Speech cues for cochlear implantees: spectral discrimination

SYDNEY '97
XVI World Congress of Otorhinolaryngology Head and Neck Surgery

Sydney, Australia
2-7 March 1997

B. HENRY, C. McKAY, H. McDERMOTT and G. CLARK

Department of Otolaryngology, The University of Melbourne (AUS)

SUMMARY

The relationship between the ability of cochlear implantees to perceive speech and their ability to discriminate between stimulation on adjacent electrodes was investigated. Speech perception ability was assessed with monosyllabic words in 8 users of the Nucleus cochlear prosthesis. The ability of these subjects to discriminate between stimulation on adjacent electrodes, in the presence of random loudness differences between electrodes, was determined. Results were averaged in the apical, mid and basal regions of the cochlea. Regression analysis showed that speech perception ability and electrode discrimination ability were correlated in the apical to mid region of the cochlea, but the two factors were not correlated in the basal region. Therefore, these results suggest that implantees require the ability to discriminate between stimulation on adjacent electrodes in the apical to mid region of the cochlea in order to achieve high speech perception scores.

INTRODUCTION

The ability of cochlear implantees to understand speech varies over a wide range. However, limited knowledge has been gained relating to the reasons for this variability. It is thought that the ability to perceive speech may be related to peripheral auditory parameters such as the electrode position in the cochlea, electrical properties of the cochlea, and spiral ganglion cell survival and function, as well as other more central auditory factors. Although it is not possible to measure these factors in human implantees, studies have been conducted which investigated some relevant patient variables such as aetiology and duration of deafness. Blamey *et al.* (1992) found that the duration of deafness was correlated with speech perception ability. However, this correlation did not account for the majority of the variability in speech perception performance.

Spectral speech information, the distribution of speech energy across frequency, is one of the important features of the speech signal that must be perceived for an implant user to be competent at understanding speech. The perception of spectral information with the Nucleus multi-channel cochlear prosthesis and the Spectra-22/SPEAK processor, is made possible by dividing the incoming spectrum into 20 frequency bands and mapping information from these bands onto 20 tonotopically ordered electrode positions within the cochlea. The stimulation on the electrodes is intended to result in hearing sensations with different pitches according to the tonotopic ordering of auditory nerves in the cochlea.

The perception of spectral speech cues would be expected to depend on the ability of the individual to discriminate between stimulation on different electrodes. Correlations between the ability to distinguish electrodes and speech recognition ability have been demonstrated in some studies. For example, Nelson *et al.* (1995) found that the ability of implantees to perceive consonants was correlated with their ability to discriminate electrodes. These studies used stimuli which did not vary in loudness. However, implantees need to perceive place of stimulation information in spite of loudness differences between electrodes in order to understand speech. Therefore, the aim of this study was to investigate the relationship between speech perception ability and the ability to discriminate between electrodes using stimuli that varied in loudness.

MATERIALS AND METHODS

Eight postlinguistically deaf adults using the Nucleus System 22 implant and the Spectra-22/SPEAK processing strategy participated in this study. Individual subject details are given in Table 1.

The subjects used the Spectra-22/SPEAK processor for the speech perception experiment. The processor was programmed with the individual's map, which was checked prior to the experiment to ensure that threshold (T) and maximum comfortable listening (C) levels were optimal. Each subject had 16 active electrodes in their speech processor map, which were allocated to a frequency range of 150 to 5750 Hz. Speech perception ability was assessed in quiet with monosyllabic words based upon those of Peterson and Lehiste (1962). Each subject was tested with 5 lists of 50 words each, presented by hearing alone at a level of 70 dB SPL. Results were recorded as the average number of phonemes correctly identified by each subject.

