ARIPUC No. 1/1966

ANNUAL REPORT
OF THE
INSTITUTE OF PHONETICS
UNIVERSITY OF COPENHAGEN

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Copenhagen, 1967

P R E F A C E

This is the first number of a planned series of annual reports from the Institute of Phonetics at the University of Copenhagen. In the future we hope to send out a report each year in February covering the preceding calendar year. This first report, however, covers not only the year 1966, but also work done in earlier years by the staff members.

The Institute of Phonetics did not come into existence as an independent institute until December 1966, and the Laboratory for Experimental Phonetics was inaugurated about the same time. The present report thus comprises what may be called the "prehistoric period" of our Institute.

The reports will contain brief surveys of the courses given in the preceding year, and longer surveys of the research undertaken, in so far as it has reached a certain degree of completion. Work in progress which has not yet given clear results will be mentioned more briefly. Papers already printed elsewhere will only be mentioned in the list of publications, except when they have been published in Danish, in which case a short summary is given.

This first report contains a general introduction about the conditions of phonetic studies at the University of Copenhagen, and a survey of our instrumentation. In later reports only instruments purchased or built in the preceding year will be included.

Eli Fischer-Jørgensen

CONTENTS.

PERSONNEL OF THE INSTITUTE OF PHONETICS
1966.

Permanent Staff:

Eli Fischer-Jørgensen (professor, director of the Institute)
Jørgen Rischel (amanuensis*) of general phonetics)
Hans Peter Jørgensen (amanuensis of general phonetics)
Oluf M. Thorsen (amanuensis of general phonetics)
Børge Frøkjær-Jensen (amanuensis of general phonetics)
Svend Lystlund (technician)
Inger Østergaard (secretary)

Part Time Teachers of General Phonetics:

Mogens Baumann Larsen (amanuensis of Danish phonetics)
Børge Spang-Thomsen (amanuensis of French phonetics)
Niels Knudsen (lecturer of German phonetics)
Wilfred Schuhmacher (teaching assistant)

Guest Research Workers:

Radhekant Dave (India)
Ved Kumari Ghai (India)
Hideo Mase (Japan)

*) An "amanuensis" is a permanent assiatant, normally attached to an institute, more or less corresponding to an assistant professor in American universities.

I N T R O D U C T I O N

The Conditions of Phonetic Studies at the University of Copenhagen - a Historical Sketch.

A. Teaching.

The teaching of phonetics has a long tradition at the University of Copenhagen. Vilhelm Thomsen lectured on general phonetics from 1881, and Otto Jespersen continued these lectures in 1895. In the same year Jespersen started lecturing on English phonetics. French phonetics had been taught already from 189o by Kristoffer Nyrup, and in the following decades, primarily due to the influence of Otto Jespersen, special courses in the phonetics of other languages were introduced. Thus, for the last 4o - 5o years courses in the phonetics of the particular languages have been given regularly to all students of Danish, English, German, and French, and phonetic knowledge has been required for the exams.

The courses in the phonetics of individual languages included also an introduction to general phonetics, and from 19o5 to 1939 no separate courses of general phonetics were given. In the year 1939, however, Louis Hjelmslev started again a separate course in general phonetics, and from 1943, when a lectureship of phonetics was established, these courses were given every year. In the beginning they were attended by a modest number of students, but the number of participants increased gradually, and now almost all students of foreign languages (approximately 5oo a year) take a course in general phonetics, normally in their first term. The course comprises 3o hours in all. The students are divided into groups of about 25, and taught by the staff members of our present institute. (For students of Danish the general phonetics is incorporated in the course in Danish phonetics.)

The course in general phonetics is followed by courses (1-2 terms) in the phonetics of particular languages. These courses are administered by the various language departments (in continuation of the older tradition) and not by the Institute of Phonetics, but there is normally a close cooperation between the teachers of specific and general phonetics, and several of the teachers have had a training in general phonetics.

In addition to the elementary course in general phonetics intended for all students of foreign languages, special courses for advanced students have been given since 1943. These courses were, for instance, attended by those who had chosen a phonetic subject for their MA thesis. Since 1960 a so-called cand.art. degree in phonetics was established. The preparation for this degree is planned to take two years of full time study. Four candidates have passed this exam up till now, and ten are preparing for it. - It is now (since January 1967) also possible to take an MA in phonetics. The study for this degree will take approximately six years.

The regular courses for the cand.art.-students now comprise (i) phonemics (ii) practical training in sound perception and production, and phonetic transcription, (iii) experimental phonetics. Each of these courses comprises three terms with two hours weekly. Moreover there is a two-term course in statistics, and various more occasional supplementary phonetic courses. Moreover there are seminars for postgraduate and advanced students.

From 1943 to 1953 all instruction in elementary and advanced phonetics was given by the lecturer in phonetics. From 1953 practical training lessons for beginners were given by teaching assistants (paid by the hour). In 1958 these assistants took over all instruction for beginners. It was not until 1963 that another permanent post was established. Further posts were obtained in 1965 and 1966. In 1966 a chair of phonetics was founded.

B. Research Possibilities.

The first vowel synthesizer was built in Copenhagen as early as 1781 by C.G.Kratzenstein, but it was not until nearly two centuries later that the University obtained a first grant for phonetic instruments. In the meantime some experimental work had been started more privately. The well-known comparatist Karl Verner made some acoustic vowel investigations in the eighties of the last century, and at the same time Georg Forchhammer worked with a phonoscope. - But Otto Jespersen was not interested in instrumental phonetics (although he worked for a time with Rousselot), and this was probably the main reason why the University did not obtain a phonetics laboratory. In the early thirties of this century Poul Andersen and Svend Smith received a grant from the Carlsberg Foundation for a kymograph and a Meyer-Schneider pitchmeter, and for a short period of time these instruments were placed in the University.

In 1933 a "room for phonetic exercises", later called "phonetic laboratory", was established at the University under the direction of professor W. Thalbitzer and from 1939 under the direction of professor Louis Hjelmslev. This, however, was not a laboratory for instrumental research, but simply a small room equipped with a grammophone, a collection of records, and a few books. An application for a real phoneticslaboratory was sent in by professor Hjelmslev in 1939, and again in 194o, without any result. In 1956 an Institute of Linguistics and Phonetics was established with professor Hjelmslev as a director. The classrooms of the institute were equipped with tape recorders and grammophones, and there was a special room where 8 students could listen to records or tapes by means of headphones. - Instrumental phonetic research had, however, to take place in other institutions. - In 1943 the Institute of Speech Pathology (which is not part of the University but belongs under the Ministry of Social Affairs) got a laboratory of experimental phonetics. This laboratory was established in close cooperation with professor Hjelmslev, and it was agreed that it could also be used by the Institute of Linguistics and Phonetics. - In 1953 the University received a Kay Electric sonagraph from the Rockefeller Foundation, and this was placed at the Institute of Speech Pathology, and used by both institutions. Moreover various students and teachers from the Institute of Linguistics and Phonetics had occasion to work at the Dentists' High School (with palatography and X-ray), at the Cardiographic Laboratories of the University Hospital and the Copenhagen District Hospital in Gentofte (particularly with pressure measurements), and at the Speech Transmission Laboratory in Stockholm. Eli Fischer-Jørgensen had also the opportunity to work for some time in 1952 at the MIT, and Jørgen Rischel at the Communication Sciences Laboratory of the University of Michigan (in 1962), and both visited the Haskins Laboratory in New York for a short time.

In the long run it was, however, very unpractical that the University did not have its own laboratory. The difficulties were augmented by the fact that the laboratory at the Institute of Speech Pathology, which from 1958 was directed by dr. Svend Smith, intensified its own research work, and the space was too limited to be used by two institutions. In 1958 some rooms in the basement of 13 St. Kannikestræde, where the Institute of Linguistics and Phonetics was housed, became vacant, and an application was sent in immediately. It took, however, 8 years before the money was granted and the rooms repaired, but in the meantime we succeeded in getting some money for instruments. In 1961 we bought a mingograph, an intensity meter, and a pitchmeter, and in the following years some supplementary equipment. This was placed provisionally in a small room in the first floor which needed repairing very badly, and which could only be very insufficiently heated. In spite of the bad conditions a good deal of instruction and research took place here during the years 1962-65.

It was thus a very great progress when, at the end of November 1966, we could take six small rooms in the basement in use as a laboratory of experimental phonetics. Shortly afterwards the Institute of Linguistics and Phonetics was divided into two separate institutes, an Institute of Linguistics with professor Gunnar Bech as a director, and an Institute of Phonetics with Eli Fischer-Jørgensen as a director. Both institutes are housed in the same building in 13 St. Kannikestræde. The Institute of Phonetics has now at its disposal: an office, four studies for teachers, a listening room (which also functions as a library), and the six laboratory rooms. - It shares two classrooms with the Institute of Linguistics and the Institute of Danish Dialectology.

Eli Fischer-Jørgensen

INSTRUMENTAL EQUIPMENT OF THE LABORATORY.

The following is a list of the instruments that were in working order or near completion by January 1st, 1967.

1. Instrumentation for speech analysis.

1 Kay-Electric Sona-Graph.

1 "Trans Pitchmeter".

1 Intensity Meter (dual channel, with active, variable highpass and lowpass filters).

1 Electro Aerometer, design Sv. Smith & B. Frøkjær-Jensen (dual channel for ingressive and egressive air).

2 Air-Pressure Manometers, type 5734 High Fidelity Blood Pressure Transducers, Electro-Physiological Instruments, Ltd., Edinburgh (employing RCA pressure tubes). A home-made DC amplifier is used with the manometers.

1 Segmentator, model IPO (Eindhoven).

1 Palatoscope with complete outfit for palatography.

1 Meyer-Schneider pitchmeter.

2. Instrumentation for speech synthesis.

1 Provisional Vowel Synthesizer (see this report p. 15).

1 Larynx Spectrum Generator.

3. Filters.

1 LC Highpass Filter (with stepwise variation of cutoff frequency).

1 Active RC Lowpass Filter.

1 Heterodyne Bandpass Filter (see this report p. 13).

4. Instrumentation for visual recording.

1 Elema Mingograph 42 (4 channels).

1 Oscilloscope, Solartron type CD 1400 (dual beam).

1 Oscilloscope, Telequipment (single beam).

1 Kymograph (with electro-motor).

5. Tape Recorders.

2 Lyrec Professional Recorders (mono, speeds $7^1/2$" and 15").

3 Revox Semi-Professional Recorders (stereo, speeds for one of the recorders $3^3/4$" and $7^1/2$", for the others $7^1/2$" and 15").

7 Tape-Recorders for general practice work (Eltra, Tandberg, Philips).

6. Gramophones.

1 Gramophone, Delphon (mono, Ortofon pick-up).

1 Gramophone, B&O (mono, Ortofon pick-up).

3 Gramophones, HMV (Ortofon pick-ups).

7. Microphones.

1 Neuman Microphone KM 56.

1 Sennheiser Dynamic Microphone MD 21.

4 Crystal Microphones of various brands.

1 Altec Microphone.

8. Amplifiers.

1 Laboratory Amplifier (mono/stereo, with matching for different impedances).

1 Telefunken Microphone Pre-Amplifier.

4 Headphone Amplifiers for use with gramophones.

9. General-purpose electronic instrumentation.

1 Oscillator, Hewlett & Packard type CD 200.

1 Function Generator, Wavetec VGC III (0,003 c/s - 1 Mc/s).

1 Frequency Counter, Rochar type A 1360 CH (5 digits).

1 Brüel & Kjaer Vacuum-Tube Voltmeter type 2409.

1 Heathkit Vacuum-Tube Voltmeter type V-7A.

1 Universal Meter, Philips type P 817.

3 Resistance Decades, Danbridge.

1 Condenser Decade, Danbridge.

3 Stabilized Rectifiers (0-20 V, 5-30 V, and 150-300 V, respectively).

(Additional oscillators, rectifiers, etc. for special purposes.)

1o. <u>Outfit for photography.</u>

1 Minolta Camera SR-1 (with various accessories).

1 Complete outfit for reproduction (including 1 Liesegang UNI-RAX with frame).

11. <u>Projectors.</u>

1 Liesegang Epidiascope.

1 Leitz Projector for slides.

1 16 m/m Tone Film Projector, Bell & Howell "Filmsound 644".

2 Overhead Projectors with accessories.

LECTURES AND COURSES IN 1966.

1. Elementary phonetics courses.

One-semester courses (two hours a week) in elementary phonetics (intended for all students of foreign languages) were given by Børge Frøkjær-Jensen, Hans Peter Jørgensen, Jørgen Rischel, W.W. Schuhmacher, and Oluf M. Thorsen. There were 4 parallel classes in the spring semester and 15 in the autumn semester (ca. 500 students in all).

2. Practical training in sound perception and transcription.

Courses were given through 1966 (two hours a week) by Eli Fischer-Jørgensen (the courses form a cycle of three semesters).

3. Instrumental Phonetics.

The courses form a cycle of three semesters with two hours a week.

1. Spring semester: Methods for the investigation of intensity and fundamental frequency.
2. Autumn semester: (a) Physiological methods. (b) General introduction and spectrography.

The courses 1 and 2 a were given by Eli Fischer-Jørgensen in cooperation with Børge Frøkjær-Jensen, 2 b was given by Eli Fischer-Jørgensen.

4. Phonemics.

A course in phonemic theory (two hours a week, continued from the preceding semester) was given in the spring semester, and a more practically oriented course in phonemic analysis (also two hours a week) was given in the autumn semester. Both courses were taught by Eli Fischer-Jørgensen and Jørgen Rischel in cooperation.

5. Seminars.

The following seminars were held in the spring semester:

a. Jørgen Rischel demonstrated a provisional device for vowel synthesis.

b. Docent Sven Öhman (Stockholm) reported on recent research on the parameters of vowels.

The following were held in the autumn semester:

c. W. W. Schuhmacher reported on the neuro-physiological theory of vocal cord vibration.

d. Dr. V. Ondračková (Prague) reported on her research with a glottograph of the type designed by Fabre.

e. Professor Roman Jakobson discussed the problems of a distinctive feature analysis of Danish.

6. Staff-classes with guests participating.

a. Docent Sven Öhman reported on his electro-myographic measurements on lip-muscles.

b. Børge Frøkjær-Jensen and Jørgen Rischel demonstrated some newly constructed equipment (respiration corset, vowel synthesizer).

Professor, Dr. Eva Sivertsen (Trondheim) and Professor, Dr. Svend Smith (Hamburg) participated.

THE RESPIRATION CORSET.

Børge Frøkjær-Jensen

In the days of the kymograph the respiratory movements were recorded by means of a pneumograph. This apparatus consists of a rubber belt containing air. During the respiratory movements of the chest or stomach the air in the belt was compressed and the pressure wave was conducted through a rubber tube to a kymographic recording device.

The apparatus has also been employed for investigations of the activity of the chest and stomach during speech.

We have under work a more up-to-date version of this instrument. Two coils, which function as primary and secondary coils of a transformer, are mounted on a springy belt placed around the chest of the subject in such a way that the distance between the coils varies with the circumference of the chest. A 10 kc/s transistorized oscillator supplies an ac-voltage to the primary coil. The secondary coil picks up the oscillations, the amplitude of which is proportional to the square of the distance between the coils. This voltage from the secondary coil is amplified in a three-stage transistorized amplifier with negative feed-back, which is made logarithmic by means of two silicon diodes in the feed-back loop. In this way it is possible to get an amplification, where the output voltage

$$V_{output} = A \cdot \sqrt{V_{input}}$$

in the desired range (11 cm variation of the distance between the coils). After the logarithmic amplification the 10 kc/s signal is rectified, and the output consists of a voltage, which is proportional to the circumference expansion of the subject's chest.

If we want to record the respiration movements of both the chest and the stomach it is necessary to use a system with two channels. In order to avoid interference between the coils of the two channels we employ different carrier frequencies for the two systems and employ tuned amplifiers. Frequencies such as 9 kc/s and 12 kc/s are suitable for this purpose. A block diagram of the whole system is shown in Fig. 1. The circuit diagram for each amplifier is shown in Fig. 2.

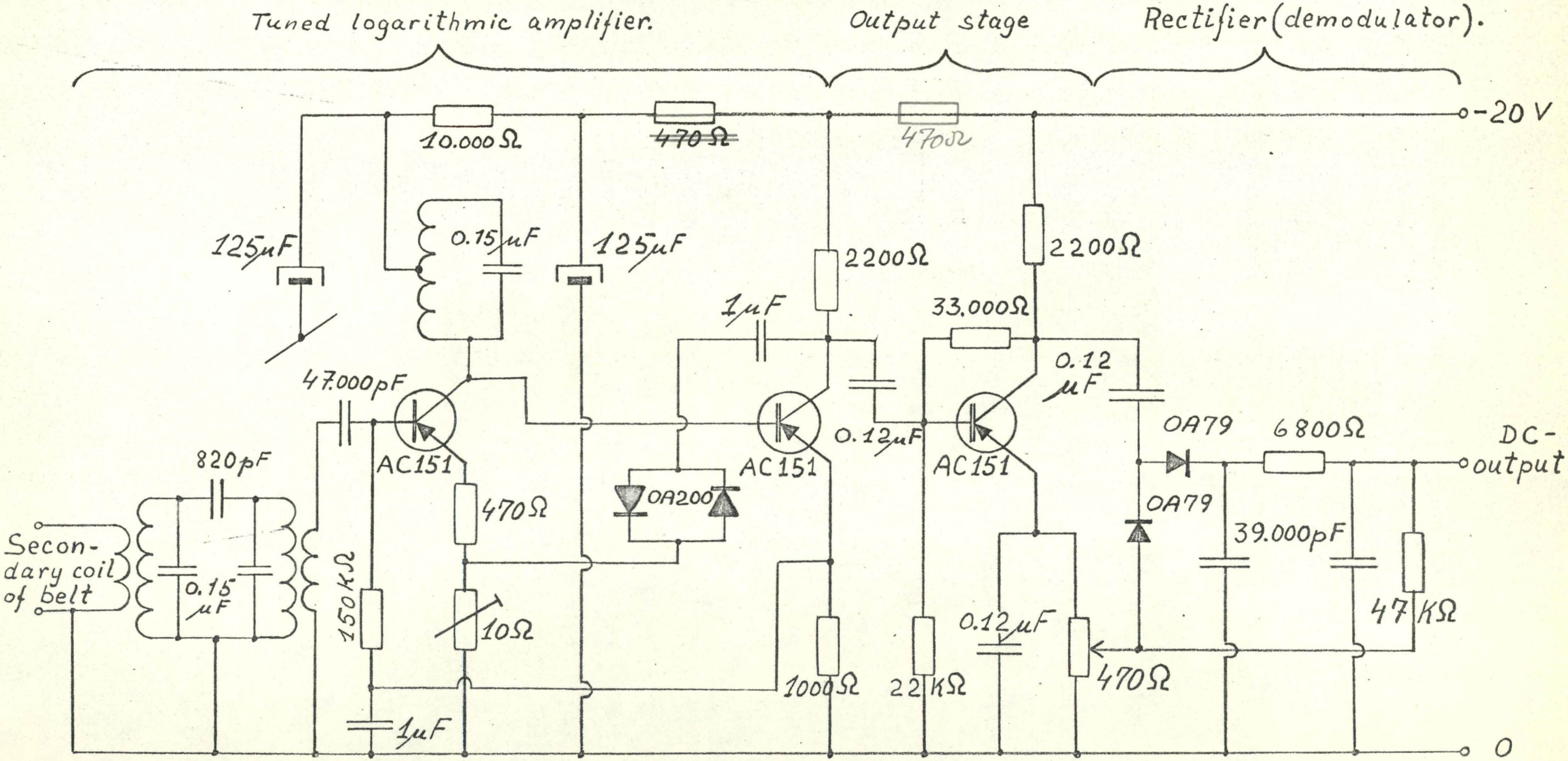

Fig.2: Tuned amplifier for logarithmic amplification. ($V_{output} = A \cdot \sqrt{V_{input}}$).

