THE IDENTIFICATION OF SYNTHETIC VOWELS BY PATIENTS USING A SINGLE-CHANNEL COCHLEAR IMPLANT

EVA AGELFORS AND ARNE RISBERG

Department of Speech Communication and Music Acoustics
Royal Institute of Technology (KTH), Box 70014
S-100 44 STOCKHOLM, SWEDEN

ABSTRACT

Vowel perception in a /bV:b/-context of patients using a single-channel extra-cochlear implant developed in Vienna has been studied by means of synthetic speech. Three patients were asked to adjust the first and second formant of a synthetic vowel sound so that they perceived the sound as a given long Swedish vowel. To study the effect of training, the experiment was made at two sessions about a year apart. Normal hearing listeners identified the vowel sounds generated by the subjects. The results of the experiment were analyzed in confusion matrices and as F1-F2 plots.

A clear effect of training could be seen. Three years after implantation the best subject could adjust the frequency of F1 and F2 quite close to the correct values.

INTRODUCTION

It has long been known that stimulation of the auditory nerve with a weak electric current results in auditory sensation. During the late fifties the first experiments were made to use this effect in an aid for the deaf. Since the beginning of the seventies, House at the Ear Research Institute in Los Angelses has been implanting deaf subjects with a simple single channel cochlear implant /1/. At the same time research and development has been going on at several laboratories both on single-channel and multi-channel devices. In a single-channel cochlear implant, the electrode is either placed in the middle ear close to the round window, or inserted a few millimeters into the cochlea. In a multi-channel device, the electrodes are placed in the cochlea at different positions along the basilar membrane.

In a single-channel implant, it seems that only time-intensity information in a speech signal can be transmitted. In a multiple-channel device, some frequency selectivity might be obtained by stimulating different nerve endings along the basilar membrane.

During the last years very good speech understanding without the support of lipreading has been reported from subjects using both single-channel and multi-channel devices. The good speech understanding reported from subjects using single-channel devices seems to indicate that they have some possibility to identify vowels. This has been studied by Doyle et al. /2/. They used natural vowels that had been equalized in duration and loudness. They concluded that "The vowel features

of F0 and/or F1 (or information related to them) accounted primarily for the vowel confusions made by these single-channel cochlear implant subjects".

Dent /3/ studied vowel discrimination by subjects that used the same implant as in the above study (the House implant, ref. /1/). The results show that "monosyllables containing high back syllable nuclei and, to a lesser degree, those containing high front syllable nuclei, can be distinguished from monosyllables containing low syllable nuclei".

White /4/ studied vowel discrimination by one subject using another type of intra-cochlear single-channel implant. He found a clear evidence that the subject used first formant information in discriminating between synthetic vowel pairs or identifying vowels in natural speech. However, he did not find any evidence that the subject could use information from the frequency of the second formant. That this to some extent is possible has been reported by the Vienna group /5/. The aim of the experiment described here is to shed more light on this problem.

METHOD

In the Swedish cochlear implant project, a single-channel implant developed in Vienna and manufactured by 3M in the USA is used /6/. The project is run at the Department of Audiology of the South Hospital (Södersjukhuset), Stockholm, in cooperation with our department. After implantation the subjects go through a longer, structured training and test program. Testing is made 1, 3, 6, 12, 24, and 36 months after surgery. In the test battery measurements of frequency and time discrimination and speech-perception ability with and without simultaneous lipreading are included. Here results on a vowel-identification experiment with three subjects is reported.

Subjects

Subject 1 was born in 1955. She had a progressive hearing loss that resulted in total deafness in 1981. She was implanted in 1984. She is an excellent lipreader and two years after implantation she had achieved some ability to understand speech without simultaneous lipreading.

Subject 2 was born in 1930. He become deaf in 1947 as a result of meningitis. He is a poor lipreader and has never used a hearing aid. He was implanted in 1984.