The ability to discriminate between stimulation to adjacent electrodes was assessed for all 16 electrodes in each subject's speech processor map. The stimuli were 500ms duration stimulus bursts of biphasic current pulses, delivered at a rate of 250 Hz, and separated by silent intervals of 500ms. The pulse widths of the stimuli were selected for each subject, and held constant for the experiment (see Table 1). Prior to beginning the comparison for a pair of electrodes, T and C levels were determined, and the dynamic range calculated as the ratio between the T and C level. At the C level, the stimuli on the two electrodes were balanced for loudness by adjusting the currents. Discrimination between the two electrodes of each pair was assessed using a four-interval forced choice task, in which three intervals comprised stimulation on one electrode, and the remaining interval, chosen at random, comprised stimulation on the other electrode. The current level of the stimulation varied randomly in each interval within the upper 60% of the subject's dynamic range. The subject

Table 1: Details of the subjects who participated in the experiment. Two different modes of stimulation were used with the subjects. In bipolar (BP) stimulation, current is passed between two electrodes. The separation of the electrodes can be varied- in BP+1, the separation between electrodes is 1.5mm, and in BP+3 the separation is 3.0mm. In common ground (CG) stimulation, current passes from the selected electrode to all other electrodes in the array, which are connected together.

Subject	Aetiology	Duration of profound deafness (years)	Age (years)	Implant experience (years)	Pulse width (μs/phase)	Mode of stimulation
S1	Congenital	1	48	9	100	CG
S2	Trauma	17	51	8	100	CG
S3	Otosclerosis	8	41	4	100	BP+1
S4	Meningitis	45	56	6	100	BP+1
S5	Unknown	3	73	12	400	BP+1
S6	Unknown	1	50	8	200/400	BP+3
S7	Otosclerosis	14	60	4	100	BP+1
S8	Congenital	30	66	10	100	BP+1

was asked to respond with which interval sounded 'different', ignoring any loudness variations. The percent correct responses out of 30 trials were calculated for each electrode comparison. Subjects needed to achieve a score greater than 40% for the result to be statistically significant ($p<0.05$). To obtain a measure of electrode discrimination in the apical, mid and basal regions of the cochlea for each subject, discrimination scores for groups of five adjacent electrode pairs were averaged in the three regions.

RESULTS AND CONCLUSIONS

The graph on the left of Fig.1 shows the mean percent correct of phonemes for each of the subjects. Scores ranged from 43.7% to 92.5%. The graph on the right of Fig.1 shows electrode discrimination ability in the three regions of the cochlea. Some subjects performed at chance levels with the loudness variation less than 60%. In these cases, the results shown are for a lower level of variation (e.g. 20 or 40%). Ability to perform the electrode discrimination task varied widely, from subject 2 who was able to perform this task almost perfectly in all regions of the cochlea, to subject 8 who was unable to discriminate adjacent electrodes in any region of the cochlea when the loudness was randomly varied.

To investigate the relationship between speech discrimination and electrode discrimination in the three regions of the cochlea, regression analysis was performed. Fig. 2 shows that there was a strong correlation between speech perception ability and electrode discrimination ability in the apical and mid regions. The subjects with high speech perception scores were able to discriminate between adjacent electrodes, while those subjects with poorer speech perception ability were not as able to discriminate electrodes. The reason for this may be that the amount of frequency information available is limited by the effective number of discriminable frequency-information channels. Good electrode discrimination ability may provide more independent information channels, so that the speech cues which are contained in the distribution of energy across frequency will be well perceived. If electrode discrimination is poor, the effective number of independent channels may be reduced, resulting in a reduction of the amount of spectral information available and therefore

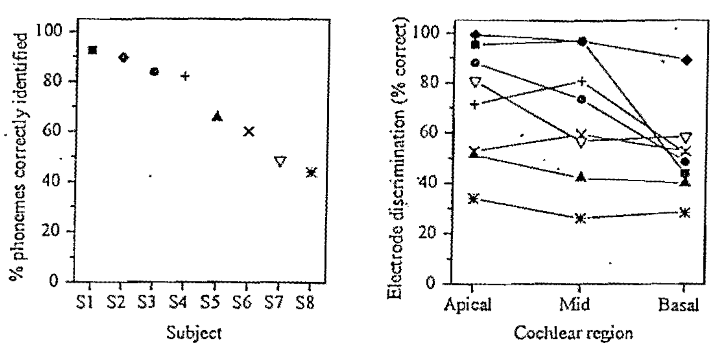

Figure 1: Speech perception ability (averaged % correct phonemes) (left) and electrode discrimination ability (averaged % correct electrode discrimination) (right). The 8 subjects are denoted by the same symbols in each graph.