A visual recording device such as the mingograph or the oscilloscope may be coupled directly to the logarithmic amplifier. If we want to record the respiratory movements on a device which consumes effect, we can take the output signal through a specially constructed dc-amplifier. This transistorized amplifier gives a current amplification of 40 dB, and a voltage amplification of about 2 dB, depending on the input impedance of the recorder. (An example of such a recorder is the Siemens "Oscillomat", which has 16 channels. This instrument writes on UV-sensitive paper with light beams whose movements are controlled by small galvanometers with frequency responses up to 15 kc/s).

The instrument is under work. The electronic part has been finished, but some work still needs to be done at the belt in order to find the best way to fix the coils.

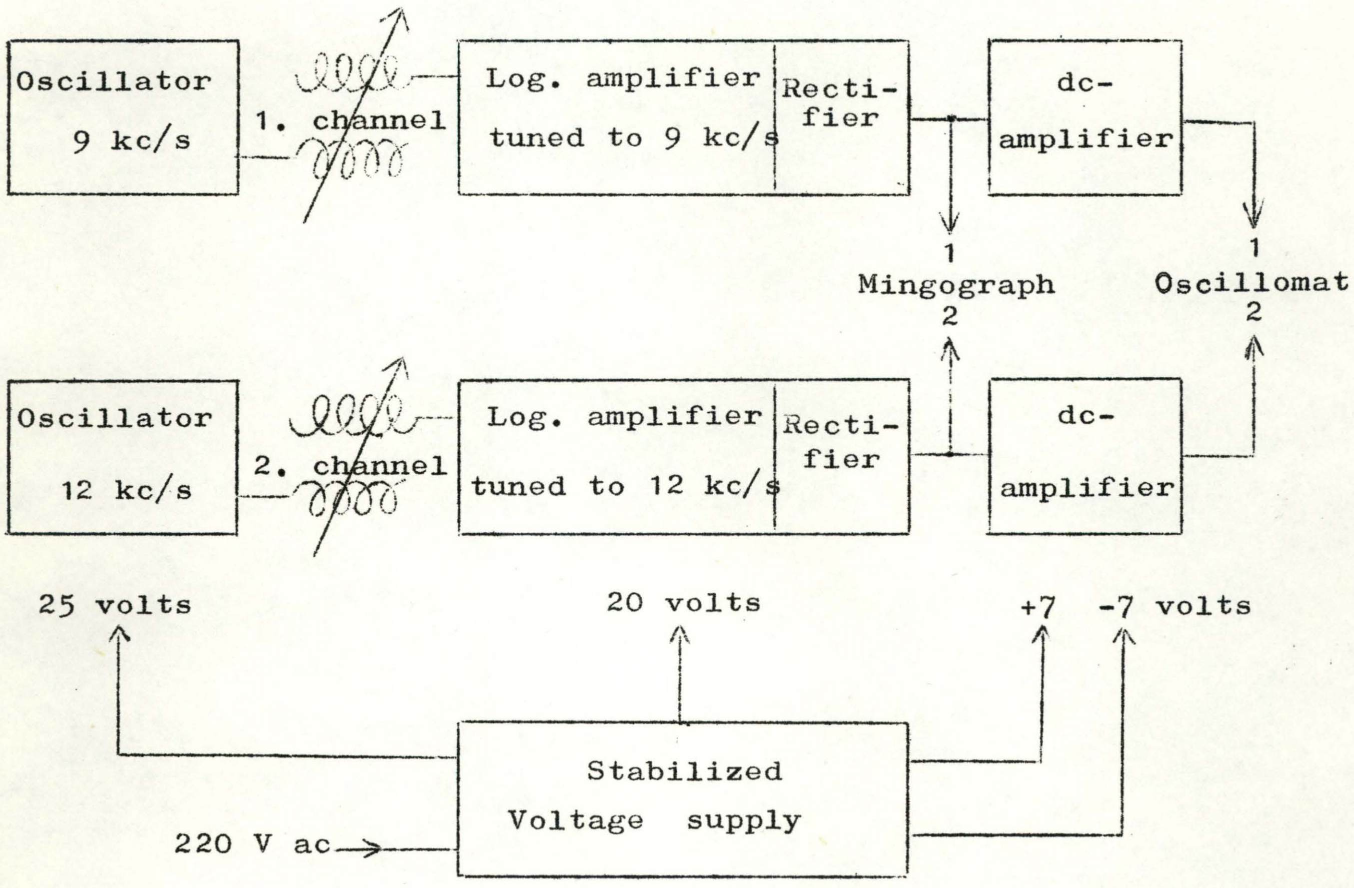

Fig. 1.

Block diagram of the two-channel Respiration Corset.

HETERODYNE FILTER.

Jørgen Rischel

A versatile bandpass filter has been in preparation for one and a half year. It functions according to the heterodyne principle, which has been utilized for this purpose by Fant (1), i.e. the entire audio signal is transposed (by successive modulations) to two different high frequency bands, and the highpass and lowpass filtering is carried out by filters operating at fixed frequencies adjacent to these frequency bands. This method makes it possible to obtain a sharp filtering with continuously variable cutoff frequencies, since the exact location of the high frequency bands relatively to the filters can be varied by changing the carrier frequencies of the modulators (i.e. by tuning two oscillators).

A problem with this kind of filter is that it is expensive and difficult to build. However, most of the ingredients are circuits in general use in carrier telephony. It seems, therefore, an attractive solution to try to compose a filter almost entirely of commercially available equipment of this kind. Systems for carrier telephony include a number of sharp filters serving under normal circumstances to separate different telephone "channels" (or groups of channels) occupying the same line and differing only in frequency. By using one such channel and tuning the carrier oscillators off their proper frequencies one can reduce the transmitted frequency band by highpass or lowpass filtering. We have been - and still are - experimenting with this kind of solution.

In 1965 the Danish Post and Telegraph Department generously deposited with us some equipment manufactured by Siemens & Halske Ltd. (all transistorized) for our experiments along this line. In principle the setup came to work well, but the inherent bandwidth limitation of the carrier telephony system (transmitting only the frequency band 300-3400 c/s), which was difficult to do away with, obviously makes it inadequate for several purposes. In December 1966, however, the said institution lent to us a modulator (also manufactured by Siemens & Halske) designed for transmission of the entire speech range (50-10,000 c/s), and this is now being incorporated into the setup. It is our intention that the filter shall - in its ultimate form - allow us to filter out any portion in the frequency range 50-10,000 c/s.

<u>References:</u>

(1) G. Fant, The Heterodyne Filter (Stockholm, 1952).

Acknowledgements:

Our thanks are due to the Royal Danish Post and Telegraph Department, Cable Engineering Service, and to the Danish Research Committee for the Technical Sciences (Danmarks teknisk-videnskabelige Forskningsråd), whose support has made the project possible.

INSTRUMENTATION FOR VOWEL SYNTHESIS.

Jørgen Rischel

I. Preparatory work.

General presentation:

A vowel synthesizer employing a heterodyne system was built by this author in 1965-66. The apparatus grew out of somewhat random experiments as a device for demonstrating synthetic vowels, and it will not form part of our permanent instrumentation for research purposes. However, the experience gained from the experimentation will be utilized in the planning of a more advanced synthesizer. In this report, therefore, I shall present the essential features of the apparatus, and the particular problems that have been considered in connection with the heterodyne technique employed.

The synthesizer is a rather compact unit comprising five formant generating circuits plus a bass-boost network. A voice generator is connected externally.

In making this provisional setup I strived to obtain an optimum of versatility and simplicity of operation in the synthesis of steady-state vowel sounds.

(a) As for versatility it was considered desirable to be able to control the frequency, bandwidth and intensity level of each formant separately. Various arguments can be given in favour of this. In phonetics teaching it is obviously useful that it can be demonstrated how the individual formants (taken as peaks of energy in the spectrum) contribute to make up the phonetic quality of the sound, and it is also useful in connection with auditory tests to provide for the possibility of manipulating the formant levels or of changing the number of formants (e.g. to perform one-formant or two-formant synthesis). In principle this is possible with the present device (although the faithfulness of sound production may not be entirely adequate). Formant frequencies are continuously variable over a calibrated range representative of adult (male) voices. Formant bandwidths are continuously variable over a (roughly) calibrated range of some 50 to 150 c/s (different for the different formants). Formant levels are continuously variable over a calibrated range of 0 to -60 dB and can further be turned down to zero ("$-\infty$"), The correct setting of formant levels presupposes, of course, a knowledge of the spectrum characteristics of the voice source employed. On the other hand, variations in formant levels can in principle be used to imitate particular voice characteristics. Variations of bandwidths and levels also make it possible to imitate nasalized vowels and some frictionless consonants with a certain degree of realism without the aid of additional circuitry (see below on "F 5").

The above considerations imply that the speech-wave is generated by adding the contributions from the individual formant generators, i.e. the electronic formant filters are connected in parallel, not in a series (cascaded) arrangement.*)

(b) Simplicity of operation is in a sense the opposite of versatility. A synthesizer with parallel connection of formant filters does not have the limitations imposed on human speech by the vocal tract anatomy, and thus a large amount of information on different parameters (16 in our setup) is necessary for correct simulation of a given vowel sound. A cascaded arrangement of formant filters reproduces more directly the transfer characteristics of the human vocal tract and is likely to be superior in high quality speech simulation, cp. the instructive comparison of the two types by Cooper (1). The relative merits of parallel and cascade synthesis of connected speech are still debated, see Flanagan (2).

If the necessary information is present, however, our present synthesizer is easy to operate. Although it was designed for steady-state synthesis only, it was considered essential that each formant be continuously variable over its whole frequency range, and that its true frequency location be directly visible on the scale. This is not generally true of simple vowel synthesizers. A frequency variation is most easily achieved by a stepwise variation (by means of switches) of the capacitors in each resonant circuit, and this is probably the method that is mostly used for the restricted purpose of vowel synthesis. However, it is a drawback of decade switches that the whole formant range cannot be shown in a sweep, and it is a more serious

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*) It must be added here that the heterodyne technique employed in our experiments dictates the use of a parallel connection of formant filters. It cannot be used with a series arrangement, even though such an arrangement might be preferred for several purposes.

drawback that the scales must be calibrated in capacitance values (microfarads, nanofarads, etc.) rather than cycles per second, so that the frequency location of a formant cannot be determined (if only approximately) without the use of additional measuring apparatus or of detailed nomograms showing the capacitance/frequency relationships.

In our synthesizer the formant frequency variation is at present achieved by means of variable capacitors. The range of variation with these is sufficient only at relatively high frequencies. This has been accounted for by heterodyning the entire signal from the voice source with a sine wave of fixed frequency, thus moving it to a suitable high frequency range, within which the formant filters (resonant LC-circuits) are tuned, and modulating back afterwards to the original low frequency location.

The heterodyne method was adopted not only with the purpose of using variable capacitors but also because it seems potentially applicable to synthesis of <u>connected speech</u>, if adequate means for capacitance variation be found. Experiments with BA 1o2 capacitance diodes (controlled by a negative DC-voltage to give a varying capacitance) inserted in one of the formant circuits of the present device gave a promising result, indicating that formant frequency variation can be accomplished in an extremely simple fashion by applying a DC control voltage directly to the resonant circuits. Admittedly, this simplicity of formant frequency control is obtained at the expense of a fairly elaborate system of modulators and filters in the synthesizer. It should be added also that the variation of formant frequency with DC voltage will not be linear. We are going to investigate into this problem.

An interesting property of heterodyne synthesizers is that a resonant frequency can be changed not only by changing the component values of the resonant circuit but also by changing the frequency of the sine wave from the carrier oscillator. A possibility which is at least theoretically interesting is to use separate heterodyne systems for the several formants. Each formant filter could then be kept at a fixed resonant frequency, and the formant frequency variation would be achieved by changing the frequency of the carrier belonging to that particular formant generator. However, this method would probably be more complicated than others in current use.

The heterodyne approaches discussed here are essentially different from that described by Lawrence as early as 1953 (3). In his parametric artificial talker a formant-like wave train (i.e. a decaying sine wave recurring at a rate corresponding to the fundamental frequency) is generated at a fixed frequency and distributed to the proper frequency locations of the individual formants by simultaneous heterodyning processes. The synthesizer described by Pohlink et al. (6) is more similar in type. However, they apply the signal directly to the formant filters and only modulate afterwards (F_o being synchronized by the carrier).

Technical outline of the heterodyne synthesizer:

A block diagram of our provisional synthesizer is shown in Fig. 1. The signal is applied to a double-balanced modulator which delivers an output consisting of two sidebands located around a suppressed carrier frequency of 15 kc/s.*) The upper sideband (15 to 2o kc/s) is used for the transmission of the signal. Via a step-down transformer the output from the modulator is applied to the formant filters, which are series resonant LC-circuits of high Q. The formant filters of odd number are fed from one transformer coil, those of even number are fed from another with phase reversal. Thus a combined response without zeroes at the cross-over frequencies (i.e. without antiformants between the formants) is obtained (cf. Weibel (4)). The "standard reference vowel" response of the whole system is shown in Fig. 2. (The comparison of envelopes obtained with parallel synthesis and with series synthesis given in Flanagan (5) presents a radically different picture for parallel synthesis

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*) This frequency appeared to be a reasonable compromise between the difficulty in obtaining narrow bandwidths of variable resonant circuits at high frequencies, and the difficulty in obtaining the high impedance necessary for the application of variable capacitors or capacitance diodes at low frequencies.

because obviously no phase inversion was used.)

"F5" covers the entire frequency range (in steps) and can be connected in phase with either the odd or the even formants. It can thus be used to simulate nasality or the like, if placed at a low frequency.

The combined output from the formant generating network is high-pass filtered at 15 kc/s (to remove remnants of the lower sideband and possible distortion products) and demodulated in a second double-balanced modulator. The low-frequency output is low-pass filtered at 7 kc/s and mixed with the (phase-correct) output from a low frequency boost channel (consisting of an LRC low-pass filter followed by a variable gain amplifier), which takes the signal directly from the input. (By this procedure the effect of nonlinearity originating from imperfect filtering in connection with the single-sideband modulation is reduced, and correct low-frequency response is obtained.)

Attempts to produce vowels of well-defined phonetic quality with the synthesizer have been reasonably successful considering the fact that we have not had a really adequate signal source at our disposal. This will be provided for in the nearest future.

Although the accuracy of the carrier oscillator is of course crucial, the synthesizer is reasonably stable in operation. Noise is kept at a low level, even though no particular care has been taken in the layout. The high signal-to-noise ratio easily obtainable with this type of synthesizer may be a feature worthy of notice.

When the provisional synthesizer was first constructed, economy had to be a governing factor in a pilot study of this kind, and low-cost components were accomodated wherever possible. Lately, various improvements especially of the modulating system have been incorporated.

2. Plans for future work.

In October 1966 the Institute received a grant from the Danish Technical Research Committee as a financial support of our acquisition of instrumentation for synthesis and filtering of speech. We are at present purchasing various measuring instruments, and in the near future we shall investigate into the principles to be fol-

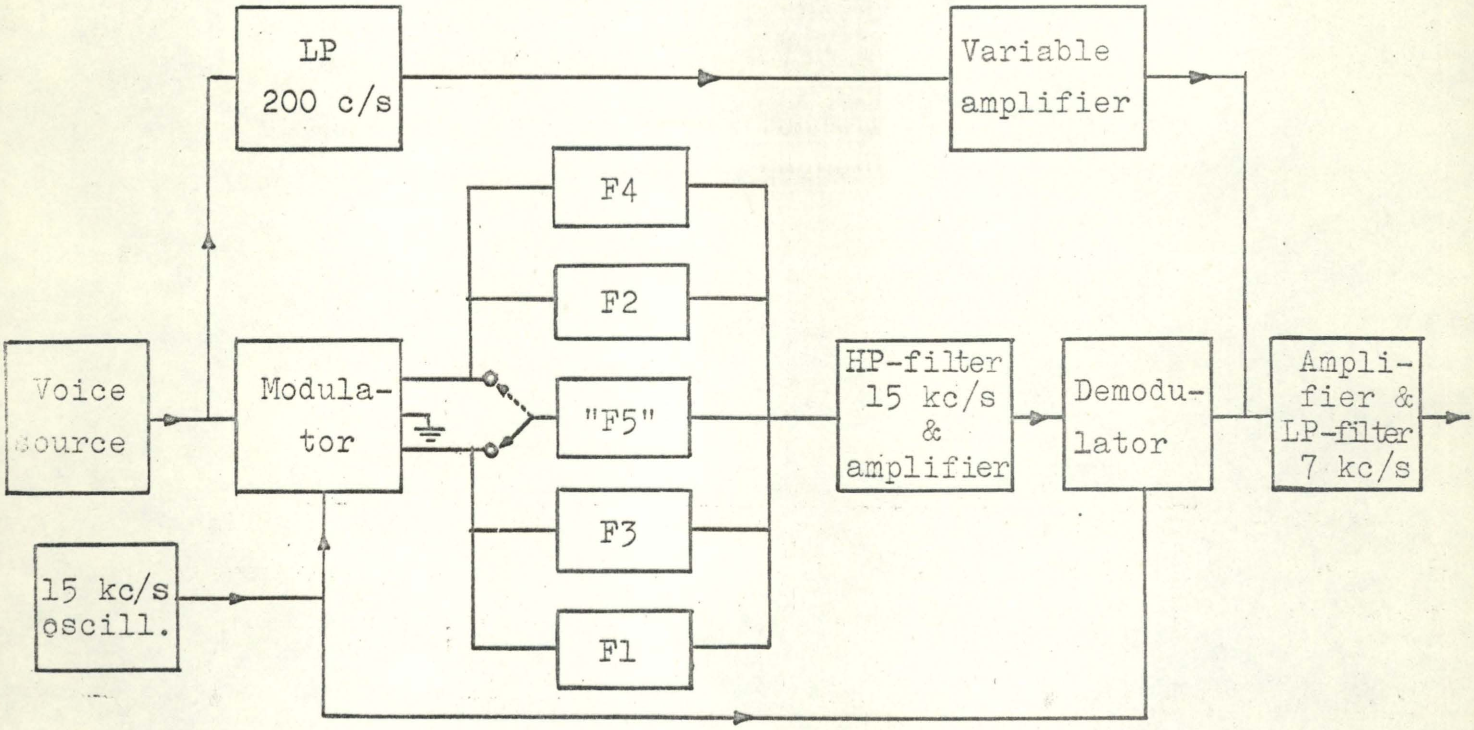

Fig. 1

Block diagram of provisional vowel synthesizer.