Subject 3 was born in 1932. He became deaf due to the effect of an ototoxic drug in 1977. He is a resonably good lipreader and uses a hearing aid in his left ear. His right ear was implanted in 1986.

Effect of training

Directly after implantation the subjects have great difficulties in using the information from the implant but this ability gradually develops. As an example, Fig. 1 shows frequency discrimination ability for a sinusoidal signal with the frequencies 125, 250, 500, 1000, and 2000. The figure shows the results for subject 2 at the test sessions 1, 3, 6, 12 and 24 months after implantation. From the beginning changes in frequency could only be detected for the lowest frequency, 125 Hz, but after 12 months, frequency discrimination ability was around 2-5 % for frequencies up to 1000 Hz. In the same way, the ability to identify speech sounds gradually improves.
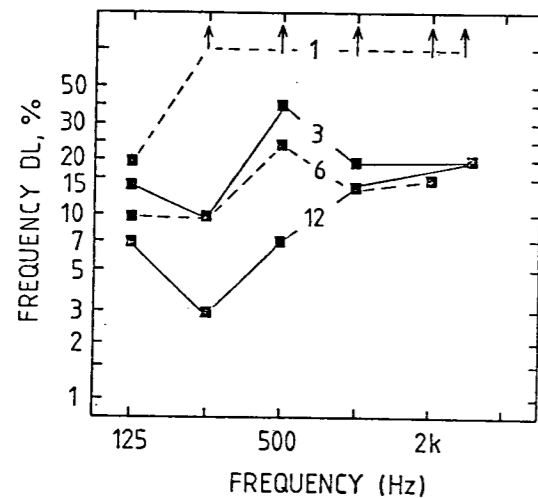

Fig. 1. Results from measurements of frequency discrimination ability for a sinusoidal signal by subject 2 at test sessions 1, 3, 6 and 12 months after implantation.

Test equipment and test procedure

In the experiment the text-to-speech equipment based on the OVE II synthesizer was used /7/. This is a cascade synthesizer with four-formant circuits. The frequency of the two lowest formants could be controlled by a joy-stick and at the same time the subjects could see the movements of the formants on an Fl-F2-display. No frequency calibration was given in the plot, and none of the subjects had any knowledge in acoustic phonetics. Formant three and four were set by the computer program at the frequencies that was typical for the intended vowel, see Table I. The test vowels were the long Swedish vowels in context /bV:b/. The formant frequencies of the nine vowels are shown in Table I. The fundamental frequency variation was the same for all vowels.

The cochlear implant was coupled to the synthesis equipment over the line input of the implant. It was explained to the subjects that they by moving the joy-stick were to locate a specific

vowel on the display. By pressing the space bar they could listen to the vowel in a /bv:b/ context. They were then allowed to play around with the joy-stick for some time. When we were sure that they had understood the task, one of the vowels was randomly selected and given in orthographic form in a syllable /bV:b/. The syllable was presented once with the formant frequencies of the vowel given in Table I. The subjects were then asked to adjust the joy-stick until they thought that the intended syllable was produced. Whenever they liked, they could listen to the synthetic syllable they had adjusted but they could not listen to the target syllable. They had to use their internal memory of the intended target.

Table I. Formant frequencies for the nine long Swedish vowels used in the experiment.

Vowel	Formant frequencies, Hz.			
	F1	F2	F3	F4
[ɑ:]	653	1000	2500	3200
[e:]	350	2200	2800	3450
[i:]	280	2200	3000	3700
[u:]	350	770	2800	3300
[ʉ:]	350	1750	2450	3150
[y:]	300	2000	2400	3400
[o:]	390	700	2400	3250
[ø:]	380	1750	2300	3350
[ε:]	450	1975	2550	3400

The matching for all nine long Swedish vowels presented in random order was made twice during each test session. The subjects were not told how well they had been able to adjust the formant frequencies of the intended vowel. For subjects 1 and 2 testing was made 12 and 24 months after surgery and for subject 3, three and 12 months after surgery. To get reference data five normal hearing subjects from our department were tested with the same program. They all had some knowledge in acoustics phonetics but as no frequency calibration was shown on the Fl-F2 plot, it was difficult for them to use previous knowledge. The same five subjects were used in a listening test where the task was to identify the vowels in the syllables produced by the implanted subjects.

