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Acoustic Analysis of Vowels in Adolescents with Profound Hearing Impairments

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The purpose of the present study was to analyze the characteristics of the speech of adolescents with profound hearing impairments. Three vowels (/a/, /i/, /u/) were recorded from a group of seven hearing impaired and three normal hearing adolescents. Samples were analyzed by the speech analyzing system: TSUKUBA-FM (DANAC 7000, B/K 2032, HP216, HP2671G). From the results of this study, the following finding were observed. 1) the hearing impaired speaker tended to produce three vowels approaching the pattern for the neutral vowel, 2) the amount of overlap of the formant frequencies were typically much greater, 3) the distribution of the formant frequencies in the hearing impaired deviated from the normal range, 4) the third formant and the fourth formant of the hearing impared were lower than those of the normal hearing. The results can be used for planning programs for their speech therapy in the hearing impaired.

Key Words：formant　Vowel　Acoustic Analysis　hearing impaired

Introduction

There have been several studies that have examined the acoustic characteristics of vowels produced by the hearing impaired speakers using spectrographic analysis (Angelocci et al., 1964; Monsen, 1974, 1978). Accurate control of vowel articulation by the hearing impaired speakers has been shown to be correlated with the intelligibility of the speech they produce (Monsen, 1976). Good vowel articulation is important in the speech. Vowels convey to the listener important information about the identity of adjacent consonants and they bear prosodic information (Monsen and Shaughnessy, 1978). However, the learning to articulate vowels correctly is difficult for many profoundly hearing impaired speakers because the appropriate articulatory configuration for individual vowels cannot be learned through audition, as it can be by the normal hearing. In learning the correct articulation of phonemes, the profoundly hearing impaired depend on visual and vibrotactile cues, which are often insufficient. And the primary articulator of vowels, the tongue, is usually hidden from the learner's views.

The important acoustic characteristic of vowel sounds is the formant frequency. The formant frequencies, especially the first (F1) and the second (F2) formants, are traditionally used to provide an acoustic description of vowels. Usually, these formant values are plotted against each other and the data points for each vowel cluster into fairly distinctive regions (Peterson and Barney, 1952). Interestingly, the acoustic vowel plot of the first formant and the second formant closely resembles the articulatory vowel space.

The study was designed to measure the nature and extent of differences of the first four formant frequencies, especially the third and fourth formants, between the hearing impaired

Table 1. Hearing level (dB)

S	SEX	AGE	MEAN	125	250	500	1000	2000	4000	8000 (Hz)
1.	F	17	R 104	70	75	115	110	110	125	NR
			L 111	75	95	105	115	110	130	NR
2.	F	17	R 99	90	100	90	110	105	90	115
			L 106	90	95	95	95	120	125	NR
3.	F	18	R 103	80	75	85	105	115	120	NR
			L 106	85	80	90	110	115	125	NR
4.	F	18	R 118	65	90	110	120	120	115	125
			L 124	80	105	120	125	125	120	NR
5.	F	18	R 104	NR	95	95	105	110	115	120
			L 104	85	95	95	105	110	110	NR
6.	F	18	R 100	75	75	90	100	110	110	NR
			L 98	65	75	90	95	110	115	110
7.	F	19	R 99	80	75	80	100	115	110	110
			L 104	70	75	85	105	110	110	110

and normal hearing speakers.

Method

1 . Subjects

Seven female hearing impaired and three female normal hearing adolescents participated as subjects. The hearing impaired subjects were selected from among the population at the T. Rehabiritaion Center. Normal hearing subjects were all judged to be free of any speech disorder. Each subject's age, sex, and hearing level in the better ear are presented in Table 1.

2 . Materials

The testing materials were three vowels (/a/, /i/, /u/). Three Japanese vowels (/a/, /i/, /u/) representing the broad outline of the vowel triangle were selected to be measured. Each subject was then instructed to sustain the vowels at a comfortable pitch.