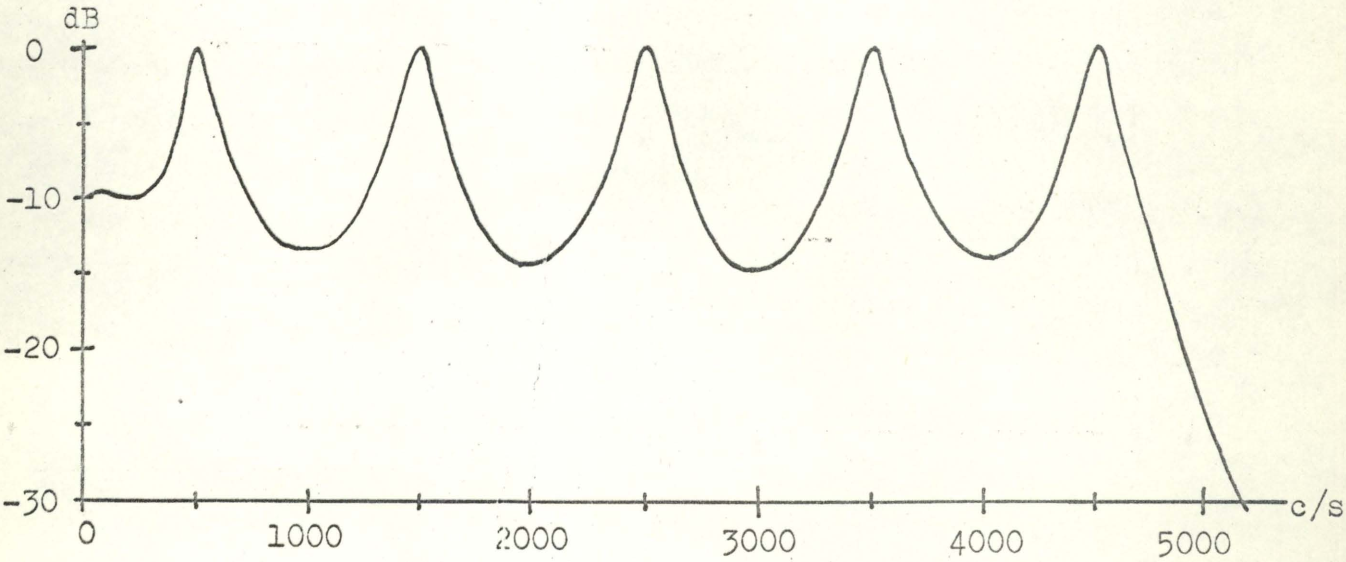

Fig. 2

Response of synthesizer with formant frequencies set for the "neutral vowel" (500 c/s, 1500 c/s, 2500 c/s, etc.), bandwidths = 100 c/s, and levels = 0 dB (the actual choice depends on the voice source spectrum).

lowed in the final choice (design or purchase) of a parametric (formant coded) synthesizer.

References:

(1) F.S. Cooper, "Speech Synthesizers", Proceed. of the Fourth Int. Congr. of Phon. Sc. Helsinki 1961 (1962), pp. 3-13.

(2) J. L. Flanagan, Speech Analysis, Synthesis and Perception (1965).

(3) W. Lawrence, "The Synthesis of Speech from Signals which have a Low Information Rate", Communication Theory ed. W. Jackson (1953), pp. 460-469.

(4) E.S. Weibel, "Vowel Synthesis by Means of Resonant Circuits", JASA 27 (1955), pp. 858-865.

(5) J.L. Flanagan, "Note on the Design of Terminal-analog Speech Synthesizers", JASA 29 (1957), pp. 306-310 (p. 310, Fig. 7).

(6) Pohlink, Tscheschner, Dumdei, "Demonstrationsmodell zur Sprachsynthese", Zs. f. Ph., Sprachwiss. u. Kommunikationsforsch. 18(1965), pp. 409-416.

PRELIMINARY EXPERIMENTS WITH THE FABRE GLOTTOGRAPH.

Eli Fischer-Jørgensen, Børge Frøkjær-Jensen, and Jørgen Rischel

In November 1966 we had the opportunity to work with F. Fabre's glottograph for a week thanks to a visit by Dr. J. Ondráčková, supervisor of the Phonetics Laboratory of the Academy in Prague.

Dr. Ondráčková gave a lecture on her work with the glottograph, and brought with her the instrument belonging to the laboratory in Prague, which we were allowed to keep for a few days after her departure.

The Fabre Glottograph measures the electrical resistance in the larynx, and can, in principle, be used to record either the vibratory movements of the vocal cords during the production of voiced sounds, or the slower variations observable in sequences of sounds.

As we had at that time no means of photographing the vibrations from the oscilloscope screen, we concentrated on experiments with slower movements, i.e. the gross variations in level of the curve in consonants and vowels, which could be recorded directly from the glottograph on the mingograph.

The plates of the glottograph in question were 3 cm high and 1 cm broad (effective area about 2 cm^2). They were in most of the experiments mentioned here below placed according to the directions of Dr. Ondráčková on either side of the throat, so that they reached somewhat above and below the glottis. The curves were recorded at a paper speed of 100 mm/sec. They were, in various instances, combined with simultaneous recordings of air flow (Electro Aerometer) and recordings of intra-oral pressure (Manometer).

The Fabre Glottograph has appeared in several slightly different designs (1),(2),(3) based on the same principles. The main problem in designing this apparatus is to obtain a stable zero-line. Firstly, it is very difficult to keep the contact resistance between the glottograph plates and the skin constant. Variations in contact resistance are mainly caused by ultra-slow variations in skin humidity, and it is hardly possible to overcome this problem. Secondly, we observed that the zero potential varied due to properties of the electronic part of the instrument; it should be possible to remove these fluctuations rather easily.

The glottograph we tried operated in the following way:

A high frequency alternating voltage is applied between the contact plates, which are connected to the input terminals of an amplifier in such a way that an increase in current from one plate to the other reduces the signal. After amplification the high frequency signal (modulated by the variations in plate-to-plate current through the throat) is detected, and via a high-pass filter with a very large time constant (4 sec.)* the output is recorded on the mingograph. The resulting curve is considered to indicate the degree of electrical resistance in the glottis.

The instrument has the great advantage of being without any inconvenience for the speaker, as he is not able to feel the weak alternating current passing his throat. It is, however, a problem whether the glottograph, in its present form, gives a reliable record of the degree of opening in the glottis, or whether other factors intervene to obscure the picture. Such factors could, e.g., be voice modulated variations in the electrical contact to the skin, the gross movements of the larynx, the conditions of the pharyngeal cavity (internal circumference and humidity), and contraction of the muscles above and around the larynx.

2.

2.1. A good many of the phenomena observed can easily be interpreted as conditioned by the degree of opening of the glottis.

This is true of the curves of Danish consonants. The Danish consonants p t k b d g f s h v were recorded initially in a syllable in small sentences of the type: "det er falle, det er palle" etc. [de: 'falə de: 'palə]'it is Falle, it is Palle'). These sentences (except those with k and g) were spoken 6 times each by JR and all were spoken 8 times by OT. - It was very clear that f s p t k showed

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*) For recordings of vocal fold vibrations the apparatus was provided with an AC amplifier (including a high-pass filter with a time constant of 25 msec., which would give a more stable zero-line). For recordings of slower movements a separate channel had been incorporated at the Speech Transmission Laboratory in Stockholm (3). Because of insufficient information about the instrument we have not tried the original channel (with short time constant).

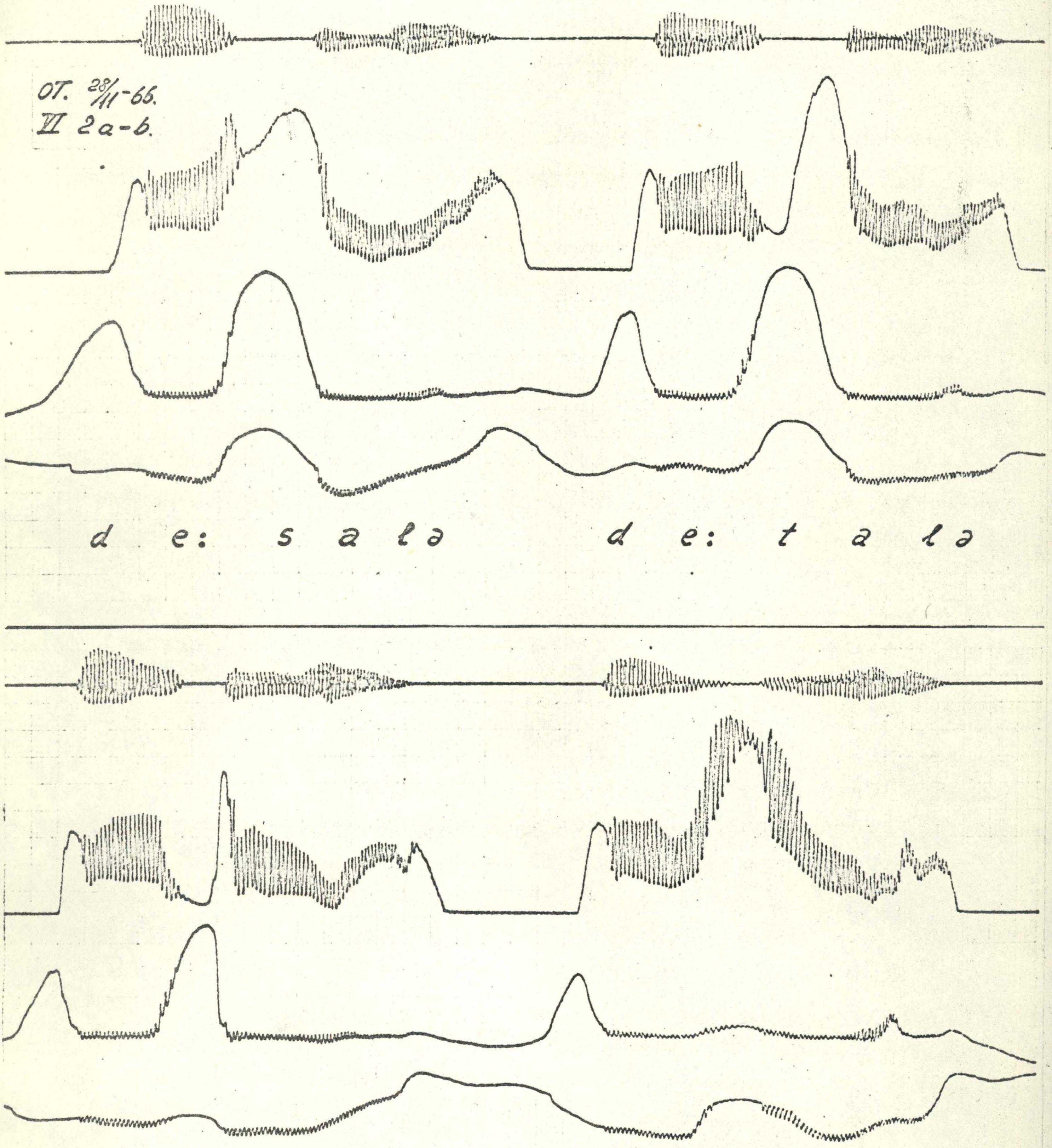

Fig. 1.

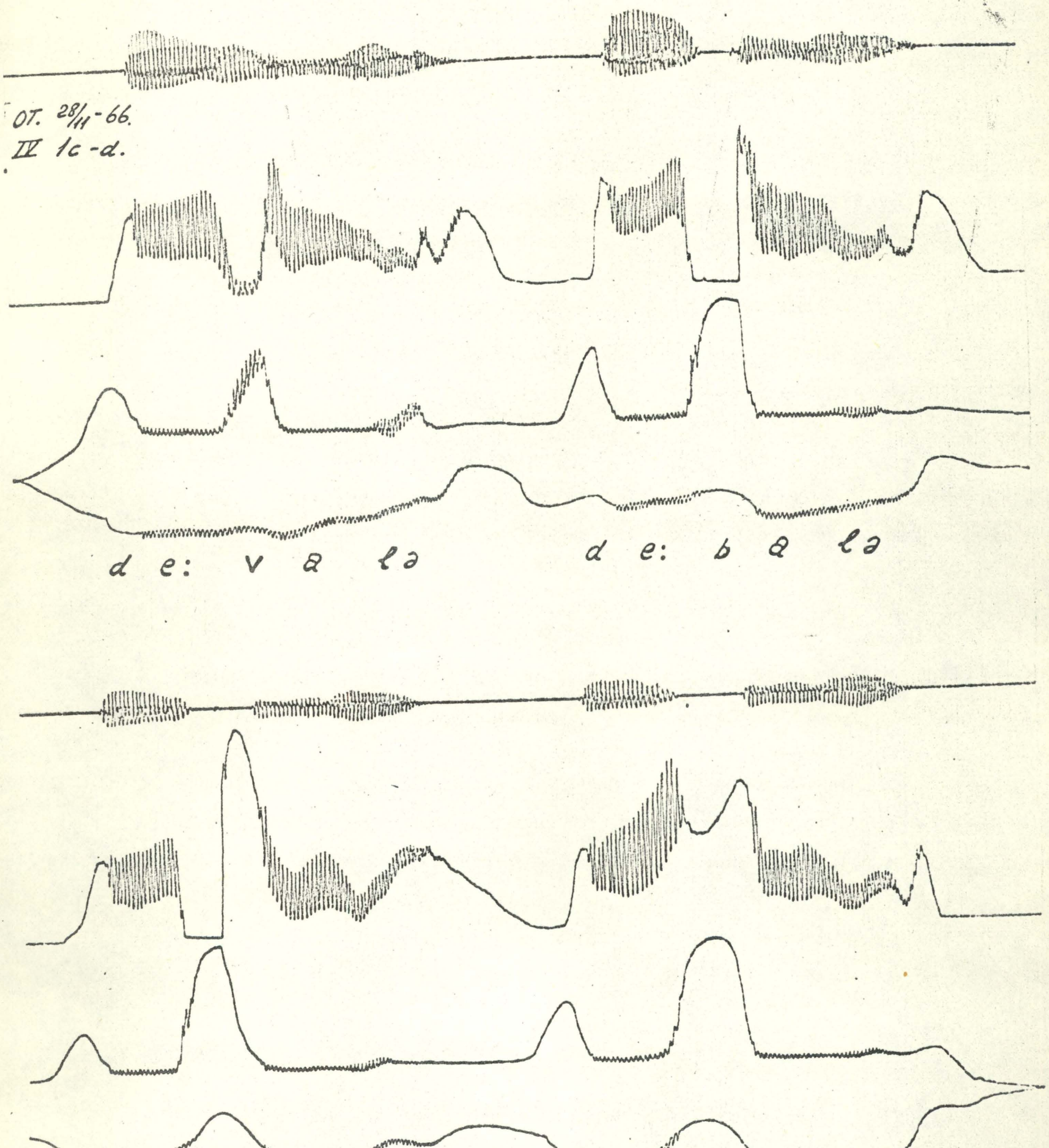

Fig. 2.

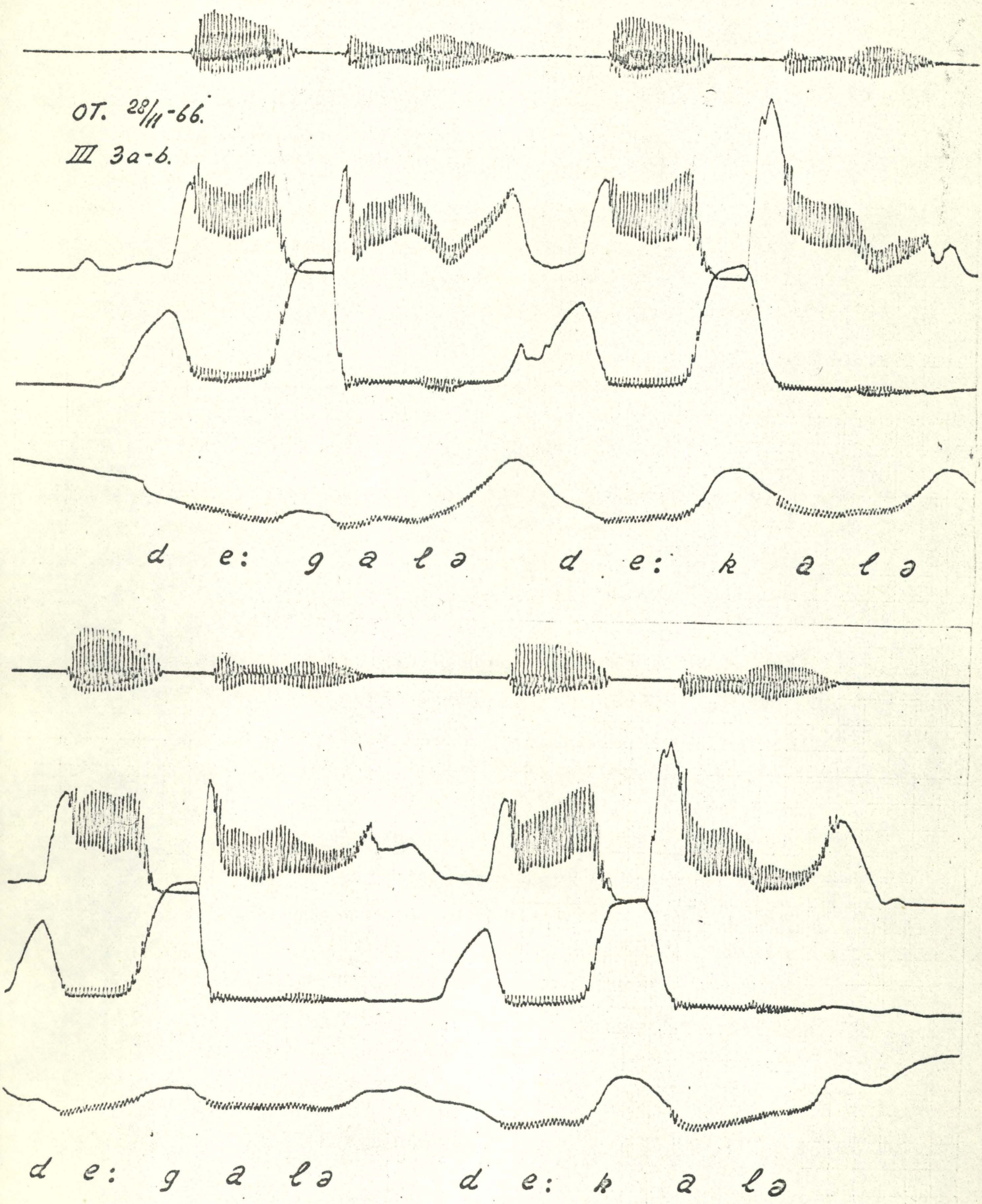

Fig. 3.

a higher rise of the curve (possibly due to higher resistance) than bdg (cp. Figs. 1, 2, and 3), but all of the just-mentioned consonants have a higher curve (i.e. electrical resistance) than the surrounding vowels; h is relatively high in OT's curves, lower in JR's. Danish fs are voiceless and spoken with open glottis, ptk are aspirated, and it has been found by endoscopic examination that the glottis opens widely during the closure of p and closes slowly during the aspiration. The glottogram also shows a rise - fall with a turning point at the moment of explosion. Danish bdg are also voiceless, but endoscopic investigations have shown that b is spoken with closed or almost closed glottis. - h is characterized by a strong air stream and there is a good agreement with the air flow curves, but, particularly for h and v, not with the curves of intra-oral pressure (see Figs. 1 and 2).

