FORMANT ANALYSIS OF DUTCH VOWELS FROM 10 CHILDREN

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INTRODUCTION.

As part of a larger study on speaker normalization, formants have been measured of twelve Dutch vowels / u, y, a, ɑ, ɛ, œ, e, i, I, o, ɔ, ø/ spoken by 10 Dutch children.
In the past, studies have been made of the formant frequencies of the Dutch vowels as spoken by males and females, e.g. Pols et al. (1973), Klein et al. (1973), Koopmans-van Beinum (1973), but no data on Dutch children have been available. This study tries to fill the gap.

SPEECH MATERIAL.

The group of children whose vowels have been measured consisted of 5 boys and 5 girls; the mean age was 9 years, the youngest was 8 and the oldest 10 years old at the time of the recordings. This group was carefully selected on their ability to speak the standard Dutch language without dialect influences. Recordings were made in an anechoic room with a Sennheiser MD421N microphone and a Revox A77 taperecorder. These recordings consisted of series of sentences of the form "V van pVt" (V from pVt) where V is one of the twelve vowels listed above. The sentences were read from paper with normal intonation by the children, each sentence was at least spoken twice. During the recordings there was always a person familiar to the child present in the recording room for reassurance. Sentences were repeated untill they were correctly spoken but in general the children made few mistakes and hardly any extra repetitions were necessary.
The sentences on tape were digitized with a sample frequency of 10 kHz and 12 bits/sample.

FORMANT MEASUREMENT.

All formant frequencies were measured in a stable segment within the first 100 ms of the first vowel of each sentence "V van pVt". The segments were selected with a speech editing program.

The main difficulty in measuring children's formants is the very high pitch of these signals. For our group of 10 children the mean pitch of all the segments we measured was approximately 320 Hz. The mean pitch for the five boys was 323 Hz and for the 5 girls, 318 Hz. Consequently one period of a child's vowel lasts about 3 ms and in the frequency domain the harmonic spacing is about 320 Hz. This is very unfavourable compared to the 7 to 8 ms duration of a male pitch period and the harmonic spacing in the frequency domain of about 135 Hz. From the children's FFT-spectra it is nearly impossible to measure formants by simple harmonic interpolation. Therefore we decided to use linear prediction analysis (LP-analysis) to do part of the job and experimenter intervention where LP should fail. The analysis was done by a computer program and figure 1 shows the procedure followed. Starting with a signal segment of 25.6 ms from the stable part of the vowel, a LP-analysis with order 10 is done (step 1). The roots of the LP-polynomial are solved and formant-bandwidth pairs are calculated (step 2). In step 3 a very rough test is done on each formant-bandwidth pair: the formant's bandwidth should be less than 1000 Hz and it's Q-factor should be greater than 1 (Q equals the frequency of a formant divided by its bandwidth). After this stage the position of the accepted formants is displayed on a graphics screen together with the segments' cepstrally smoothed FFT-spectrum. Optionally the LP-spectrum and the FFT-spectrum can be displayed as well and there is a possibility to resynthesize the analysed segment with either the LP-coefficients or the accepted formants.