3 . Measurements

Recording were made of each subject pronouncing these vowels. A microphone (SONY ECM290E) was placed about 15 centimeters from the subject's mouth, and recordings were made in a quiet room on the tape recorder (SONY SL-B5, SONY PCM-F1). Fig. 1 shows the blockdiagram.

Spectral analysis of the collected data was made on the speech analyzing system: TSUKUBA-FM (DANAC 7000, B/K 2032, HP216, HP2671G). The analysis parameters were as follows; frequency span 6.4kHz, record length 125ms, sampling interval 61.0μs, weighting hanning, averaging overlap 75% (Table 2). Formant frequencies were made in the steady-state portion of the vowel as near as possible to

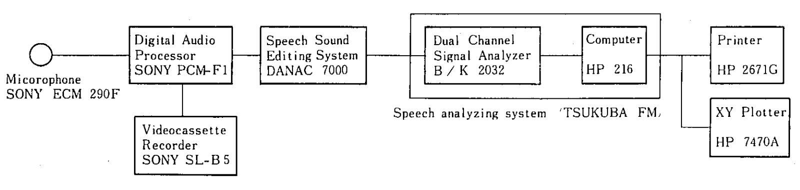

Fig. 1 Blockdiagram

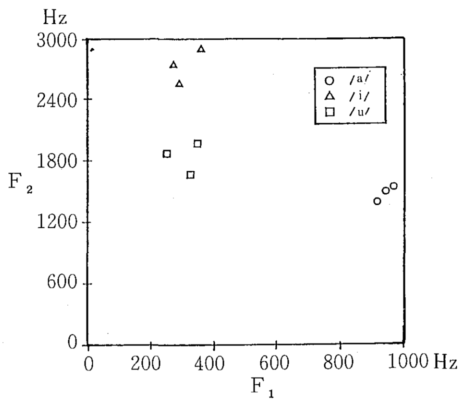

Fig. 2-1 Formant frequency values (F1-F2 diagram, Normal)

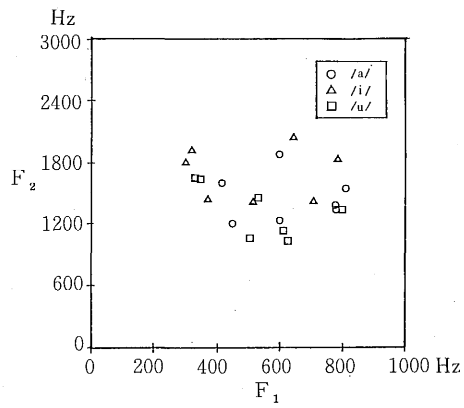

Fig. 2-2 Formant frequency values (F1-F2 diagram, Hearing-impaired)

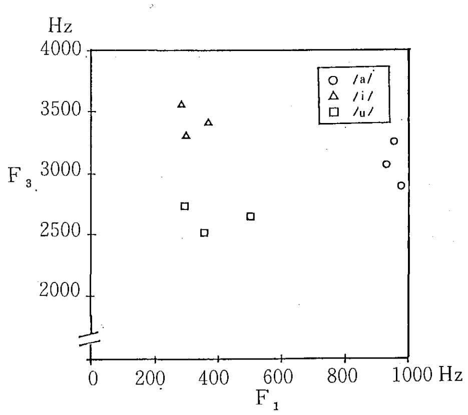

Fig. 3-1 Formant frequency values (F1-F3 diagram, Normal)

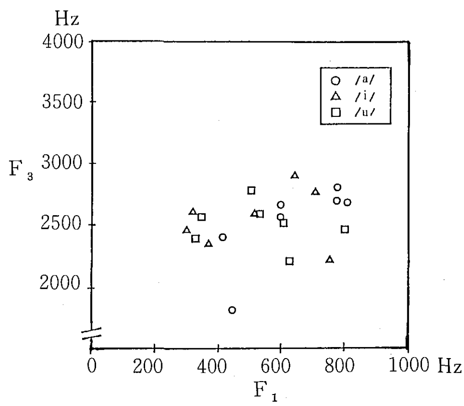

Fig. 3-2 Formant frequency values (F1-F3 diagram, Hearing-impaired)