2.2. Similar short sentences with stops only were spoken by three French subjects (SRO, P, and CHH). Endoscopic examination has shown SRO to have a slightly open glottis in p. She has less difference between ptk and bdg than the Danish subjects. For the other two no endoscopic examination could be made. CHH is bilingual and has also spoken the Danish sentences (with aspirated ptk). Her Danish labials are relatively low compared to those of the Danish subjects, but the dentals and velars are higher. The unaspirated French p and t are lower than the Danish sounds, but this is not true of k.

2.3. Three Danish subjects have spoken the syllables a?a and aha a number of times. The curves show a fall for ? and a rise for h. - A few words with "stød" (phonetically creaky voice) show a drop for the stød. The curve rises between words and sentences to a high position of rest.

2.4. A Gujrati speaker (RD) has spoken a series of normal and breathy vowels. The latter show slightly higher glottograms and stronger air flow than the normal vowels. This is what might be expected.

2.5. Finally a German subject (WS) has spoken a series of words with different German vowels. For the front unrounded vowels the lax vowel [ɪ] shows more resistance (and stronger air stream) than [iː], [eː], and [ɛː], which is in agreement with E.A. Meyer's theory that the glottis should close less firmly in lax vowels. For the rounded vowels, however, the relations do not hold.

All this can be explained by assuming that the curve reflects the degree of opening of the glottis.

3. A series of other differences observed in the curves can, however, not be explained in this way.

3.1. All the French subjects show higher resistance for velars than for dentals and labials. The same is true for CHH's Danish curves, but a similar difference is not found for the Danish subject OT. This difference can hardly be due to differences in the opening of the glottis, but may perhaps be explained by movements of the whole larynx. The larynx is moved upwards when the tongue is raised to the top of the palate as in k and g, and this seems to influence the glottogram.

3.2. Very strongly voiced b, d, g spoken by three different Danish subjects show a definite rise in the curve of the stop. In these cases one should rather expect the larynx to go down (and this can also be directly observed). It is not very probable that both a rise and a fall in the position of the larynx should cause the glottogram to go up. - In the case of the strongly voiced bdg there is also a distention of the pharynx, which might influence the glottogram.

3.3. Various persons (OT, JR, EFJ, WS, RD) have spoken series of different vowels or series of words with different vowels. There is a clear tendency for narrower vowels to have the glottograms at a higher level. This is particularly true of u and y. - It is rather dubious whether this could be due to differences in the glottis, particularly as the differences in the glottograms are very pronounced. One might rather think of differences in the parynx. Here again, as in the voiced bdg a certain distention of the pharynx in the narrow vowels may play a role.

The role of the pharynx can be made probable by the observation that if the upper part of the plates is covered with isolating tape, so that only the part situated below the glottis is accessible to transverse current, the rise in voiced bdg does not take place (tried on JR) whereas this rise is very pronounced when only the higher part of the plates is used. The difference between the vowels is also less clear when only the lower part of the plates is used.

3.4. Most of the persons used in the experiments pronounced the short sentences on a rather level tone, but with a slight rise on the syllable with a (de: 'palə). On the glottogram a is in almost all cases lower than e (which may be due to the vowel quality, or to tone, or to intensity). But one subject (P) has spoken the sentences once with falling and once with rising intonation, and one more Danish subject (BST) has spoken the French sentences with falling tone. In the sentences with falling intonation, there is a very strong rise of the whole curve, whereas there is a strong fall in the curves with rising tone. If this has anything to do with raising or lowering of the larynx, it would show (as in the strongly voiced bdg) that the glottogram goes up when the larynx goes down, since persons not trained in singing generally tend to raise their larynx when the pitch is raised. In the sentences with rising intonation spoken by P, the whole glottogram goes down, but the stops (and particularly k and g) show a very pronounced rise.

This type of glottograms thus raises a long series of questions. Probably various factors influence the glottograms at the same time. For the purpose of measuring these changes it would be more appropriate to use smaller electrodes placed at well-defined places.

It is now our intention to build a glottograph according to the principles used by Ohala (4) and others (5), (6) (i.e. measuring the amount of light passing through the glottis) and to attempt to throw light on some of the problems mentioned above by comparing the two types of glottograms.

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(1) On the principle of design, see for example Ph. Fabre, "Glottographie respiratoire", Comptes Rendus des Séances de l'Académie des Sciences No. 6 (1961), pp. 1386-88; id., "La glottographie en haute fréquence, particularités de l'appareillage", Comptes Rendus de la Soc. de Biologie CLIII, 7 (1959), pp. 1361-64.

(2) R. Husson, Physiologie de la phonation (1962), pp. 32-40.

(3) Quarterly Report 4/1966, Speech Transmission Laboratory, RIT Stockholm, pp. 15-21.

(4) John Ohala, "A New Photo-electric Glottograph", Working Papers in Phonetics 4/1966, University of California, pp. 40 ff.

(5) B. Sonesson, "On the Anatomy and Vibratory Pattern of the Human Vocal Folds ...", Acta Oto-Laryngologica Suppl. 156 (Lund 1960), pp. 46-77.

(6) A. Malécot and K. Peebles, "An Optical Device for Recording Glottal Adduction-Abduction", Zeitschrift für Phonetik, Sprachwissenschaft und Kommunikationsforschung 18 (1965), pp. 545-550.

ACKNOWLEDGEMENTS: Our thanks are due to Dr. J. Ondráčková and to the Academy in Prague for the kind permission to test the glottograph of the said institution.

PHONETIC ANALYSIS OF DANISH STOP CONSONANTS.

Eli Fischer-Jørgensen

In the beginning of the fifties the author started an analysis of Danish stop consonants. Some of the preliminary results of the acoustic analysis were summarized in an article in 1954.(1). In the following years the study was concentrated on the difference between the two stop series ptk and bdg, which was examined from articulatory, acoustic and auditory points of view. Material from other languages as well was included for comparison. - In 1958 a rather extensive bulk of material had been collected, and I had planned to work all this material together in a monograph on the fortis-lenis problem with special reference to Danish. This plan was, however, interrupted for several years due to illness, and some of the methods and results are now more or less out of date. - It is my intention now to take up single aspects of this problem in a series of shorter reports and articles. For the moment I only want to give a very brief summary of the main results of the earlier investigations.

In Danish the two series of stops ptk and bdg are distinguished only under very restricted conditions. The exact definition of these conditions raises various problems, but in a brief formula (which presupposes the delimitation of structural syllables) it can be stated that they are only distinguished initially in a syllable. In this position ptk are aspirated (and t is affricated), bdg unaspirated, and both series are voiceless. Finally before a pause aspiration is optional and non-distinctive, and the stops are normally voiceless, at any rate at the end. When occurring medially they are unaspirated, and voicing depends on the preceding sound. After voiced sounds they are often fully (but generally not very strongly) voiced, the extension and degree depending on the tempo of speech and on individual factors. According to the most common phonemic interpretation the dental and labial stops in medial and final positions are considered as members of the phonemes /t/ and /k/, whereas the fricatives [ð] and [ɣ], which do not occur initially are considered as manifestations of /d/ and /g/. -- We are here mainly concerned with the stops in initial position.

In articulatory terms the difference between ptk and bdg can be characterized as follows: ptk seem to be produced with wide open glottis during both closure and aspiration, whereas bdg are produced with a closed or only slightly open glottis (this assertion is based on preliminary endoscopic investigations). The intra-oral air pressure during the closure is slightly higher for ptk than for bdg, but the difference is only about 4-8 per cent, and most of this difference is due to a certain rise of the air pressure during the closure of ptk; but the air stream from the mouth after the explosion (measured by means of an aerometer) is clearly stronger in ptk than in bdg. - The lip pressure on the other hand (measured by means of a rubber bulb) is generally higher for b than for p, and the tongue pressure seems higher for d than for t; the subjective sensation of organic pressure is in agreement with these findings. The duration of the closure is longer in bdg than in ptk, the difference being slight, but significant. It is particularly clear for d compared to t, t having a shorter closure and a longer aspiration than p and k.

As for the acoustic intensity it is quite clear that the aspiration and affrication noise of ptk is stronger than the slight aspiration that may be found in bdg, but no clear difference has been found between the intensity of the explosions, which on the whole have a wide range of variation. It is, however, evident that t has a weak and short explosion (weaker than that of d) followed by a strong fricative phase, which is clearly distinguishable from the explosion by the frequency of the noise. - Formant transitions to a following vowel are longer after bdg than after ptk. This may simply be due to the fact that most of the transition after ptk takes place during the aspiration.

Thus in regard to duration of closure and intensity of organic pressure bdg seem to behave like fortes compared to ptk, but in regard to duration of the open phase, speed of air stream and intensity of aspiration noise ptk are stronger than bdg. Only if aspiration is considered as part of the fortis-lenis opposition, not as a separate opposition, can ptk be considered as fortes in Danish.

From the auditory point of view the decisive difference between ptk and bdg lies in the aspiration. Tape cutting and splicing experiments have shown that an exchange of the explosion phases of p/b t/d k/g has no effect on the perception, and that a pause between explosion and vowel is not sufficient for the perception of ptk, there must be aspiration noise present.

Tests with identification of foreign stop consonants in meaningsless monosyllables cut out of words show that Danish listeners normally identify unaspirated voiceless stops (in Dutch, French, Hindi) as bdg, whereas voiced aspirated stops (Hindi) are normally identified as ptk. -

In later reports and articles a number of these points will be treated in more detail with documentation and references.

References:

1. Eli Fischer-Jørgensen: "Acoustic Analysis of Stop Consonants", *Miscellanea Phonetica* II (1954), pp. 42-59.

THE DANISH LONG VOWELS. *)

Børge Frøkjær-Jensen

This paper presents part of an analysis of the Danish long vowels in stressed position which was made in 1959/60. The paper summarizes an earlier article in Danish (1).

The investigation took place at the phonetics laboratory of Dr. Svend Smith at the Institute of Speech Disorders in Hellerup, where the Sona-Graph of the Institute of Linguistics and Phonetics was placed at that time.

25 subjects were recorded: 10 male speakers, 9 female speakers, and 6 children. In order to avoid mispronunciations, all the recordings were played back twice to the speakers, after which I also carefully have controlled the recordings myself. Because of the small number of subjects it was considered important to choose speakers without speech defects and with a pronunciation which by most Danish speakers would be estimated as correct and good Danish.

The linguistic material:

The following long vowel phonemes occur in Danish: /i:/ - /e:/ - /ɛ:/ - /a:/ - /y:/ - /ø:/ - /œ:/ - /u:/ - /o:/ - /ɔ:/. All these phonemes were analysed in stressed position in the most common Danish word type, the bisyllabic structure: 'CV-Cə. It was considered preferable to use words beginning with /h/ in order to avoid influence in the beginning of the vowel from the preceeding consonant or word. Thus all the vowels occur under the same test conditions, i. e. /h/ + long stressed vowel + unstressed syllable with ə. Unfortunately it is not possible to find a series of words with commutation between all the Danish long vowel phonemes.

The vowel [ɑ:] which is a combinatory variant of the /a:/-phoneme before and after /r/ was included in the analysis.

The following series of words were chosen for the analysis:

hine	[hi:nə]	hyre	[hy:ʁə]	hule	[hu:lə]
hede	[he:ðə]	høre	[hø:ʁə]	hove	[ho:və]
hæve	[hɛ:və]	høne	[hœ:nə]	håne	[hɔ:nə]
have	[ha:və]	harve	[hɑ:və]		

*) Part of a thesis for the cand.art.-degree. (See also p. 47.)

The Danish long narrow vowels are not influenced by /r/, therefore the vowels in the examples "hyre" and "høre" do not represent particular variants as for the /a:/-phoneme.

4oo words were recorded on the tape recorder, and the long stressed vowels from these words were analysed on the spectrum analyser ("Sona-Graph") to determine the formant frequencies.

The formant frequencies:

On the basis of 1o subjects I have found the following average formant frequencies for male speakers:

	/i:/	/e:/	/ε:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	233	277	356	512	685	24o	3o5	38o	254	348	413
F_2	2123	2o87	1968	1741	1139	1846	1628	1552	72o	75o	866
F_3	3oo9	2713	248o	2282	2458	2o37	2o13	2o31	2121	226o	2193
F_4	3327	3388	337o	3416	345o	3172	3151	3151	3247	3116	3172

(Average of the vowel formant frequencies in Danish for male speakers).

It is often very difficult to determine the formant positions of F_3 and F_4 from spectrograms of the back vowels /u:/, /o:/, and /ɔ:/ because of the very weak energy in the upper part of the spectrum, and very often the upper formants do not appear at all. In the formant frequency chart F_3 and F_4 of /u:/ are thus based upon 4 subjects only.

In an article by Dr. Svend Smith (2) the formant frequencies of the Danish vowel sounds are given for the first time. The findings of Dr. Smith were based upon direct listening to the formants by ear and controlled with the aid of a Siemens Tonfrequenz Spektrometer.

I have found that these formant frequencies are in rather good accordance with the frequencies from my investigations and corresponding analyses made by Eli Fischer-Jørgensen. The differences are small, but they are nevertheless clear. Dr. Smith has explained that the reason may be traces of Hellerup dialectal pronunciation in his speech. This is probably true of the rounded back vowels. If, however, we examine more closely the relations between the formant frequencies of Dr. Svend Smith and my subjects, we may observe that

(1) F_1 is higher in all vowels spoken by Dr. Smith,

(2) F_2 is lower in the front vowels, and

(3) F_2 is higher in the back vowels.

This is an interesting result, because it must mean that Dr. Smith during his pronunciation kept an intensity level in the phonation which was higher than the intensity level of normal speech.

(For further explanations: see the **next article in this report:** "Changes in formant frequencies and formant levels at high voice effort").

The analysis has given the following formant frequencies for female speakers and for children's voices:

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	278	345	413	572	808	247	346	413	290	371	432
F_2	2587	2555	2415	2145	1327	2041	1850	1817	797	778	968
F_3	3397	3161	2984	2898	2885	2383	2317	2537	-	(2660)	(2612)
F_4	4014	4082	4132	4118	3856	3685	3685	3656	(3755)	3749	3757

(Average of the vowel formant frequencies in Danish for female speakers).

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	304	407	479	553	985	281	413	478	305	413	461
F_2	2921	2571	2575	2347	1479	2181	1873	1831	794	875	981
F_3	3522	3287	3291	3043	2721	2605	2599	2682	(3155)	(3600)	(3160)
F_4	4427	4383	4339	4314	3997	3863	3932	4018	(3900)	(3915)	3933

(Average of the vowel formant frequencies in Danish for children's voices).

The last table of the vowel formant frequencies for children's voices is not statistically relevant because the material was too inhomogeneous. The table is only based upon 4 boys and 2 girls from 9-13 years old.

Accuracy:

The formant frequencies are subject to some uncertainty. It is not possible to read the spectrograms with an accuracy of more than ± 15 c/s. Furthermore the frequency response of the Sona-Graph may cause some shift in formant frequency if it is not quite flat. All analyses in this investigation were made with the "high-shaping" frequency response of the Sona-Graph. This means that all first formant frequencies probably are o - 25 c/s lower in real speech than the analyses state. Taking the accuracy of reading into consideration I suppose, without having done any experiments on the uncertainty, that the real frequencies of the first formant are o - 3o c/s lower than the charts indicate, and that the uncertainty for the other formant frequencies is in the order of ± 15 c/s. *)

Difference between male and female formants:

The cavities of the female vocal tract is smaller than the cavities of the male vocal tract. That means: the female formants must be higher than the corresponding male formants. Gunnar Fant has pointed out (3) that the female formants are on an average 17 % higher than the male formants, and the investigations of Chiba and Kajiyama (4) show that the female vocal tract is 15 % shorter than the male vocal tract.

On the basis of my material I have calculated the average difference in percentage between the female and the male formant frequencies and found it to be 16.1 %. Similarly, we find an average difference between the men's and the children's formant frequencies of 24.9 %. The greatest differences appear between the formant frequencies of the unrounded front vowels, and the smallest differences appear between the unrounded back vowels(5).

The phoneme areas:

Vowel diagram no. 1 shows the phoneme areas for standard Danish based on recordings from 1o male subjects. F_1 and F_2 are plotted into the co-ordinate system along the vertical and the horizontal axis, respectively. Envelopes have been drawn around the different phonemes and the variant [ɑ:] . You find 1o dots

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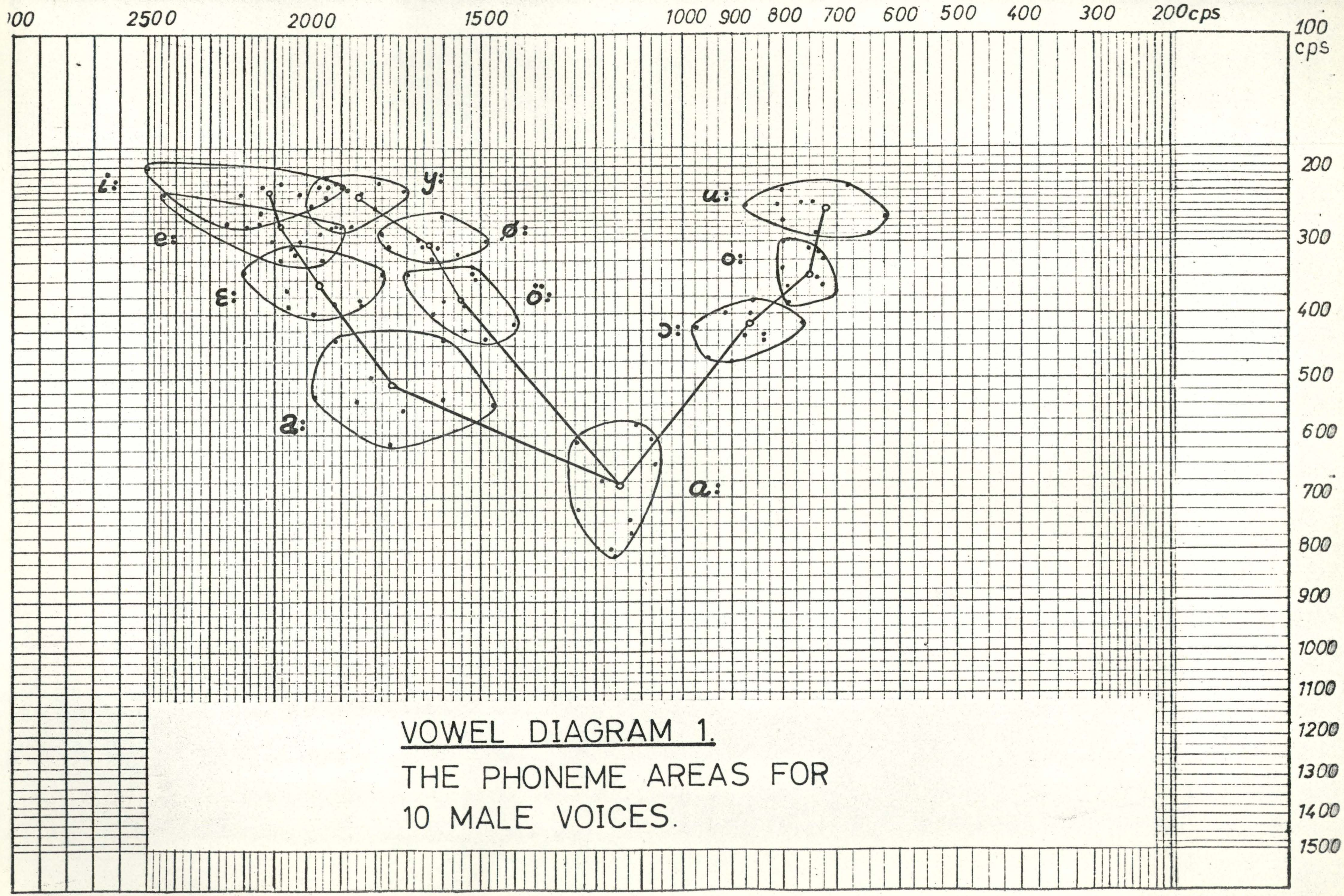
*) A presentation of the sources of error by sound spectrography based upon analysis of synthetic vowels is made by B. Lindblom (6).