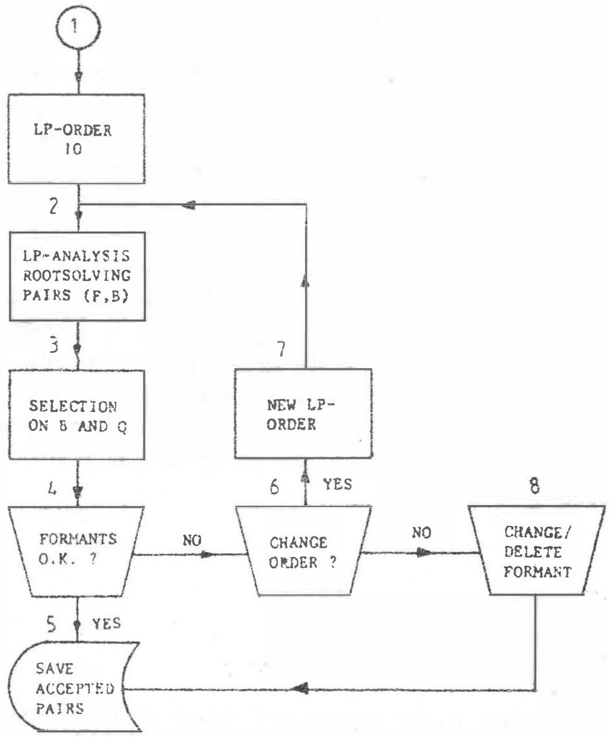

Fig. 1 Formant extraction procedure. Step numbers are explained in the text.

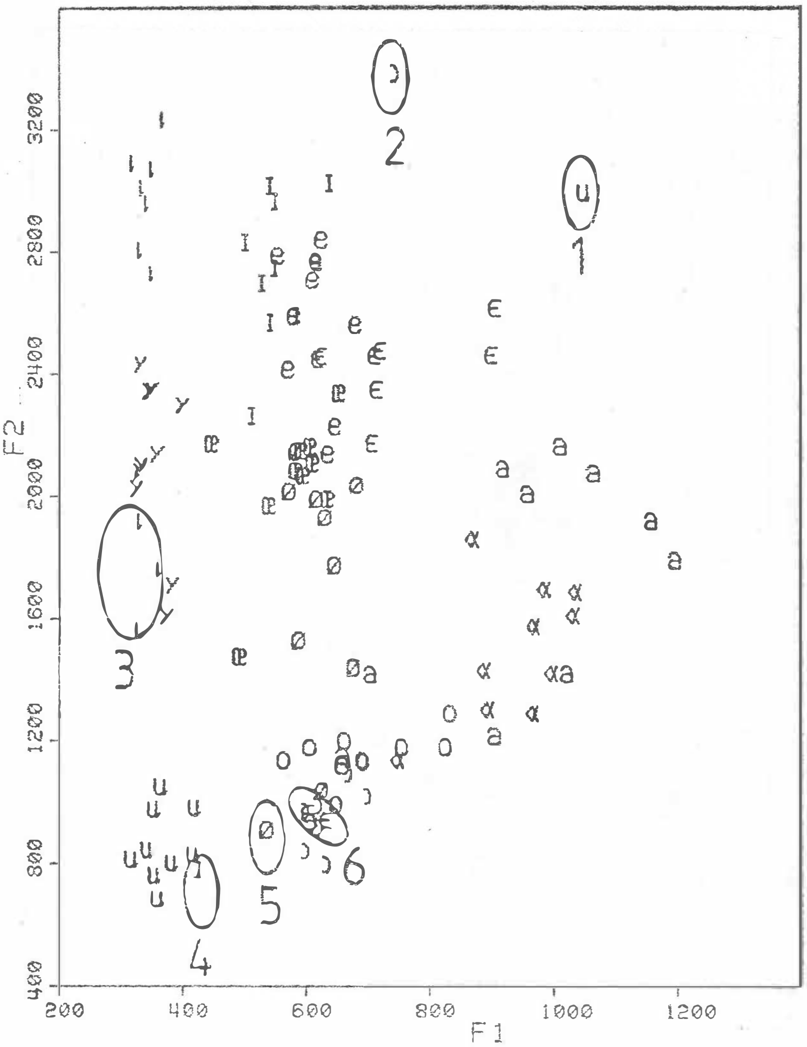

Fig. 2 First formant vs. second. Automatic run with LP-order 10. Numbers are explained in the text.