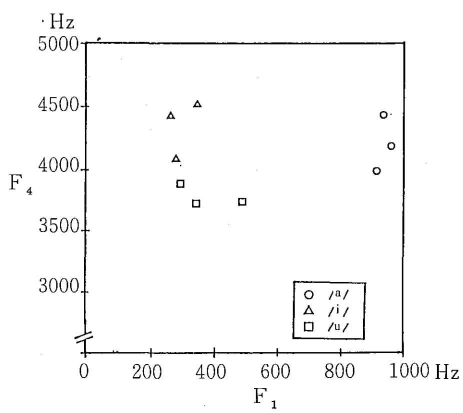

Fig. 4-1 Formant frequency values (F1-F4 diagram, Normal)

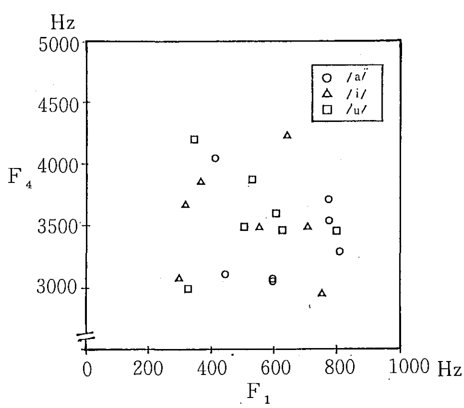

Fig. 4-2 Formant frequency values (F1-F4 diagram, Hearing-impaired)

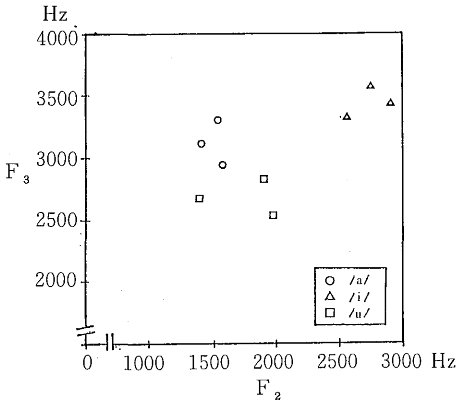

Fig. 5-1 Formant frequency values (F2-F3 diagram, Normal)

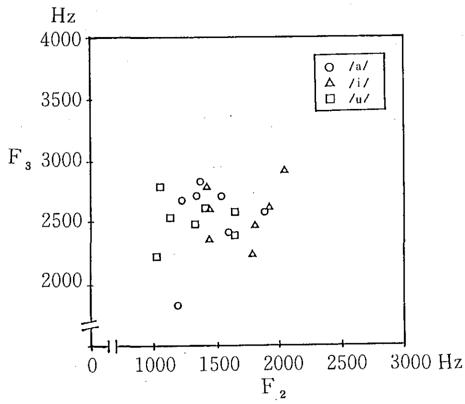

Fig. 5-2 Formant frequency values (F2-F3 diagram, Hearing-impaired)

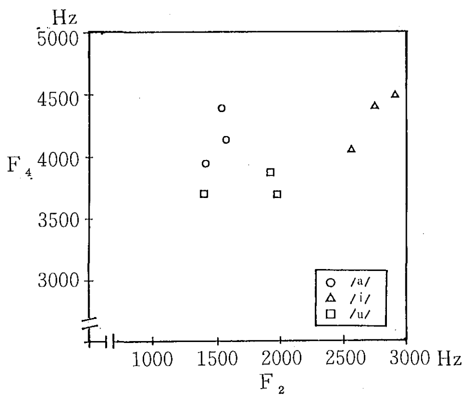

Fig. 6-1 Formant frequency values (F2-F4 diagram, Normal)