VOWEL DIAGRAM 1.

THE PHONEME AREAS FOR
10 MALE VOICES.

in each envelope, one dot from each of the 1o recordings of the subjects.

For each phoneme envelope I have calculated the mathematical average frequencies for F_1 and F_2 and plotted these averages into the phoneme envelopes. All the average phonemes have been connected by lines. In this way we get a vowel triangle which is very similar to the well-known vowel triangle based on articulatory and auditory principles.

The mel-scale has been used in all the vowel diagrams in order to give a depiction which corresponds better to the auditory aspects of speech than does the linear frequency scale.

We observe that the phoneme areas are badly defined because of the overlapping between /i:/, /e:/, and /y:/, and further between /e:/ and /ɛ:/. That means that we find F_1/F_2 combinations in Danish which may be perceived e.g. either as /i:/ or as /e:/.

It is not certain that we still have overlappings between the areas if we take the formant intensity levels in account, or if we consider F_3 and F_4, but unfortunately it is very complicated to depict all these parameters in a two-dimensional vowel chart.

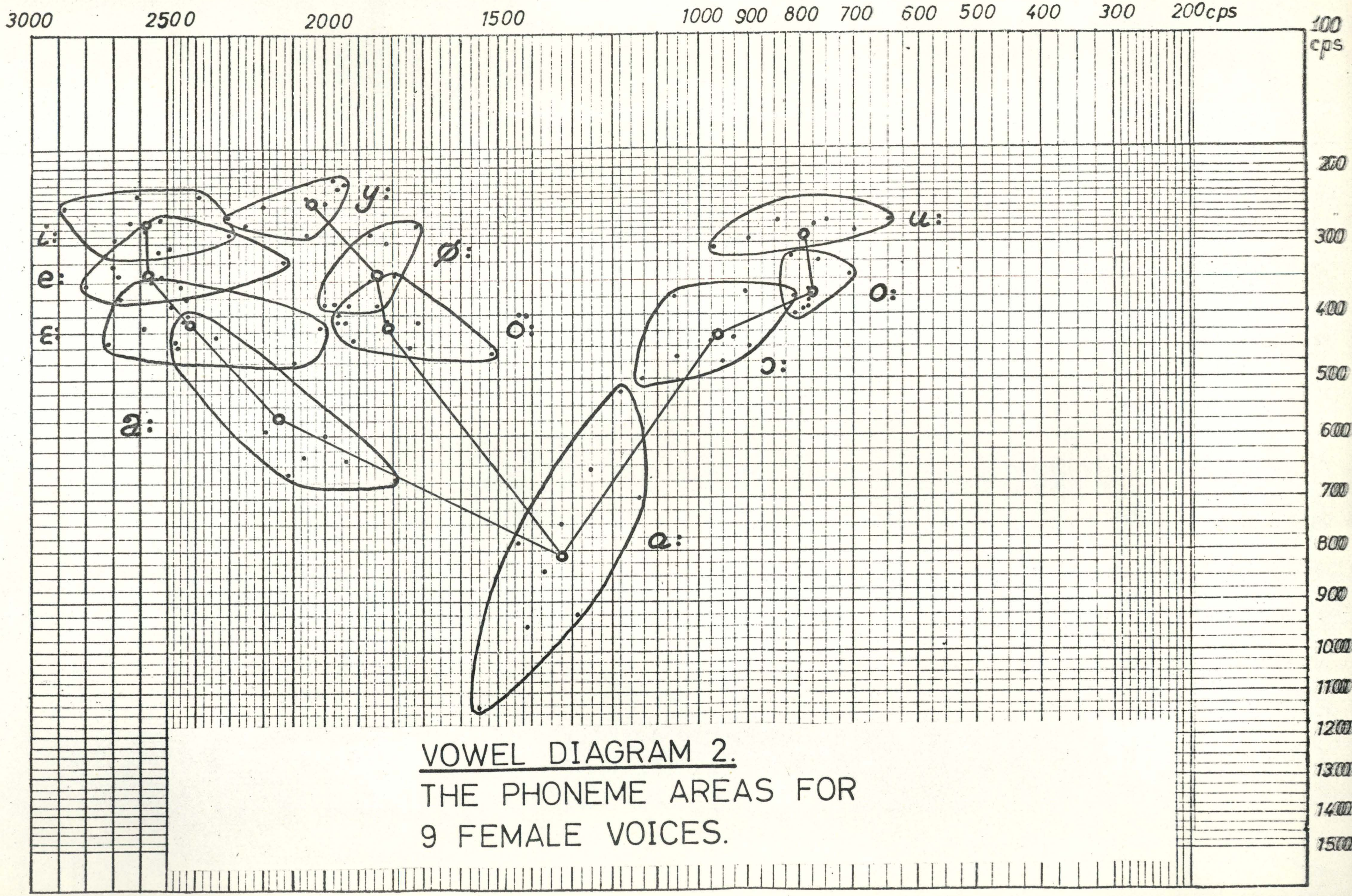
It is interesting to notice that the subject who has the best distinction between the phonemes, is a professional speaker at the Danish Radio.

Vowel diagram no. 2 shows the same phoneme areas for 9 female speakers. Notice here the great variability of the /a: - ɑ:/ phoneme in Danish.

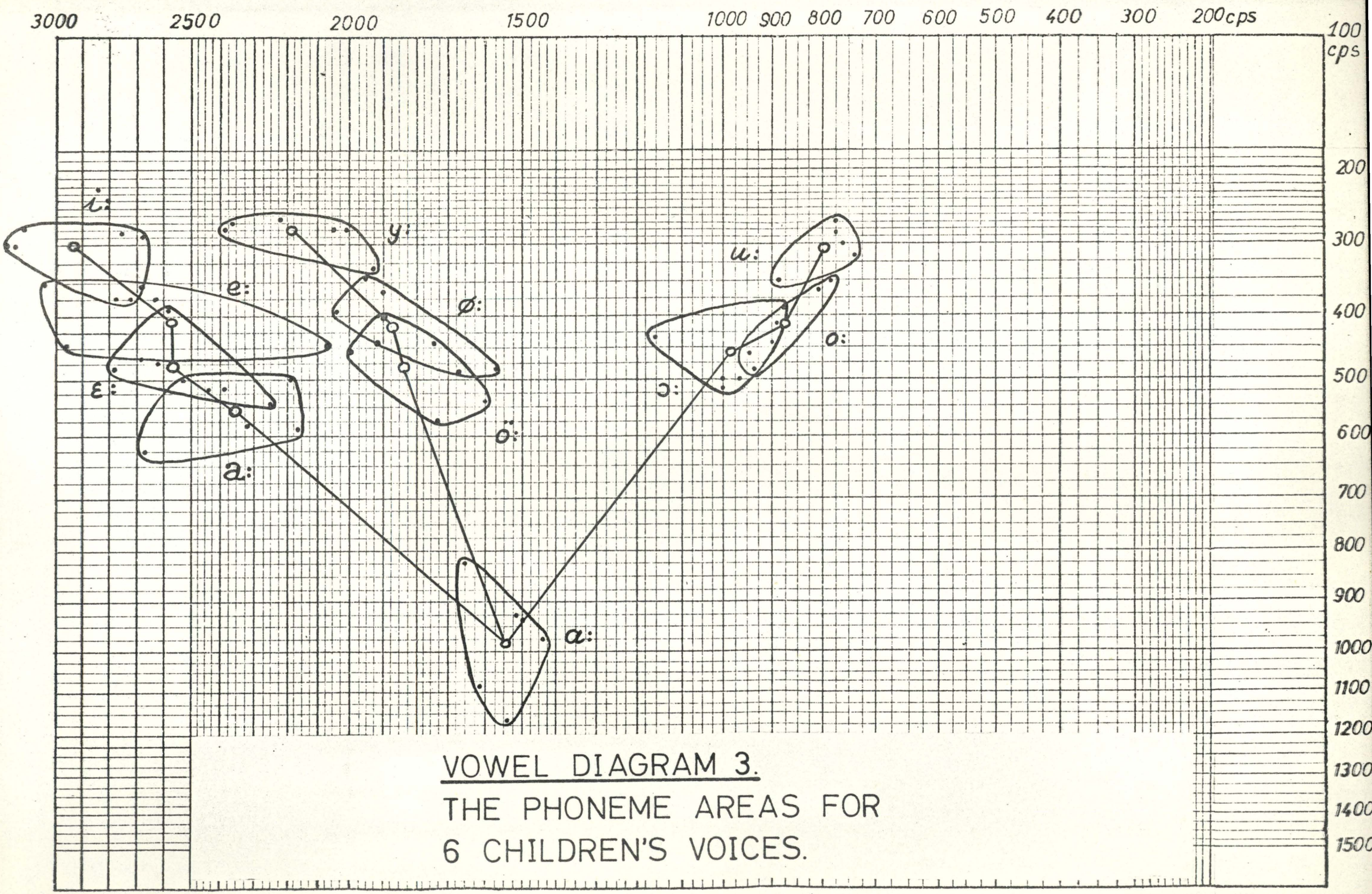
Vowel diagram no. 3 depicts the phoneme areas for 6 children's voices.

In vowel diagram no. 4 the phoneme areas of the male and female speakers are combined. It is interesting to see that the male and female front vowels are almost separated in this vowel diagram. For the back vowels the merging is more marked, but still we observe that the female speakers have a higher F_2 than do the male speakers.

If the children's phoneme areas had been plotted into the same vowel diagram (no. 4) you could observe a total separation between the corresponding phonemes of men and children.

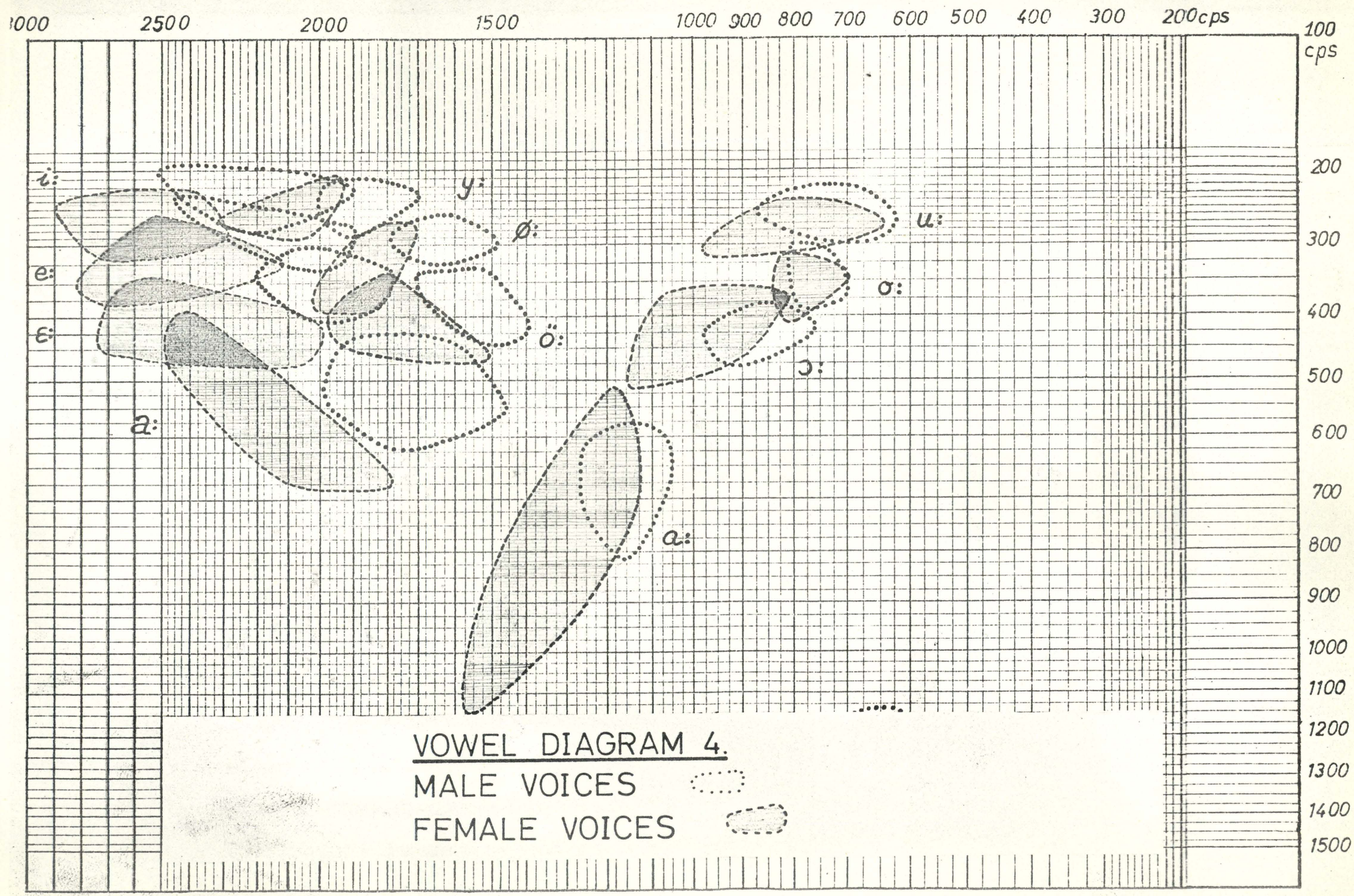


VOWEL DIAGRAM 2.
THE PHONEME AREAS FOR
9 FEMALE VOICES.



VOWEL DIAGRAM 3.

THE PHONEME AREAS FOR
6 CHILDREN'S VOICES.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VOWEL DIAGRAM 4.
MALE VOICES
FEMALE VOICES

The phoneme areas for one speaker:

One subject has spoken the eleven bisyllabic words with long stressed vowels lo times over a period of one year. The results are given in vowel diagram no. 5 based on the following average formant frequencies:

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	274	32o	423	557	757	263	356	466	295	39o	5o2
F_2	2187	2112	2o68	188o	1139	1898	1599	1572	768	732	88o
F_3	2988	2755	26o4	2449	2641	2144	21o3	2184	2156	255o	2483
F_4	339o	3367	33o7	333o	353o	3547	2962	31o8	3o93	3o61	3o13

(Average of the vowel formant frequencies for 10 recordings spoken by one speaker).

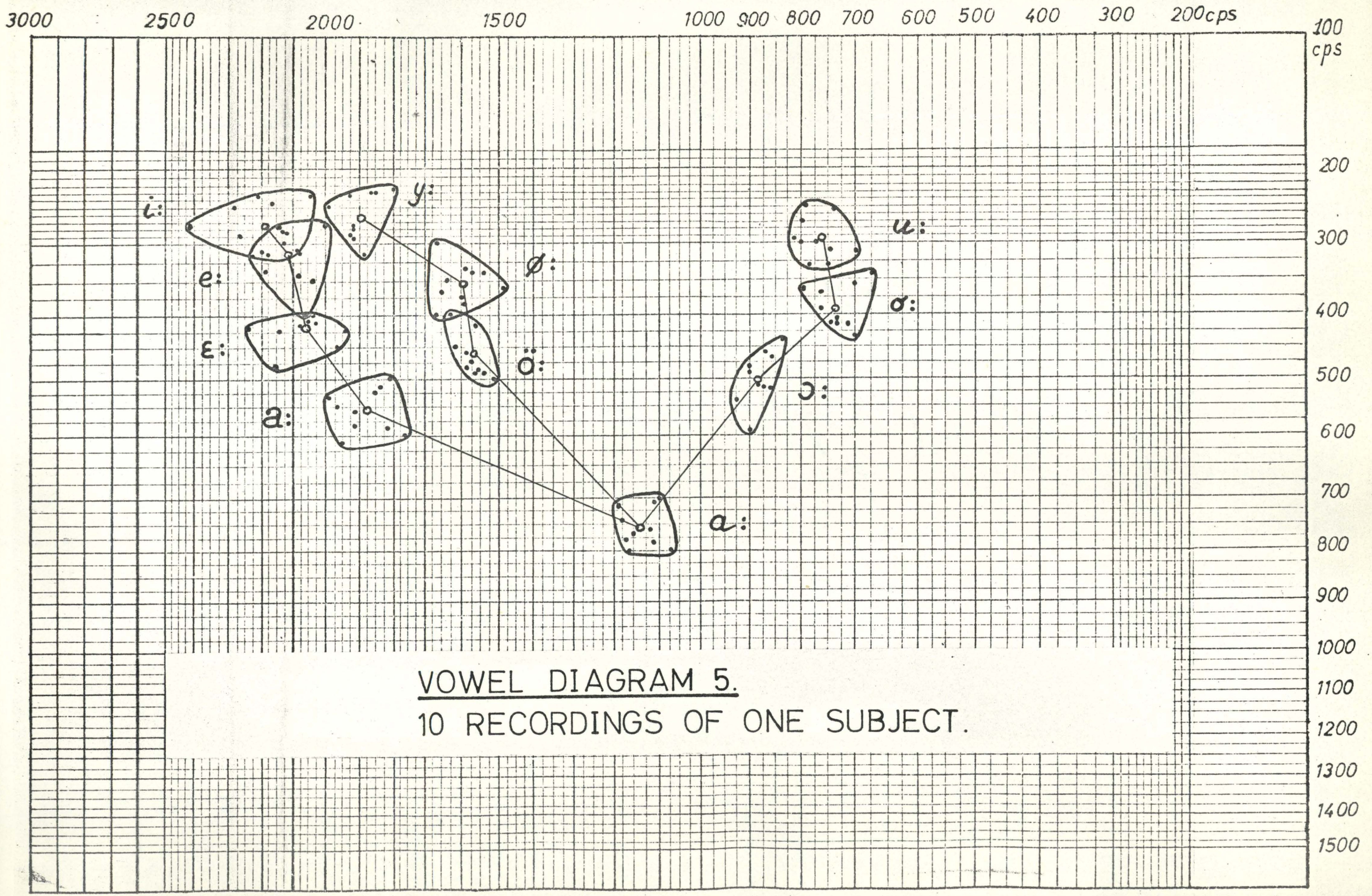
The lo recordings were, furthermore, spoken with different intensity levels. They therefore tell us a good deal about the variability in vowel articulation of the human voice. We may see that the phoneme areas are rather small (the variations in intensity level and the long time intervals between the recordings being taken in account). Overlapping of any importance only occurs between the phoneme envelopes of /i:/ and /e:/. If F_3 were taken in consideration (in a sort of three-dimensional pattern) the overlapping areas would be diminished because F_3 of /i:/ is spread out in the frequency range 3165-2665 c/s, and F_3 of /e:/ is spread out in the range 292o-264o c/s, but we still have some overlapping.