On the basis of the display and/or the resynthesis, the experimenter can decide to accept or reject the calculated formants (step 4). This is the critical stage in the measuring process because it is now that the phonetic knowledge of the experimenter comes into play, as e.g. his information about the identity of the measured sound signal. This knowledge is absolutely necessary to decide correctly whether the calculated formants are the "good" ones or not. To illustrate this point we did an automatic run with order 10, to calculate the formants of the children's vowels without experimenter intervention. These automatically measured formant values are shown in figure 2. At first glance the results of the automatic calculation don't look bad at all but closer inspection reveals considerable errors, especially if we compare the results with figure 3 where the formants are shown as measured with experimenter intervention.

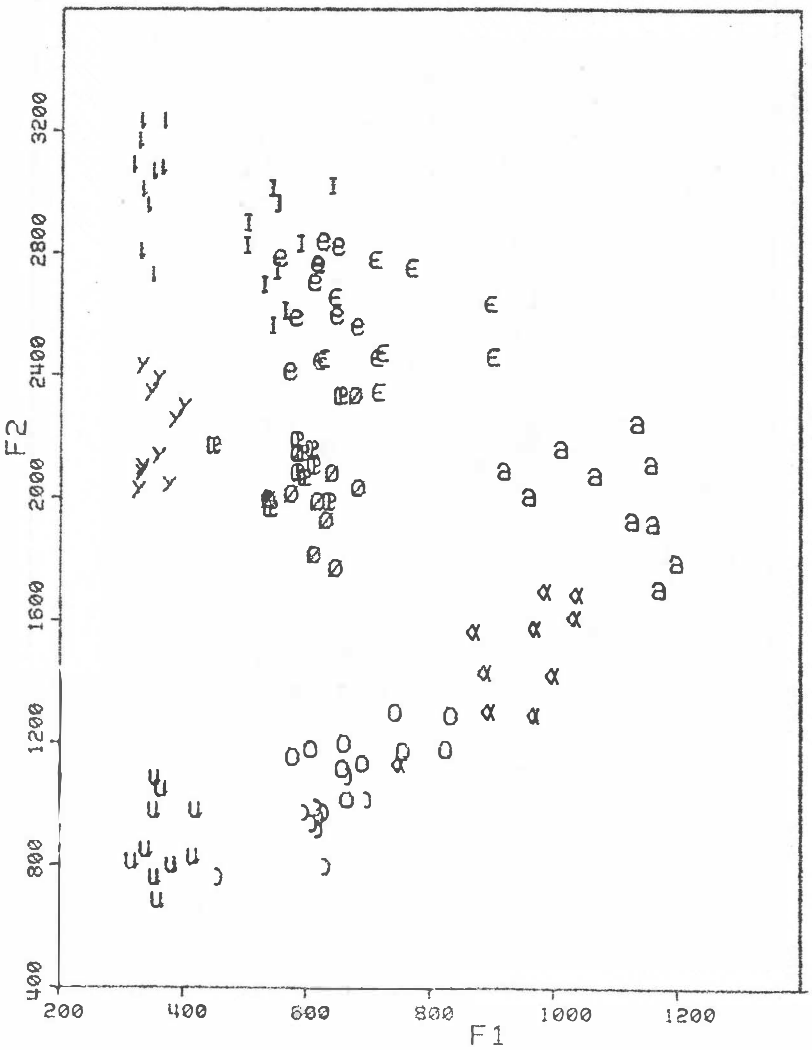

Fig. 3 First formant vs. second. Measurements with experimenter intervention.

Some typical mistakes in figure 2 are:
- first formant is absent (e.g. u-1, ɔ-2),
- extra formant (e.g. the i-3 cluster),
- in a restricted frequency region two formants are found instead of one (e.g. I-4, ø-5 and ɛ-6 cluster),
- the clustering per vowel is not done well.

An automatic run with LP-order 8 gave better results but still the results are inferior to the measurements with experimenter intervention (figure 3). At step 4 in figure 1 we had two possibilities: we could make the program interactive and let the experimenter decide what to do with the measurement, or we could refine the decision algorithms so that the measurement would run automaticly in a perfect way.