RESULTS AND DISCUSSION

The results from the experiment are shown as gross confusion matrices for the three subjects in Fig. 2a-2f. In the matrices, the vowels are arranged after increasing Fl based on the means of the results from the normal hearing subjects. The submatrices for vowels with about the same Fl are indicated. In Fig. 3a-3d the Fl-F2-plots for subjects 1 and 3 are shown and the area where the normal hearing subjects placed their vowels is indicated.

A clear improvement over time can be seen especially in the results for subjects 1 and 3, see Fig. 3. This does not result in an increase in per cent correct identified vowels in the listening test with normal hearing persons. Three months after implantation subject 3 has almost no ability to identify the vowels but one year after implantation he makes clear differences in adjusting the formant frequencies but most of them are
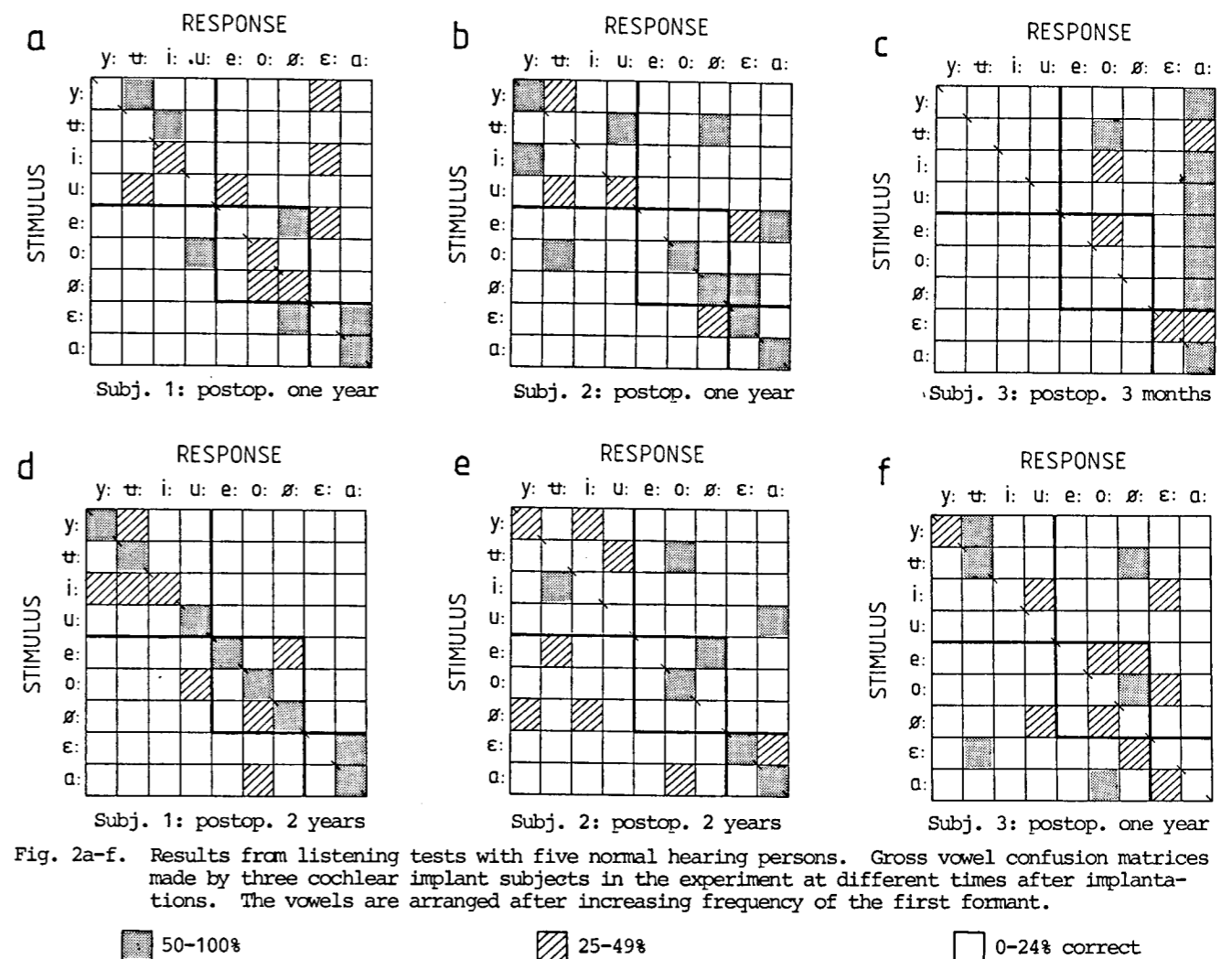