Corrections for F_3:

Gunnar Fant (7) has suggested a mathematical formula which combines the effect of F_2 and F_3 into one formant:

$$F_2' = F_2 + 1/2\ (F_3 - F_2)\ \frac{F_2 - F_1}{F_3 - F_1}$$

The application of this formula probably depends on the vowel system under consideration. The correction of F_2 may perhaps be used with advantage in vowel systems such as the Danish one, which has both rounded and unrounded front vowels. We get



VOWEL DIAGRAM 5.
10 RECORDINGS OF ONE SUBJECT.
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200cps
100 cps
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
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i:
y:
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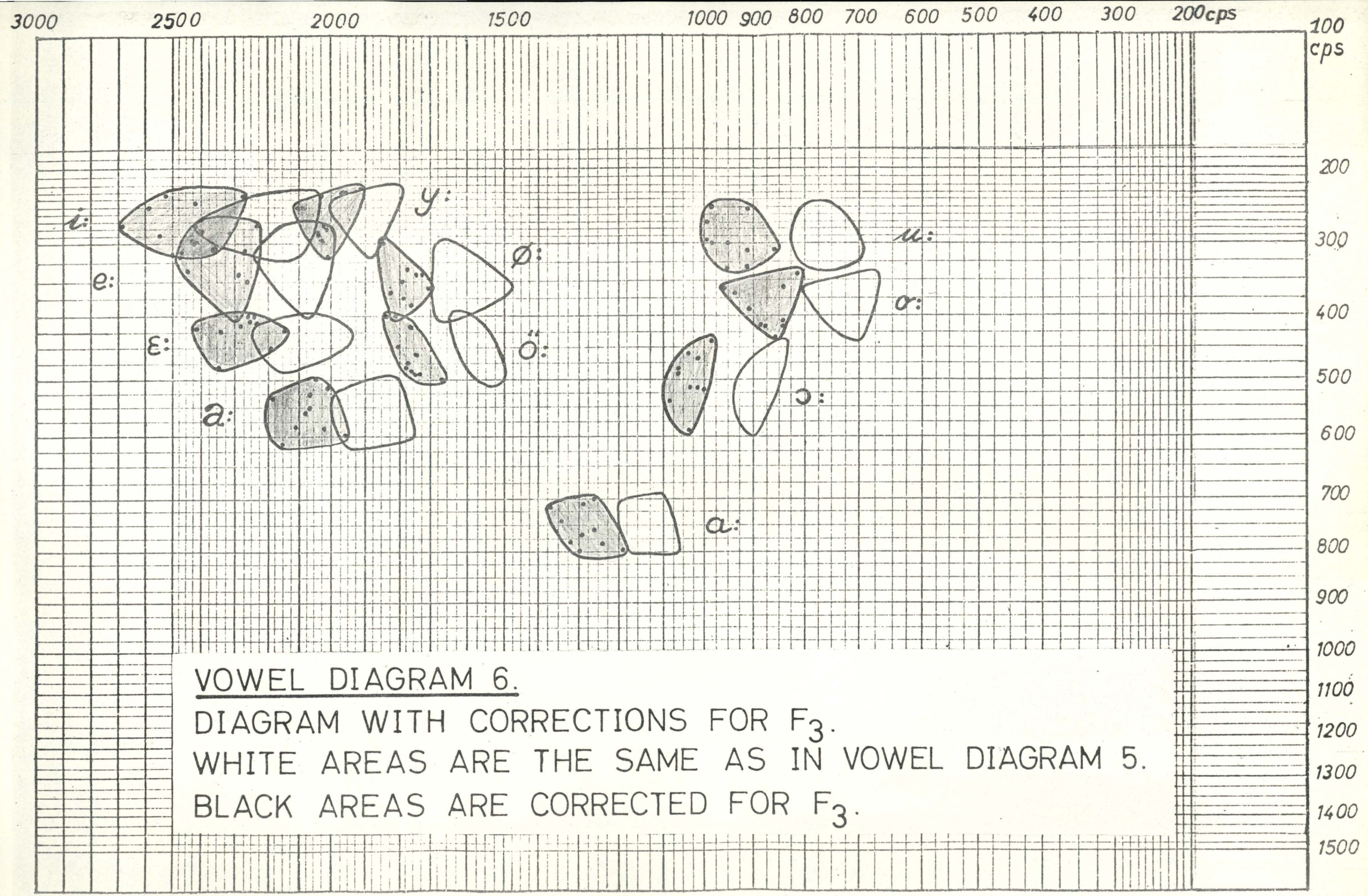
ɔ:
ɑ:



VOWEL DIAGRAM 6.

DIAGRAM WITH CORRECTIONS FOR F_3.

WHITE AREAS ARE THE SAME AS IN VOWEL DIAGRAM 5.

BLACK AREAS ARE CORRECTED FOR F_3.

a better differentiation between the phoneme envelopes in the pairs /i:/ - /y:/,/e:/ - /ø:/, and /ɛ:/ - /œ:/ when using this formula.

I have tried to calculate the F_2' formant frequencies from the last vowel diagram, no. 5. These calculations are used in vowel diagram no. 6 which represents the same recordings as diagram no. 5, but in diagram no. 6 both the normal phoneme envelopes and the F_3-corrected envelopes are drawn. We see the differences most clearly between the pairs /i:/ - /y:/ in the two depictions.

It is, however, dubious whether the advantage we obtain by using this correction for F_3 is worth the time we must use for calculations on a large amount of material.

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(1) B. Frøkjær - Jensen, "De Danske Langvokaler", Tale & Stemme 2(1963), pp. 59-75.

(2) Svend Smith, "Analysis of Vowel Sounds by Ear", Archives Néerlandaises de Phonétique Experimentale XX(1947), pp. 78-96.

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(4) Chiba and Kajiyama, The Vowel (1941).

(5) Gunnar Fant, "A Note on Vocal Tract Size Factors and Non-Uniform F-Pattern Scalings", Quarterly Progress and Status Report 4(1966), Speech Transmission Lab., RIT, Stockholm, pp. 22-3o.

(6) Björn Lindblom, "Accuracy and Limitations of Sona-Graph Measurements", Proceedings of the IV. International Congress of Phonetic Sciences, Helsinki 1961 (1962), pp. 188-2o2.

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CHANGES IN FORMANT FREQUENCIES AND FORMANT LEVELS AT HIGH VOICE EFFORT.

Børge Frøkjær-Jensen

In combination with the study mentioned page 34 ff. in this report an acoustic study has been undertaken to illustrate how an increase of voice effort affects the spectral composition of vowels.

The analysis comprised 2o subjects, who all were able to shout (not everybody can increase the voice effort to a "real shout"). All the subjects were recorded on tape when reading a word list containing the Danish long vowels in stressed position in two-syllable words of the type /hV-Cə/. Some of the subjects were recorded when reading the words with a higher degree of voice effort, and they were all finally recorded while shouting the words from the list.

The absolute sound level pressure was not observed during the recordings because of lack of equipment for that purpose, and the investigation should therefore be considered as preliminary. The speakers started the recordings with what may be called normal speech level. Then the voice effort was gradually increased to shout by some of the subjects. The remaining subjects only shifted between talking and shouting. The shout level varies for different speakers. Some persons can shout with an absolute sound pressure level of 7o-8o dB, whereas others are only able to shout with a level of 5o-6o dB, or not able to shout at all.

In a future investigation I should like to fix various speaking and shouting sound levels, e.g. 3o, 4o, 5o, 6o, and 7o dB re 0.0002 dyn/cm^2, and only subjects able to phonate and articulate all the vowels at these levels should be included in the investigation.

The entire material consists of 319 spoken vowels and 22o shouted vowels. During the recordings I took notes concerning the position of the larynx and mouth opening. All recordings were analysed on the Sona-Graph with the purpose of finding relations between changes in formant frequencies and changes in formant levels. The high-shaping filter of the Sona-Graph was used, and all the vowels were analysed with both narrow band and wide band filter, and several of the measurements were controlled by means of narrow band section sonagrams.

A. Directly observable changes in the articulation:

When the subjects increased their voice effort the following articulatory changes were observed:

1. The larynx may be either raised or lowered during a shout. Most people raise their larynx when shouting, but singers appear to lower their larynx when the intensity level is increased.
2. Higher intensity level is accompanied by a stronger contraction of the muscles of the larynx and pharynx. The muscles of the floor of the mouth (musculus mylohyoideus) is more contracted, too, i.e. the mouth is more open.

   This causes a better acoustic impedance matching between the mouth cavity and the air outside the mouth: more sound energy is transmitted to the surrounding air, and the damping is reduced. As for the "Radiation Load at the Mouth" see reference no. (1).
3. This impedance matching (A2) is probably improved by pulling the tongue backwards.

B. Changes in formant frequencies:

1. The above-mentioned changes in articulation influence the formant frequencies, and for all male voices, female voices, and children's voices separately, I have calculated the mean values of the formant frequencies both in normal speech and in shout.

   In the diagram shown below I have indicated whether the formant frequencies in shout are higher (+) or lower (-) than those for normal speech. The three symbols in each column indicate the direction of change for male voices, female voices, and children's voices, in that order.

	i:	e:	ɛ:	a:	ɑ:	y:	ø:	œ:	u:	o:	ɔ:
F_1	+++	+++	+++	+++	−++	++−	+++	+++	+++	+++	+++
F_2	−−−	−−−	−−−	−−−	+++	−−−	−−−	−−+	+++	+++	+++
F_3	−−−	−−−	−−−	++−	+++	+++	+++	+++	?	?	++−
F_4	−−−	−−−	−−−	−+−	−+−	−+−	++−	−+−	−+−	−−?	++−

The diagram shows that:

F1 is raised in all vowels in shout as compared to speech.

F2 is raised in the back vowels and lowered in the front vowels (this lowering is more pronounced in the unrounded than in the rounded vowels).

F3 is raised in the rounded front vowels and lowered in the unrounded front vowels.

The material is too restricted for anything conclusive to be said about the back vowels, but possibly they follow the front vowels in the separation of rounded/unrounded.

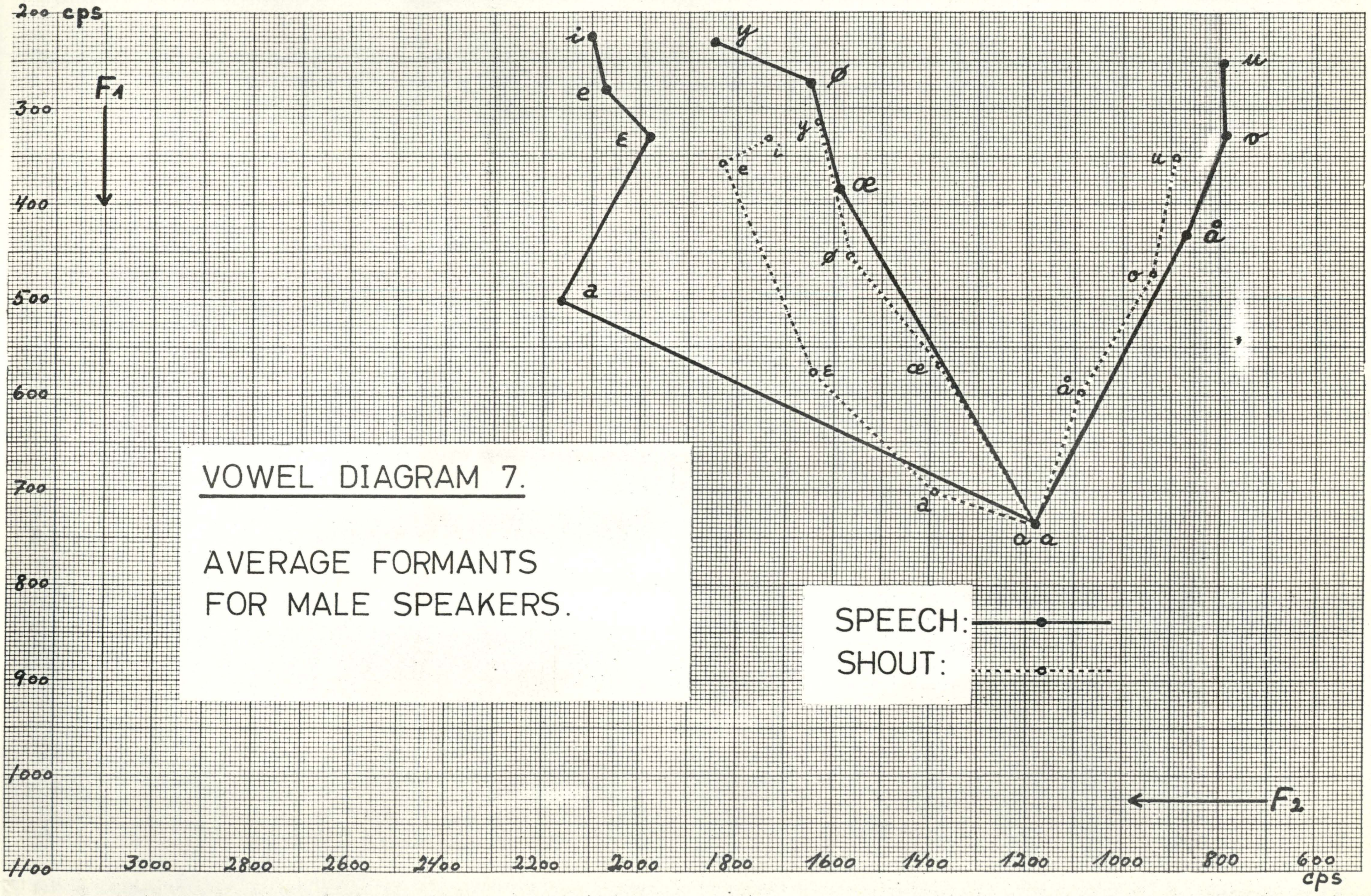
F4 follows F3 to a certain degree, but is probably individually conditioned by the subject.

2. Some of these variations are shown in vowel diagrams "7" and "8" (which are taken out of a larger set of diagrams). Diagram no. 7 shows the male vowel patterns in normal speech and in shout. Only the calculated average frequencies have been plotted into the diagram. The averages are normal arithmetical mean values measured in c/s (it would perhaps have been more significant to calculate the average of the formant frequencies represented in terms of the mel scale).

The main tendency to be observed is that the vowels are moved in the direction towards a more open and more central articulation at higher voice effort. Vowel diagram no. 8 for female speakers shows this tendency more clearly. In spite of these changes in phoneme areas when the voice effort is increased, all the shouted vowels utilized in this investigation are clearly identifiable. (The badly identifiable shouted vowels were omitted from the investigation during the tape recordings.)

3. Besides the changes in the formant pattern we can observe a change in the fundamental frequency. The fundamental frequency goes up when the intensity level is increased, sometimes the fundamental frequency is one octave higher in shout than in normal speech. This connexion between intensity level and fundamental frequency has been observed before (2).

4. The formant structure becomes less regular because of many small uncontrolled contractions of the muscles in the speech organs.



VOWEL DIAGRAM 7.
AVERAGE FORMANTS
FOR MALE SPEAKERS.
SPEECH:
SHOUT:
F1
F2
200 cps
300
400
500
600
700
800
900
1000
1100
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
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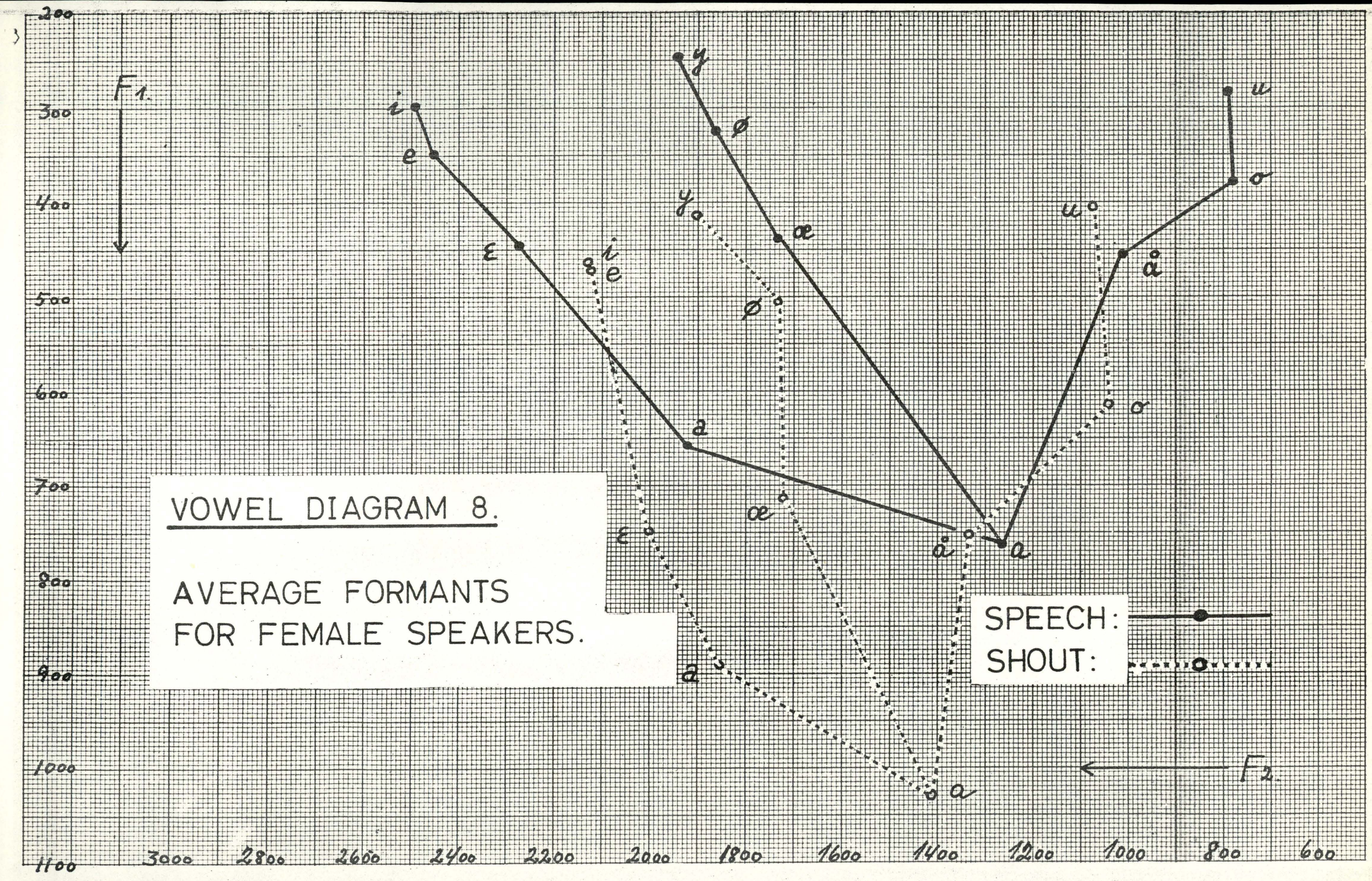
o
å
ɑ


VOWEL DIAGRAM 8.
AVERAGE FORMANTS
FOR FEMALE SPEAKERS.
SPEECH:
SHOUT:
F1.
F2.
200
300
400
500
600
700
800
900
1000
1100
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
i
e
ɛ
a
y
ø
œ
u
o
å

C. Changes in formant levels:

On the basis of the present material it is possible to measure the relative changes in the spectral distribution of energy when the subjects change their voice effort.