The more the decision algorithms are to be refined the more knowledge is needed to implement them. With our present knowledge we were not able to design a fully automatic procedure. Therefore the analysis program was made interactive in such a way that the experimenter could change the order of the LP-analysis (step 7) or reposition and delete formants (step 8) if he decided not to accept the measurement. As can be seen from figure 3, in which the results of the interactive analysis are shown, a very good clustering per vowel is achieved. The mean values for the formant frequencies of each vowel are given in table I, together with their standard deviations. A comparison between the mean formant values of the 5 boys and the values of the 5 girls did not show any significant differences.
In the formant-plane of figure 4 we have graphically displayed the mean formant values for each vowel from the 10 children together with the mean formant values from 6 adult males and 6 adult females that we measured in an analogous way. The average formant frequencies of these males and females can be found in tables II and III respectively together with average formant frequencies from other studies: for males the studies of Govaerts (1974), Pols et al. (1973) and Koopmans- van Beinum (1973) for females the studies of Nierop et al. (1973) and Koopmans- van Beinum (1973). Our data are in agreement with the data from the cited studies accept for the relative positioning of /o/ and /ɔ/ in the formant plane. Contrary to the data of the cited studies we found the /o/ lying closer to the /ɑ/ and the /ɔ/ closer to the /u/. A check on the formants of /o/ and /ɔ/ in /p-t/ context confirmed our relative positioning.
As can be seen from figure 4 the mean formant values for a given vowel from the males, females and children lie on an approximately straight line through the origin which strongly suggests linear scaling. This implies that vocal tract length differences could explain much of the differences between the positions of the vowels in the formant plane for males, females and children. The difference between the male-female position is somewhat smaller than between the female-child position.

CONCLUSION.

Formant frequencies have been measured for all twelve Dutch vowels as spoken by ten children, 5 boys and 5 girls. Comparison of the mean formant values per vowel from these children with the mean formant values of male and female speakers suggests linear scaling. No significant differences could be found between the mean formant positions for each vowel from boys and girls.