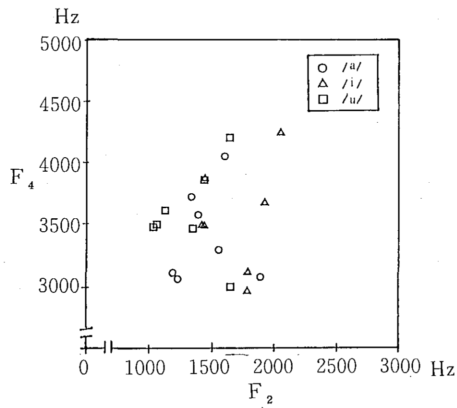

Fig. 6-2 Formant frequency values (F2-F4 diagram, Hearing-impaired)

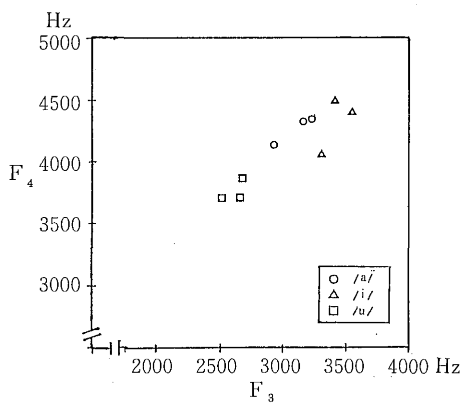

Fig. 7-1 Formant frequency values (F3-F4 diagram, Normal)

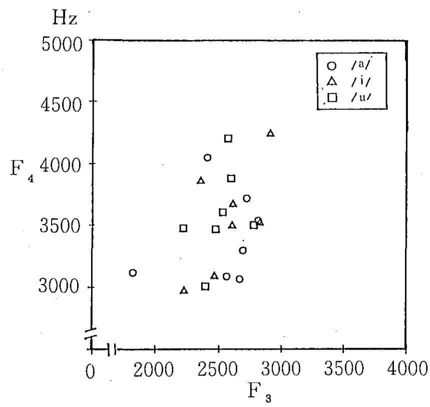

Fig. 7-2 Formant frequency values (F3-F4 diagram, Hearing-impaired)

Table 2. Analysis parameters

Frequency Span	6.4kHz
Record Length	125ms
Sampling Interval	61.0μs
Weighting	Hanning
Averaging	75%

the middle of the vowels.

The data on the formanat frequencies were obtained by a liftered spectrum analysis on a computer (B/K 2032, HP216). Acoustic parameters were the first four formants. There were the first, the second, the third, and the fourth formant frequencies. Measurements of the formant frequencies were made for the three vowels recorded by each of the subjects.

Results

The intent of this study was to compare the hearing impaired speakers with normal speakers. The data for the frequencies of the first four formants of three vowels are shown in Fig. 2 to Fig. 7. These figures indicate the dimensions of vowel space. Figures are indicated in two respects: the amount of overlap in the frequency values for individual vowels, and the range of variation of the formants. Each of the four formant frequencies for each of the three vowels was plotted in this way. It is clear that here the vowels may be separated in normal hearing subjects, simply by plotting the second formant against the first formant (F1-F2 diagram). Points for each vowel lie in isolated areas, whis no overlapping of adjacent areas. For the hearing impaired subjects, considerable overlapping of areas is indicated, particularly between /i/ and /a/, /u/ and /a/. It can be seen in these figures that the hearing impaired differed in their ability to produce these vowel sounds. The vowel/i/ in the hearing impaired had much more restricted range of the first and second formants than did normal hearing. For example, the hearing impaired the vowel /i/ whth formant frequencies very near to those of the vowel /a/ or /u/ whth formant frequencies. These three vowels were not much more adequately separated.

As seen in Fig. 2 to Fig. 7, the first formant range in the hearing impaired was 570 Hz (from 230 to 800 Hz), and in normal hearing subjects was 800 Hz (from 200 to 1000 Hz). The second formant range was 1100 Hz in the hearing impaired and 1700 Hz in the normal hearing. The third formant range was 1300 Hz in the hearing impaired and 1200 Hz in normal hearing. The fourth formant was 1500 Hz in hearing impaired and 800 Hz in normal hearing.