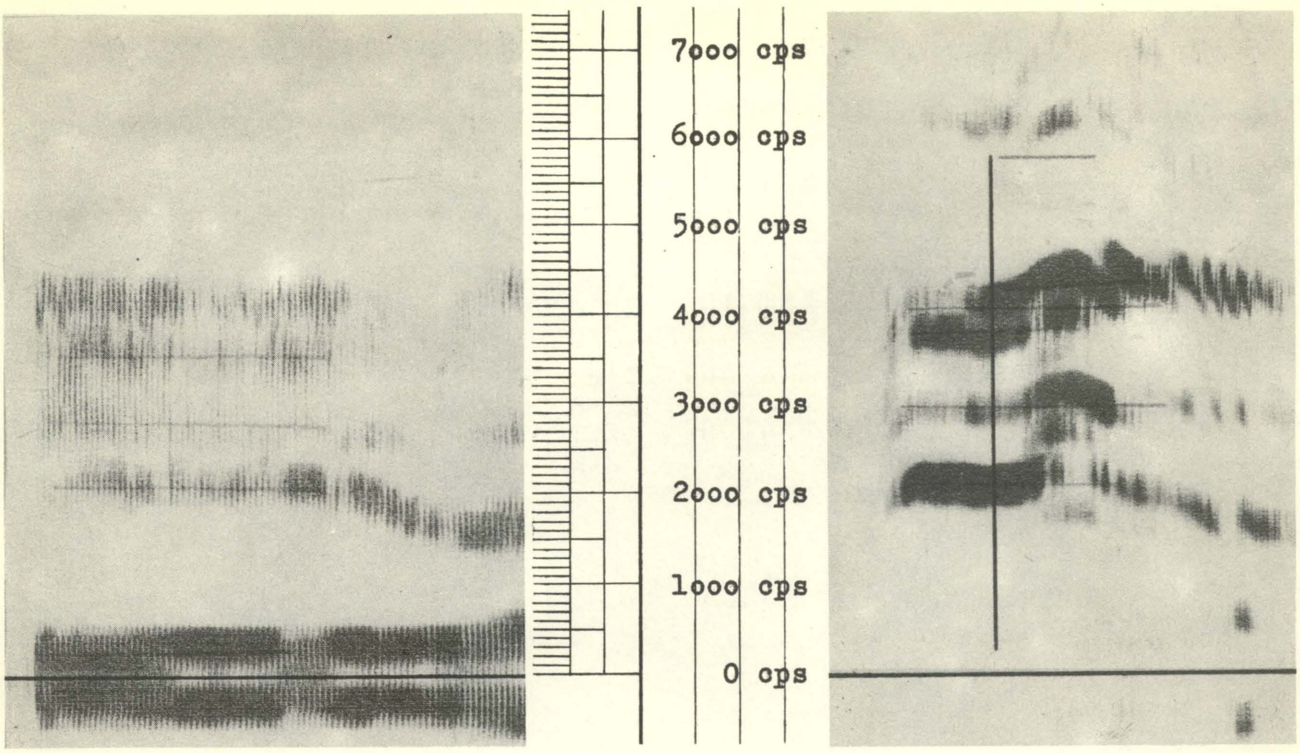
1. The spectrum above 2500 c/s is intensified and the spectrum below 1500 c/s is weakened. The frequency limits depend upon sex and age.
2. As a result of (C1) the harmonics in the range of the first formant may be reduced in intensity level in relation to the rest of the spectrum. In some cases F1 does not show up at all in the sonagrams.
   I have measured a 15-2o dB reduction of L1 (level of F1) in relation to the remaining part of the spectrum. (3)
3. F3 and F4 often contain more than half of the total energy (F5 is often prominent, and may even be the strongest formant).
4. The auditive result should be that the energy center of the upper formant areas thus moves upwards.

A few sonagrams illustrate this:

5. The next page shows sonagrams of the Danish words "hede" [he:ðə] and "hule" [hu:lə] . The first sonagram [he:ðə] is made from the recording of a female voice at normal speech effort. F1 is clearly most prominent; F2, F3, and F4 are all considerably weaker.

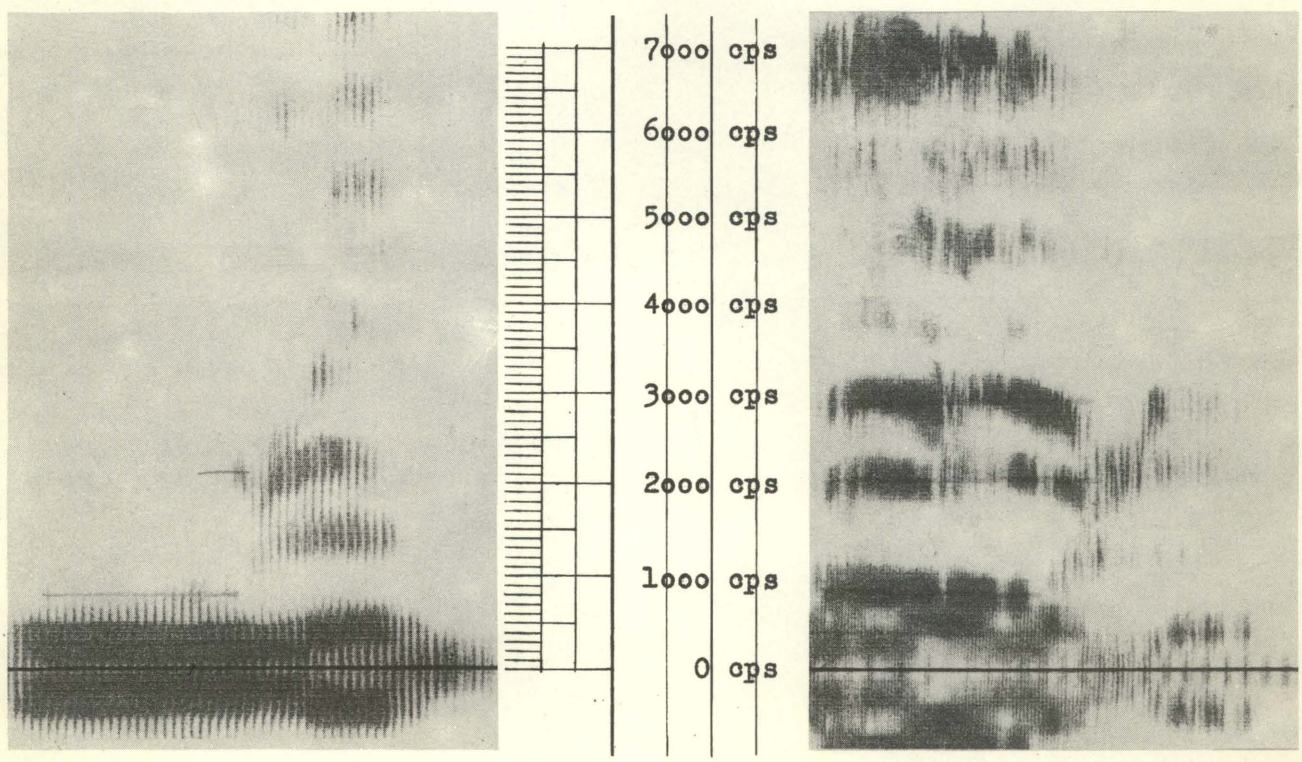
   The next sonagram shows the word [he:ðə] shouted by the same speaker. It is highly conspicuous that F1 does not show up at all in this sonagram of shout, and that the higher formants F2, F3, and F4 are very strong and well defined.

   The second sonagram of the word [hu:lə] shows the same shift in spectral energy. In normal speech nearly all the spectral energy is concentrated in F1. F2 is barely visible, and the same is true of F3. In the sonagrams of shout F2, F3, and F4 are stronger than F1.
6. The change in energy distribution of the shouted vowels is mainly due to a shift in poles and zeros in the primary voice spectrum (4),(5),(6),(7),(8). However, we are not yet equipped with instruments for acoustic investigation of the voice source (inverse filtering).



he: ð ə   he: ð ə

Normal speech - - - - - - - contra - - - - - - - shout



hu: l ə   hu: l ə

I have only shown a few of the most typical modifications that can be observed from my material. Other features of interest have not been investigated in sufficient detail for presentation.

D. Conclusion.

1. Because of the upward shift (see section B) of F_1 and the downward shift of F_2, the vowel quality of the front vowels changes in the direction close → open, whereas the back vowels, because of the constant relation between F_1 and F_2, change perceptually from the quality associated with male voices to that of female voices and ultimately to that of children's voices.
2. Because of the shift in intensity level (see section C) with the upper part of the spectrum emphasized and the F1-region weakened, we must get a perceptual change of the vowel quality in the direction open → close for the front vowels, whereas the back vowels will only get a brighter timbre.
3. In spite of the fact that both the formant frequencies (dependent on articulation) and the distribution of energy in the spectrum (dependent on primary voice source) are changed, the vowels are clearly identifiable.

   The nearest explanation seems to be that the changes in articulation are oppositely directed to the changes in voice source spectrum in such a way that the outcome of the two changes is that the identity of the vowels is preserved.

References:

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(3) B. Frøkjær-Jensen, Comments of the closing session of "Speech Communication Seminar" in Stockholm (1962): "Variations in the Glottal Spectrum", Proc. of the SCS, Vol. III, Discussions, pp. 12-17.

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STUDIES OF THE PROSODIC PROPERTIES OF DANISH WORDS.

Jørgen Rischel.

The prosodic features characterizing Danish word structures are being analysed. It is to be examined in detail for Standard Danish how tonal contours, stød, etc. serve to signal on the one hand the syllable number (and the structure of syllables), on the other hand the grammatical structure of the word. An acoustical analysis is made alongside with a structural study of Danish word phonology.

Acknowledgements:

My Nordic studies are supported by a subvention from Ludvig F. A. Wimmer's Legacy.

STUDIES OF DIPHTHONGS IN FAROESE.

Jørgen Rischel

A synchronic and diachronic description of the vowels and diphthongs in Faroese is in preparation. Some general considerations will be presented in this brief report. Previously, a survey of the sounds in Faroese has been published in Danish (1), and an article on the long and short vowels (presenting some spectrographic material) appeared more recently (2). It has been shown in these articles that there is in Faroese no simple phonetic one-to-one correspondence between long and short vowel units: most of the long units are either clearly diphthongal or intermediate between the short ones in their phonetic quality. The structural analysis poses serious problems, which I hope to discuss in a future paper.

The true diphthongs in Faroese seem to constitute three groups, viz. I. diphthongs ending in a narrow palatal glide: [ɛi, ai, ʊi, ɔi], II. diphthongs ending in a narrow velar glide: [ʉu, ɔu/œu/ɛu] (with dialectal variation), III. diphthongs ending in a very open vowel: [ɛa, ɔa]. Diphthongs of group I occur both long and short; these are (except [ʊi] old diphthongs. Most of the other diphthongs originate from long vowels, and some of these present developments that are at first sight quite puzzling. However, a pattern of development emerges.

We can postulate two tendencies in the development of diphthongs in Faroese: a. a tendency for open vowels to become opening diphthongs (diphthongs of group III originating from Old Norse é, æ, a and from á, respectively), b. a tendency for close vowels and closing diphthongs to move from front to back or from back to front, old front vowels becoming back-front (Old Norse í, ý became [ʊi]) , and old back vowels becoming front-back (Old Norse ú became Modern Faroese [ʉu] or rather [ʏu]). This occurred also with diphthongs with a more open first vowel (ey or øy became [ɔi]), although with ei and ó it took place only in some dialects (ei to [ɔi], ó to [œu, ɛu]). - Somewhat apart from the rest, old au has become [ɛi].

It is the primary purpose of the continued study to determine more exactly the phonetic quality of the diphthongs in the major dialects of Modern Faroese and thus to test the phonetic validity of the classification of the diphthongs suggested above. This is further to support the generalizations made about the developments. Scholars writing on the sound history of Faroese have generally taken each vowel or diphthong per se and have strived in vain to "explain" the peculiar developments of the individual vowels or diphthongs (especially í > [ʊi]). It seems to this author that no explanation can be hoped for unless we test the possibility of writing the developments on a common formula. This, however, demands a close examination of dialects. The "standard language", which has been the basis of most writings on the subject, presents a rather mixed picture, and only by studying the vowel patterns of some of the more peripheral dialects can one hope to disclose the systemic features in Faroese diphthongization and thus get a valid starting-point for explanations. A hypothesis that must obviously be tested says that the diphthongization of long vowels was forced upon them by the quantity shift, since the short vowels, when lengthened, might otherwise coalesce with the old long vowels. It can be shown that the conditions were essentially different from those of Icelandic, for example.

References:

(1) Jørgen Rischel, "Om retskrivningen og udtalen i moderne færøsk" in Jacobsen & Matras, Føroysk-donsk orðabók (Faroese Danish Dictionary), 2nd ed. (1960), see pp. XVIII-XXV.

(2) Jørgen Rischel, "Toward the Phonetic Description of Faroese Vowels", Fróðskaparrit 13 (Torshavn, 1964), pp. 99-113.

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MURMURED (BREATHY) VOWELS IN GUJRATI.

Eli Fischer-Jørgensen

An investigation of Gujrati breathy vowels is in progress. A preliminary result is that these vowels have a stronger airflow and that their acoustic spectrum shows an increased intensity of F_o compared to F1. A more detailed account of the results will be given in the report for 1967.

ANALYSES OF FRENCH ACCENT.

Børge Spang-Thomsen

A series of French sentences, composed by the present contributor and spoken by three French subjects, has been analysed at the Institute. The vowels in cue words were measured with regard to spectral composition, duration, intensity, and fundamental frequency. This material is to supplement the data published in an earlier article on French accent (1). The vowels occurring in the original material were both stressed and unstressed and both short and long. The short vowels mostly appeared in open syllables, and when occurring finally these were very difficult to measure since it could not be determined how much of the final phase recorded by the instruments is actually perceived by the human ear. The supplementary material is composed in the same way, but now all the short vowels occur in closed syllables, so that they can be delimited. Furthermore, the unstressed syllables of the new material are distributed in such a way that the subjects have been prevented from pronouncing them stressed by mistake, as it sometimes happened in the original material.

- A series of spectrograms (wide, narrow, and cross-sections) of a selection of sentences from the gramophone records belonging to Mme Léon's French Pronunciation Exercises (2) has been taken at the Institute. This material is intended as verification of the points of view advanced in a recent article (3) in the tome II, fasc. 1, of the Revue Romane (Copenhagen, 1967). In this article it is claimed that, contrary to the traditional view, the accent of French is a word accent which is not bound to the final syllable. This implies that the so-called mute e should be regarded as a neutralisation of all the other vowels in the unaccented position. This view is tenable only if the appearance of mute e in accented syllables is excluded. However, some phoneticians count with a mute e even in this position as something different from /ø/ and /œ/. We hope to show on the basis of the material under analysis that only /ø/ and /œ/ are found in the stressed position.

References:

(1) Børge Spang-Thomsen, "L'accent en français moderne", Orbis Litterarum, Supplementum 3 (1963), pp. 181-208.

(2) Monique Léon, Exercices systématiques de prononciation française (Paris, 1964). (Reviewed by BST in Moderna Språk (1966), pp. 116-129.)

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FEATURES OF THE ACOUSTICAL AND PHYSIOLOGICAL STRUCTURE OF THE FRENCH NASAL VOWELS. *)

Ole Kongsdal Jensen

The purpose of this work was to examine the validity of the general opinion on the articulation of the French nasal or nasalized vowels, as stated by Maurice Grammont in his "Traité pratique de prononciation française", p. 55 (Paris 1958). This I have done partly by resuming and comparing the results of former investigations of the subject, partly by doing instrumental work.

All scholars,except Durand (1), agree in finding that the first formant of nasalized vowels is weakened compared to the first formant of the corresponding oral vowels, and the same is often found to be true of the higher formants, too. Moreover, many investigators find that nasal formants are added at 1000 c/s, 2000 c/s, etc., which can also be found in the nasal consonants. Delattre (2) and Fujimura (3) find a nasal formant at some 250 c/s. Fant (4) is of the opinion that "the intensity reduction of the first formant is the major perceptive cue for nasalization."

My own work was done in order to compare French nasal and oral vowels in similar surroundings, and further to search for acoustical features shared by nasal vowels and nasal consonants. These investigations were made during 1965. A material of 95 french words with nasal and oral vowels: [ɛ], [a] , [ɑ], [ø] ; [œ]; [o] , [ɔ]; [ɛ̃], [œ̃], [ɑ̃], [õ] (the narrowest oral vowels were of no value for comparison) in stressed position and in different surroundings (e.g. hais: hein, c'est: sain, mais: main), plus 6 phrases with the same vowels for control, were recorded - twice for each person - on magnetic tape (BASF LGS 35) with a Lyrec tape recorder; 4 French male subjects with an acceptable Paris accent were used. (With my present experience, I should prefer fewer words and more persons and recordings for greater statistic certainty.) - Afterwards, the second recording of each person was analysed acoustically by means of the Sound Spectrograph (Sonagraph). Wide, narrow, and section

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*) MA - thesis completed in February 1966.

spectrograms were taken of all vowels. Furthermore, I made double flow-graphs (mouth and nose air-flow) of a restricted material (27 words), using the Electro-Aerometer constructed by Svend Smith and Børge Frøkjær-Jensen.*) 4 subjects were used for this recording: the first and third of the men from the acoustical recording, plus two French women with the same linguistic characteristics. I made a tape recording of what was said into the aerometer for control. Here, too, two recordings of each person were made - each with the words in two different orders to minimize the influence of rhythmization (one of the women said the 95 word list twice), and the second recording was measured.