Fig. 2a-f. Results from listening tests with five normal hearing persons. Gross vowel confusion matrices made by three cochlear implant subjects in the experiment at different times after implantations. The vowels are arranged after increasing frequency of the first formant.

still far away from the correct values. Three months after implantation 17.4% of his vowels were correctly identified in the experiment and 12 months after implantation 9.6% was correctly identified. Fig. 2f and Fig. 3d, however, show that he adjusts the frequency of the first formant close to the correct value.

The results of subject 1 are good 12 months after implantation and are improving one year later. It is clear that she uses F2-information in finding the vowel on the display, see the vowels /i:/ and /y:/ in Fig 2a. All F2-values for these vowels are placed at high frequencies. For one /i:/- and one /y:/-vowel, however, Fl is placed too high. In the experiment three years after implantation almost all vowels are placed close to the correct targets.

Subject 2 has limited ability to perceive vowel information and he does not show any improvement in the experiment two years after implantation.

With subjects 1 and 2 a simple pitch-scaling experiment has been made. Subject 1 can scale pitch up to 2000 Hz but subject 2 only up to about 700 Hz.

It is apparent that a single-channel cochlear implant presents the central processor with an abnormal pattern of the acoustic signal. Timing information is reasonable well preserved but frequency information is very different from normal. From the beginning the subjects have great difficulties in interpreting the information but through learning they gradually improve their ability. Variations are, however, great between the subjects.
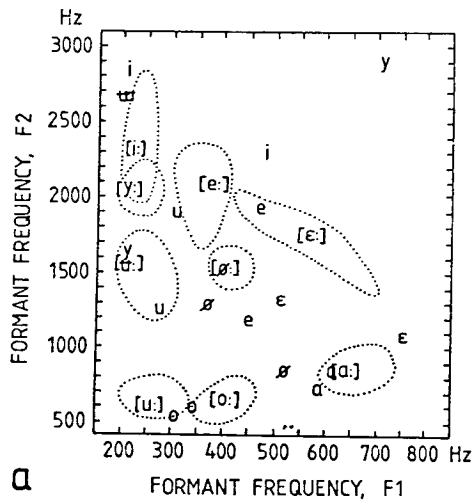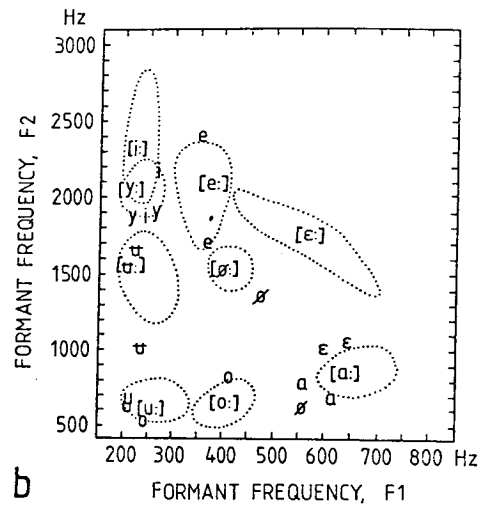
Fig. 3a. Subject 1: postop. one year