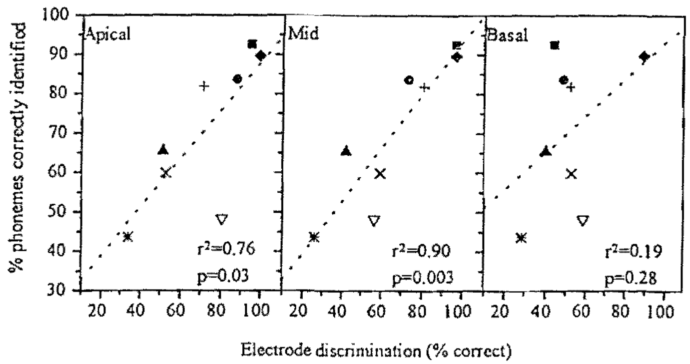

Figure 2: Relationship between speech discrimination ability and electrode discrimination ability in the apical, mid and basal regions of the cochlea. A significant p-value indicates that the regression line is significantly different from zero, and thus the null hypothesis, that there is no relationship between speech perception ability and electrode discrimination ability, may be rejected.

adversely affecting overall speech understanding.

The ability to understand speech and electrode discrimination ability were not significantly correlated in the basal region of the cochlea (Fig. 2). This may be associated with the relative importance of spectral cues for speech perception in the basal compared to the mid to apical frequency regions. The frequencies mapped to the electrodes in the apical to mid region of the cochlea range from 150 to 2700 Hz. This region contains critical spectral speech cues, including cues about the frequency of the first and second vowel formants and primary cues on consonant place of articulation. In the basal region, the frequencies mapped to electrodes span the range 2400-5750 Hz. The elements of speech in this frequency region, such as the broad band noise bursts of some consonants, do not require fine spectral discrimination. Therefore, electrode discrimination may be relatively less important to speech perception in this region.

It is unlikely that the perception of spectral speech cues is limited solely by the ability to discriminate between electrodes. Spectral speech information should be related not only to the number of discriminable channels, but also to whether the percepts evoked by electrical stimulation are tonotopically ordered. The investigation of whether the percepts are tonotopically ordered is part of ongoing research in this laboratory.

In summary, the speech perception ability of implantees was associated with their ability to discriminate between stimulation on adjacent electrodes in the mid to apical region of the cochlea, but not in the basal region. Therefore, the results show that in order to achieve high speech perception scores, implantees require the ability to discriminate between stimulation on adjacent electrodes in the apical to mid region of the cochlea.

REFERENCES

BLAMEY, P.J., PYMAN B.C., GORDON, M., BROWN A.M., DOWELL, R.C., AND HOLLOW, R.D. Factors predicting postoperative scores in postlinguistically deaf adult cochlear implant patients. Ann. Otol. Rhinol. Laryngol. 101: 342-348, 1992.

NELSON, D.A., VAN TASSELL, D.J., SCHRODER, A.C., SOLI, S., AND LEVINE, S. Electrode ranking of 'place pitch' and speech recognition in electrical hearing. J. Acoust. Soc. Am. 98: 1987-1999, 1995.

PETERSON, G., AND LEHISTE, I. Revised CNC lists for auditory tests. J. Speech Hear. Disord. 27: 62-70, 1962.

SYDNEY '97
XVI World Congress of Otorhinolaryngology Head and Neck Surgery
Sydney, Australia
2-7 March 1997