients. However, the degree of improvement observed gives some reason for optimism in the wider application of the new system. Significant improvement was also evident for vowel recognition with the new
processor, however, the consonant recognition study did not show a significant result. Two factors may have influenced this outcome. As shown in Table 1, Group A showed significantly better consonant recognition in postoperative results. If the Group B subjects had shown improvement with the new processor, this result may be obscured as the Group A subjects are better at this particular task. The particular set of consonants used may also have an effect on the result. The additional information provided by the MSP is in the high frequency range and one might expect this information to have the greatest influence on recognition of the voiced and unvoiced fricatives and affricates. These sounds are not well represented in the group of 12 consonants used in this study. It may be worthwhile devising a study using different sets of consonants to define more precisely the advantages provided by the new coding scheme.

The results in noise are particularly encouraging. Early studies of closed-set performance with competing noise using the FOF2 coding scheme 4, showed that scores reduced to chance level with a SNR of +10 dB. Evaluation of the FOF1F2 speech coding scheme in noise indicated a significant improvement over the FOF2 scheme. Performance on the closed-set Four Choice Spondee test was unaffected at a SNR of +10 dB, significantly degraded at +5 dB, and close to chance level at 0 dB with the FOF1F2 scheme. Although this demonstrated useful improvement, open-set sentence testing still showed significant degradation of scores at +15 dB and virtually zero scores at +10 dB. In the present study, the subjects using the new system maintained good performance on closed-set testing at 0 dB SNR (72.5% for the Four Choice Spondee test) and scored well for open-set sentences at +10 dB SNR (64.5%). These results suggest that these subjects can maintain their speech perception performance in moderately noisy environments, particularly as an additional advantage of 5 to 10 dB is provided by the directional ear-level microphone. This advantage was not available during this study as the signal and noise were presented via a single loudspeaker from one direction. The directional microphone provides some advantage in many everyday acoustic environments as background noise is often coming from all directions whereas the signal is from one particular direction. When oriented towards the signal source, the directional microphone will tend to enhance the signal and reduce the noise.

Further studies are necessary to evaluate the new speech processor system on a larger cross-section of the implant user population. It will also be important to perform more detailed analysis of perceptual tests to show what acoustic features of speech are better presented via the new system. A number of changes have taken place in the transition to the new processor including the hardware, the coding scheme and the noise suppression system. It would be useful to be able to describe more precisely how each of these changes has contributed to improved performance.

### Table 1. Comparison of subject groups using WSP III

<table>
<thead>
<tr>
<th></th>
<th>Group A (n = 4)</th>
<th>Group B (n = 4)</th>
<th>All adult implantees using WSP III (n = 33)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>Mean 53.3 2.9</td>
<td>Mean 53.0 3.6</td>
<td>Mean 50.8 NA</td>
</tr>
<tr>
<td><strong>Exp</strong></td>
<td>SD 8.0 21.4</td>
<td>SD 14.6 2.4</td>
<td>SD 12.10</td>
</tr>
<tr>
<td><strong>Tracking</strong></td>
<td>26.3 21.1</td>
<td>18.5 21.1</td>
<td>21.7 21.1</td>
</tr>
<tr>
<td><strong>Vowel</strong></td>
<td>61.0 71.5</td>
<td>65.3 74.3</td>
<td>58.8 70.5</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>74.8 64.8</td>
<td>11.5 3.2</td>
<td>15.6 15.5</td>
</tr>
<tr>
<td><strong>Open-set</strong></td>
<td>70.5 48.8</td>
<td>3.2 11.5</td>
<td>26.3 38.5</td>
</tr>
<tr>
<td><strong>Sent</strong></td>
<td>24.7 25.1</td>
<td>63.0 20.5</td>
<td>11.1 11.9</td>
</tr>
<tr>
<td><strong>Words</strong></td>
<td>26.0 11.1</td>
<td>25.1 20.5</td>
<td>11.9 11.5</td>
</tr>
</tbody>
</table>

L: Lipreading alone; LS: Lipreading with speech processor. Age and experience are reported in years; months. Speech tracking scores are reported in words per minute. All other scores are percent correct (auditory alone).
Conclusion

This preliminary study has indicated that a new miniature speech processor developed for use with the 22-electrode cochlear prosthesis and using a more sophisticated speech coding scheme provides significantly improved speech perception performance for a group of implant users. Significant improvements were seen in both quiet and competing noise conditions. The results in noise were particularly encouraging in that subjects' performance showed minimal degradation in levels of noise that are commonly encountered in everyday environments.

References

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Author/s:
Dowell, Richard C.; Whitford, Lesley A.; Seligman, Peter M.; Franz, Burkhard K.-H. G.; Clark, Graeme M.

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