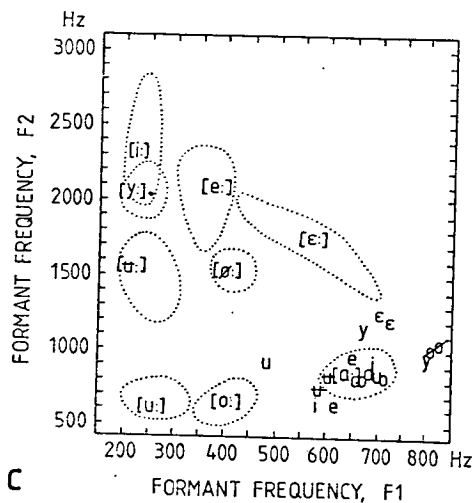Fig. 3b. Subject 1: postop. two years

Fig. 3c. Subject 3: postop. three months
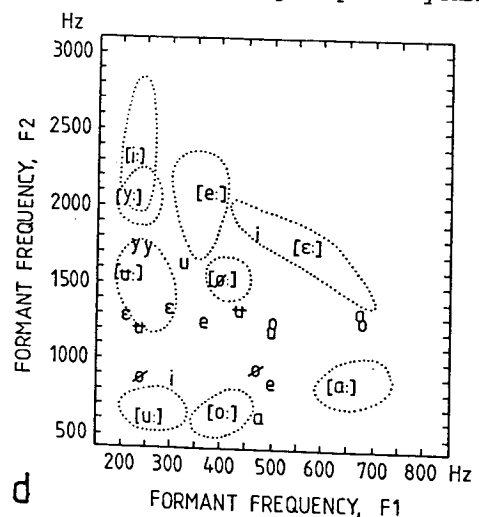The normal hearing subjects' mean values are placed within square brackets.

Fig. 3d. Subject 3: postop. one year

REFERENCES

/1/ W.F. House, "Cochlear implants", Ann. of Otology, Rhinology and Laryngology, Suppl 27, 85, No 3:2, 1983.

/2/ K.J. Doyle, J.L. Danhauer, B.J. Edgerton, "Vowel perception: Experiments with a single-electrode cochlear implant", J Speech and Hearing Res., 29, 179-192, 1986.

/3/ L.J. Dent, "Vowel discrimination with the single-electrode cochlear implant: A pilot study", Ann. of Otology, Rhinology and Laryngology, Suppl 91, 91, No 2:3, 41-46, 1982.

/4/ M.W. White, "Formant frequency discrimination and recognition in subjects implanted with intracochlear stimulating electrodes". In C.W. Parkins and S.W. Anderson (Eds.), Cochlear protheses: An Internat. Symp. Annals of the New York Academy of Sciences, 405, 348-359, 1983.

/5/ E.L. v. Wallenberg, I.J. Hochmair-Desoyer, E.S. Hochmair, "Speech processing for cochlear implants", Proc. Seventh Annual Conference of the IEEE/Engineering in Medicine and Biology Society, Chicago, 1114-1118, 1985.

/6/ I.J. Hochmair-Desoyer, E.S. Hochmair, K. Burian, R.E. Fischer, "Four years of experience with cochlear prostheses". Medical Progress through Technology 8, 107-119, 1981.

/7/ R. Carlson, B. Granström, "Linguistic processing in the KTH multilingual text-to-speech system", Conf. Record, IEEE-ICASSP, Tokyo.

× × × × ×

184

Se 66.3.4