These differences may be observed in the formant frequencies given on Fig. 2. The first formants for the hearing impaired in vowel /i/ and /u/ are seem to be higher than those of the normal hearing speakers. And the second formant for the hearing impaired in vowel /i/ and /u/ are lower than those of the normal hearing. As seen in Fig. 7, the third and fourth formants are also appreciably lower in the hearing impaired subjects and the values for the third formant and the fourth formant have large variations between individuals.

Discussion

Traditional classifications for vowels employ such categories as tongue position (high-low, front-back), and degree of lip rounding. These refer to articulatory events and are important to our discussion of the acoustic characteristics of vowels. In general, the hearing impaired speakers have been found to produce back vowels correctly more often than front vowels (Boone, 1966; Geffner, 1980; Mangan, 1961; Smith, 1975) and low vowels correctly more often than those with mid or high tongue positions (Geffner, 1980; Smith, 1975).

The most important acoustic characteristic of vowel sounds is the frequency of the first and second formants. In the formant frequency measurements of the speech of the normal hearing, each vowel has a characteristic range for the frequency of the first formant and the second formant (Peterson and Barney, 1952). However, individual vowels are not identifiable with absolute frequency values for the first and second formants, because they are dependent on the size of the speker's vocal tract and thus must vary depending on the speaker's age and sex. The formants of children are higher than those of female adults, female adults are higher than those of male adults. The subjects population of this study included only females and these subjects spanned early adolescences.

An interesting propety of the frequency articulatory plots of the first formant versus the second formant is that the diagram so closely resembles the articulatory plot of vowels used by phoneticians. The vowel /i/ has the highest second formant and the lowest first formant. The vowel /o/ has the lowest second formant and /a/ has the the highest first formant. When the hearing impaired speakers produce vowels poorly, the phonological space defined by the maximum and minimum frequencies of the first two formants is small, the third and fourth formant frequencies and lower than those of the normal hearing. The vowel triangle appeares to be collapsed, and the auditory impression created by the vowel sounds tends overwhelmingly to be that of a neutral, indistinct schwa.

In the speech of the normal hearing subjects, these is usually some amount of overlap in the formant frequencies of adjacent vowels. But for the hearing impaired, the amount of overlap is typically much greater, and the range of the frequencies of both the first formant and the second formant is less (Angelocci et al., 1964; Monsen, 1976). The consequence of the restricted range of formant frequencies in the speech of the hearing impaired speakers is that vowels tend to be heard incorreclty. All vowels will tend to be perceived as a neutral, indistinct schwa. The articulatory source of restricted formant frequency movement is insufficient and inappropiate positioning of the tongue, protrusion of the lips, or opening of the mouth.

Finally, in suprasegmental level, an often noted characteristic of the speech of the hearing impaired is an abnormal control over duration and fundamental frequency (Ando and Canter, 1969; Brannon, 1966; Kato et al., 1987a; Kato et al. 1987b; Kato and Yoshino, 1989a, 1989b; Yoshino, 1985, 1987). In particular, the duration of words or sentences often seems excessively long, and the pitch contour over individual words is either too high, too monotonal.

This study suggests that the hearing impaired speaker tends to produce all vowels approaching the pattern for the neutral vowel. This error has implications at the segmental as well at the suprasegmental level.

Conclusion

In this study, the production of the three vowels were examined spectrographically in the speech production. That is, acoustic analysis was carried out on the speech of the normal hearing and the hearing impaired speakers.

The results were as follows. In the speech of the subjects with hearing impairments, the second formant were reduced in frequency and range. Dimineshed formant frequency were very noticeable in the speech of the subjects with hearing impairments. Second formant frequency of the vowel /i/ was typically lower in the subjects with hearing impairments, compared to those without impairments. In the hearing impaired speakers, the values for the third and fourth formant have large variations between individuals and also lower than those of normal hearing.

The data from this study are interpreted to suggest that the hearing impaired speakers use a estricted amount of tongue movement to achieve vowel differentiation. We have suggested that differences in vowels produced by hearing impaired speakers are achieved primarily by means of variation in the formant frequencies (F1, F2, F3, F4).

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