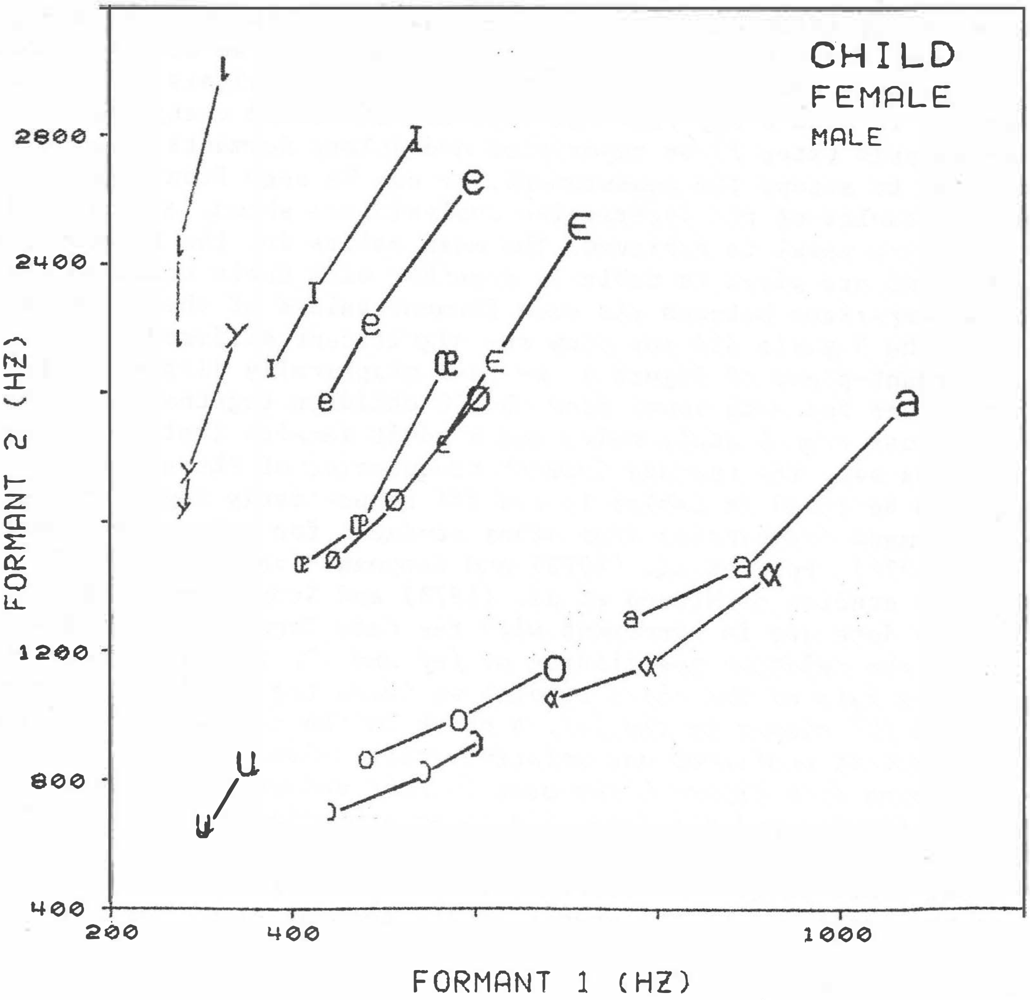

Fig. 4 Relative positioning of formants from children, female and male speakers.

Table I. Mean formant positions with standard deviations of 10 children. Data are in Hz.

vowel	F1	sigma	F2	sigma	F3	sigma
u	365	30	883	126	3308	405
y	353	24	2211	143	3061	120
a	1085	91	2006	160	3168	222
ɑ	935	84	1474	178	2975	387
ɛ	728	95	2551	140	3581	195
œ	582	54	2123	101	3185	187
e	612	36	2686	130	3448	305
i	338	16	3039	160	3735	213
I	549	38	2820	153	3599	206
o	700	81	1176	77	3212	268
ɔ	614	60	942	94	3259	283
ø	617	43	2013	152	3219	216

Table II. Average formant frequencies of Dutch vowels pronounced by male speakers.

	Govaerts		Pols et al.		Koopmans-van Beinum		Weenink	
vowel	F1	F2	F1	F2	F1	F2	F1	F2
u	290	720	339	810	334	813	311	664
y	275	1775	305	1730	308	1819	290	1654
a	890	1360	795	1301	738	1409	779	1320
ɑ	770	1160	679	1051	639	1292	691	1070
ɛ	590	1695	583	1725	618	1877	574	1857
œ	325	1640	438	1498	438	1596	419	1489
e	390	2170	407	2017	403	2218	445	1992
i	225	2280	294	2208	306	2494	283	2187
I	320	2000	388	2003	374	2196	386	2098
o	420	815	487	911	464	899	489	880
ɔ	540	875	523	866	538	928	452	720
ø	413	1500	443	1497	406	1650	453	1503

Table III. Average formant frequencies of Dutch vowels pronounced by female speakers.

	Nierop et al.		Koopmans-van Beinum		Weenink	
vowel	F1	F2	F1	F2	F1	F2
u	320	842	403	851	315	686
y	288	1832	371	2064	297	1774
a	986	1443	855	1439	902	1491
ɑ	762	1117	757	1277	799	1182
ɛ	669	1905	753	2231	633	2122
œ	490	1688	488	1788	484	1616
e	471	2352	475	2527	497	2237
i	276	2510	376	2734	287	2480
I	465	2262	448	2594	435	2338
o	505	961	505	926	592	1007
ɔ	578	933	605	995	555	847
ø	476	1690	495	1914	523	1692

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