On the spectrograms, I measured F_o and the first 4 vowel formants, plus extra resonances of interest (not always visible). I compared the spectra of the oral and nasal vowels, also observing how they develop in time. For one single vowel I took cross-sections at different sampling points.

To visualize the particular quality of the nasal vowels, I plotted them with the oral vowels in a two-dimensional chart (mel scale), with F1 and F2 as coordinates. It is seen that [ɛ̃] and [œ̃] lie close together around [œ] with a tendency towards [a], [ɑ̃] tends towards [ɔ] , and [õ] lies between [ɔ] and [o] (cp. Fig. 1, which represents one male informant).

From the acoustical analysis I conclude that the following acoustical features separate the French nasal vowels from the oral vowels:

1. F1 is weakened (sometimes not in [ɑ̃]).
2. The low formant Fu appears at about 200 c/s; it is probably equal to the first formant N1 of the nasal consonants.
3. The other formants are weakened, especially F3.
4. Extra formants may occur at about 1000 c/s and 2000 c/s, sometimes at 3000; they are probably identical with N2-N4 (4) of the nasal consonants; these formants are generally weak.

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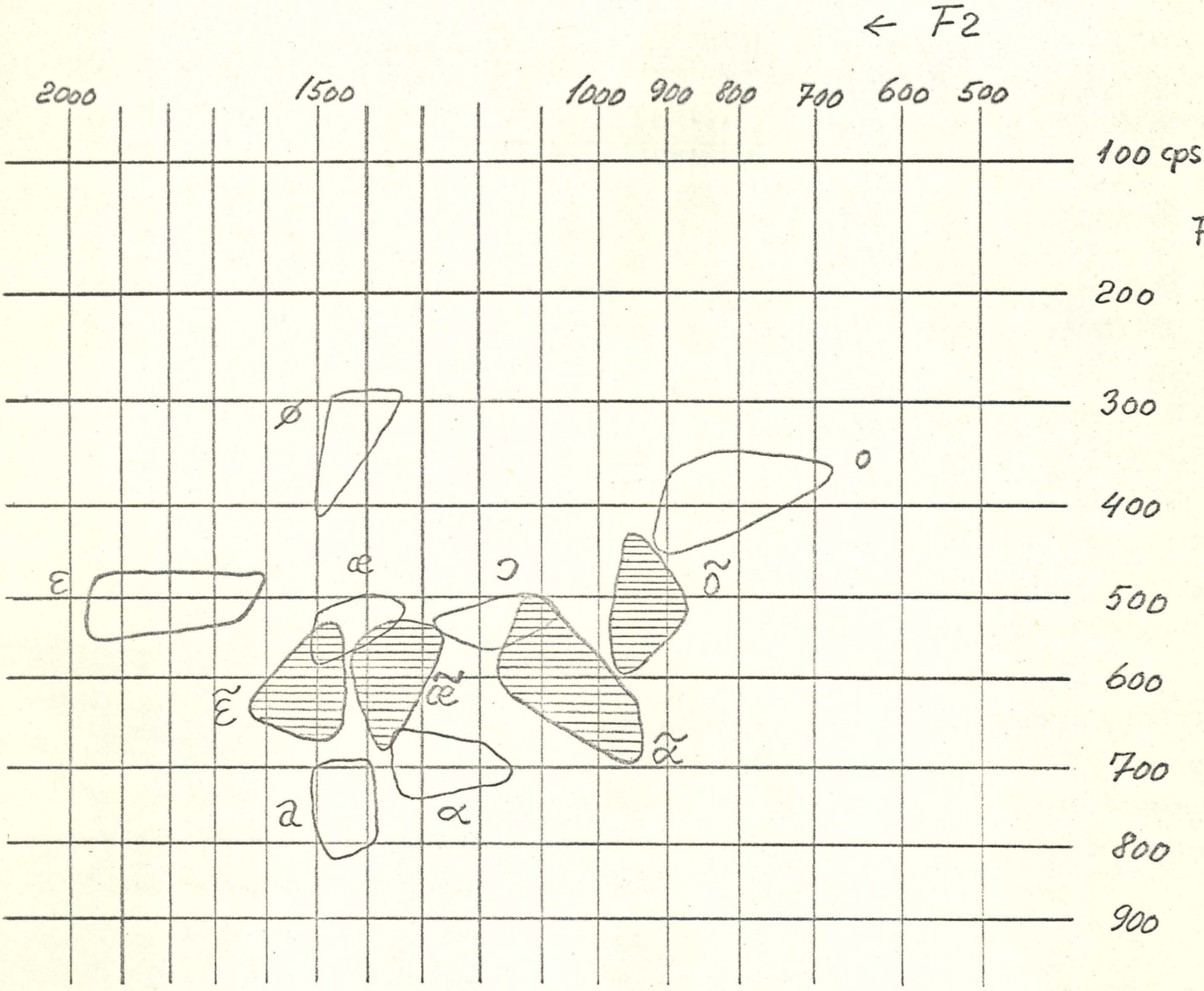
*) The air-flow opens a rubber valve, through which a light beam hits a photo-electrical cell, and the current from the cell is amplified and recorded on a Mingograph.



← F2
2000
1500
1000
900
800
700
600
500
100 cps
F1 ↓
200
300
400
500
600
700
800
900
ø
o
ɛ
œ
ɔ
õ
ɛ̃
œ̃
ɑ̃
a
ɑ

Fig. 1

5. The degree of nasalization is generally constant in isolated vowels (except that [õ] often changes). In context, however, the degree of nasalization increases from the beginning of the vowel to the end, so that the vowel probably often ends in a nasal consonant - in final position [N], before an occlusive a nasal consonant with the same point of articulation as the occlusive (3). After an occlusive one can often see an oral phase in the first part of the vowel, and the features mentioned (1.-4.) appear after some csecs. The features found in the nasal vowels are also seen in oral vowels adjacent to a nasal consonant, only to a smaller degree, and especially in the part of the vowel that is close to the consonant.

- - - -

For illustration I tabulate the average formants for subject no. 3:

F_o: average: 1o9 cps; variation: 93 c/s - 143 c/s.

Vowel	Fu	F1	F2	F3	F4
[ɛ]	(193)	514+	1798+	2619	3728
[a]	(19o)	752+	1453+	2449	3657
[ɑ]	?	7o5+	1244+	2415	3662
[ø]	((171))	334+	1429(+)	2162	3262
[œ]	(c.2oo)	531+	1429+	2356	3452
[o]	(175)	39o+	815	229o	(3286)
[ɔ]	(188)	518+	11o5(+)	241o	346o
[ɛ̃]	2o8+	629	1518(+)	2732	3649
[ɑ̃]	197+	6o1	1o54(+)	2283	3532
[œ̃]	219+	586	1359+	2455	3516
[õ]	218+	514	933	2118(?) (2833?)	3248

+ means a relatively strong formant, (+) means a weaker formant. Formant frequencies in brackets are uncertain.

As for air-flow, I recorded the expiration and inspiration by the nose, the expiration by the mouth; and the vibrations of the vocal chords (oscillogram from a throat microphone) at a speed of 100 mm per sec. The extension of each vowel was determined by comparing all four curves, and I measured the middle height of the two expiration curves above a zero line drawn between the lowest points of these curves. Examples are given in Fig. 2.

As these measures are relative, I invented the factor q = the ratio between nose expiration and mouth expiration for a given sound. With a certain reservation, q expresses the relative degree of nasalization. As expected, q is very low (practically zero) for the oral vowels, and many times higher for the nasal vowels - when q of the corresponding oral vowel has any positive value at all, that of the nasal vowel is mostly 10-20 times higher. The q-values of oral vowels may be due to a general "nasal" pronunciation, except in very open vowels (see later). In nasal surroundings the q-value of oral vowels are often higher than in "pure" oral vowels.

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For illustration I give the q-values of subject no. 3:

Vowel	q	q (normalized)
[ɛ̃]	0.86 (0.87)	1.0 (1.0)
[œ̃]	0.97	1.13 (1.12)
[ɑ̃]	2.1 (1.6)	2.4 (1.8)
[õ]	2.8 (1.14)	3.3 (1.3)

The numbers in parentheses are based upon the entire vowel, the others on the nasal phase only (if such a "phase" occurred).

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The result of the physiological part of the investigation can be expressed as follows:

In the articulation of Paris-french nasal vowels, the velum is lowered, either before or simultaneously with the onset of voice. [õ] (and sometimes [ɑ̃]) is more strongly nasalized than the others (maybe this has something to do with the small mouth opening in [õ]). Oral vowels before nasal consonants are slightly nasalized towards the consonant; the same is probably

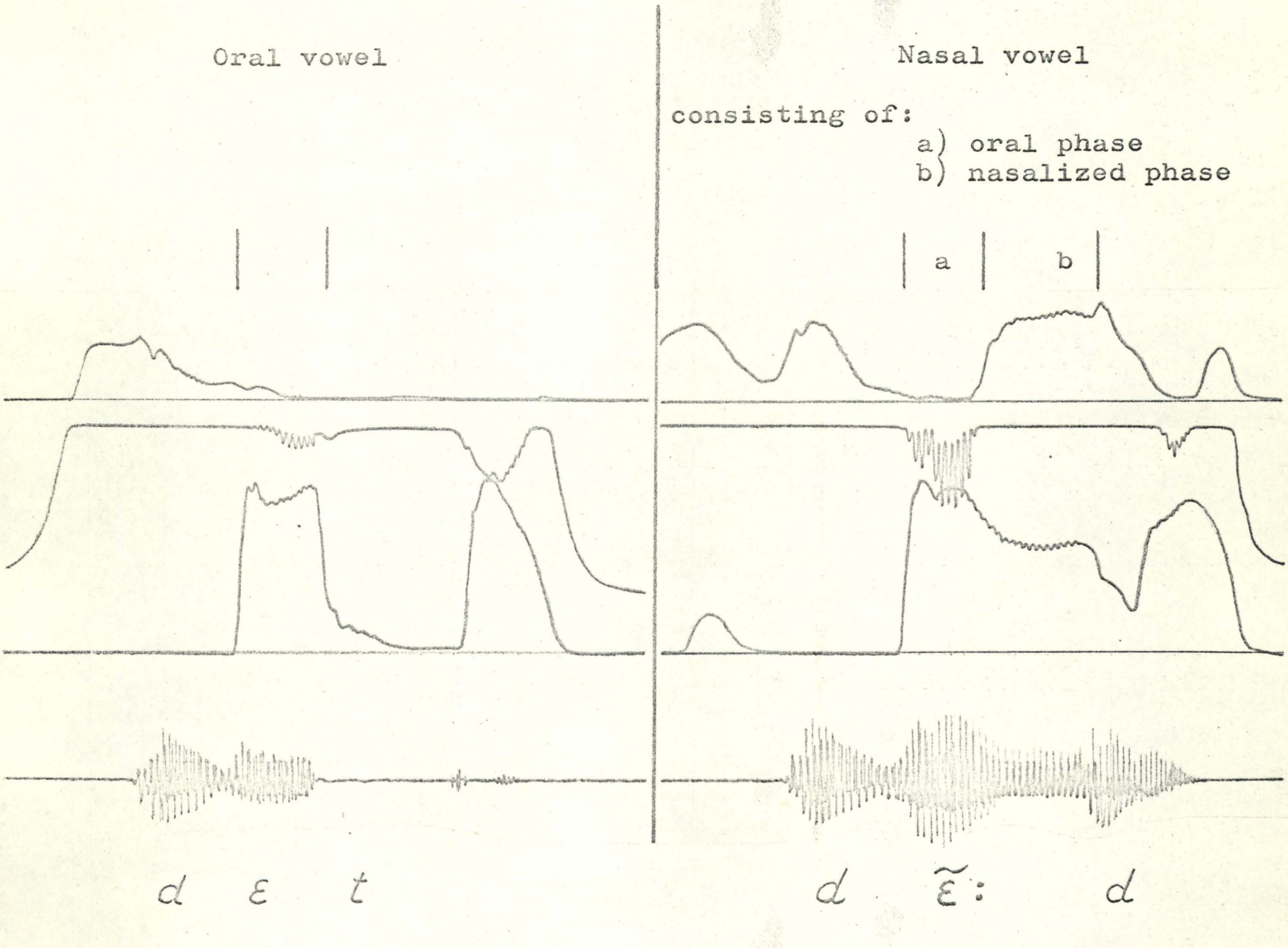

Fig. 2.

Curves from top to bottom:

(1) nasal egressive air,

(2) nasal ingressive air (less integration than (1) and (3)),

(3) oral egressive air,

(4) oscillogram.

true after nasal consonants, and, in any case, between two nasals. In the open oral vowels, the velum is supposed to touch the back wall of the pharynx rather loosely, so that the passage to the nose is not entirely cut off.

I should have liked to supplement these investigations with an examination of synthetic vowels; however, this has not been possible; but I can refer to the results of Delattre (5), House & Stevens (6), and Fant (4).

The final result of the work can be resumed this way:

The nasal vowels of Paris French are presumably produced with the glottis, the tongue, and the jaw articulating as in the corresponding oral vowels. There is, however, a lowering of the velum which causes complicated changes in the vowel spectra, the main elements of which are a reduction of F1, the appearance of Fu at about 200 c/s, and the extra formants, especially at 1000 c/s and 2000 c/s; these three features are probably mainly due to the nose-pharynx cavity (3). The most strongly nasalized vowel is [õ] , after that follows [ɑ̃] , then [ɛ̃] and [œ̃]. In the final part of the vowel, the vowel formants often disappear; maybe the word then ends with a uvular nasal consonant [N] , maybe it is just a result of the relaxation of the articulatory organs. The nasal element is different for the different nasal vowels, inasmuch as their degree of nasalization is different. - As for the timbre, [ɛ̃] and [œ̃] are close together between [ɛ], [œ] , and [a], [ɑ̃] coincides almost with [ɔ], and [õ] lies between [ɔ] and [o].

So, Grammont was not quite wrong!

Table for comparison of different studies on nasality.

Feature	Joos	Smith	Durand	Delattre	House	Fujimura	Fant	Ego
F1(÷)	+	+		+	+	(+)	+	+
F2, often (÷)′	+	+		+	(+)		+	(+)
F3(÷)\`		+		+	+		+	+
F4+ or \`		+		(+)	?			(+) subject 4
Fu		+		+		+	?	+
Fx1 1000	+	+		(+)cons.	?	?	+	(+)
Fx2 2000		+		+	?	?	+	(+)
F÷500						+		
F÷900-1800					+		+	(+) subject 4
Fx 7500			+					

(÷): weakened. +: extra strong. ′: rises. \`: descends.

Fx: extra formant. F÷: anti-formant.

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(5) Delattre et al., "An Experimental Study of the Acoustic Determinants of Vowel Color", Proc. VIIth Intern. Congr. Ling. (London, 1952).

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VOICE ASSIMILATION OF STOP CONSONANTS AND FRICATIVES IN FRENCH AND ITS RELATION TO SOUND DURATION AND INTRA-ORAL AIR-PRESSURE.*)

Oluf M. Thorsen

The phonemes examined are the consonants participating in the correlation voiceless:voiced or tense: lax:

(I) p t (k) f s ʃ**)

(II) b d (g) v z ʒ

The difference in voicing is the most characteristic auditory feature; but as this distinction is neutralized in groups consisting of I + II or II + I through regressive assimilation, the linguistically relevant difference is generally considered to be one of force of articulation. This can only be true if the force of articulation of the consonant is preserved in spite of the voice assimilation, which is the opinion held by most phoneticians of French. (1).

The investigations, here presented in a short, preliminary form, were made in 1956-57 in the Cardiologic Laboratories of the University Clinic, Copenhagen, and of Gentofte County Hospital, under the supervision of Eli Fischer-Jørgensen.

The French stops and fricatives were examined in respect to

1. voicing
2. intra-oral air-pressure
3. lip-pressure
4. duration
5. duration of the preceding vowel.

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*) Thesis work for the cand. art.-degree, completed in July, 1962.

**) /k/ and /g/ are excluded, because it was impossible to obtain curves of intra-oral air-pressure during these sounds from the unexperienced subjects.

Intra-oral air-pressure was picked up by a polyethylene tube (7 cm long, outside diameter 1.5 mm, bore o.8 mm) inserted into the mouth behind the point of articulation and connected to an electrical condenser manometer (2). The outputs from the manometer and from a throat microphone were recorded on photographic paper (speed 10 cm per sec) by means of an Elema oscillograph. Simultaneously, these curves were visible on a cathode-ray oscilloscope. A small rubber bulb (19x12x8.5 mm) connected to the manometer was used for recording of lip-pressure. All examples were recorded on tape, and wide-band spectrograms were taken of many of the recordings in order to assure correct segmentation.

Subjects were five Parisians, one girl (MC) and four men (MN, GS, GV, JT), 2o to 31 years old.

The material consisted of 147 short phrases or sentences, like, for instance, "la robe de ma femme", "la robe te va mal", "l'Europe de nos jours", "l'Europe te rappelle", spoken 3 to 4 times by each subject: 20 examples with single consonants in different positions, 1o3 with the consonants in groups (I + I, II + I, I + II, II + II), and a list of 24 examples with /p/ and /b/ (for lip-pressure measurements).

1. Voicing.

Voicing was measured on the larynx curve (i.e. the oscillogram from the throat microphone) and on the air-pressure curve. The start of the consonant can be identified by a sudden rise of the air-pressure curve, plus a disturbance of the vibrations on the larynx curve.

In unvoiced postvocalic single consonants, the vibrations continue into the beginning of the consonantal phase. The mean value for 154 single consonants, initial or final in the stressed syllable, was 2.7 cs.

A voiced intervocalic consonant is normally 100 per cent voiced, - among fricatives there were scattered examples of incomplete voicing. In final position before a pause all voiced stop consonants are normally 100 per cent voiced, whereas fricatives normally have an unvoiced ending phase - in several cases these are only 40 per cent voiced, sometimes even less.

1.1. Unvoiced groups.

There were a few examples of insertion of [ə] in groups of II + I, all resulting in non-assimilation of the voiced consonant.

The voiced beginning of unvoiced groups (I + I and II + I) was compared to the duration of the preceding vowel (phonemically short and long vowels were treated separately; the figures given refer to short vowels). It came out that in groups I + I the voiced beginning, measured in percent of the duration of the first consonant, decreased with increasing duration of the vowel, and the same was true of II + I up to a certain point: when the vowel exceeded a duration of about 4 cs, the effect was the opposite, so that now I (+I) and II (+I) became more and more different. In every example these findings were compared to the duration of the consonants, the length of the sentence, the distance from the final stressed syllable, and the syntactical structure. The following interpretations, which have to be tested on a larger material, are proposed:

The increase of the percentage of voicing in both I (+I) and assimilated II (+I) as the vowels (and the consonants) get shorter, due to longer test sentences and less stressed syllables, I explain as an increase of the assimilatory power of the preceding vowel at greater syllabic speed (3).

The increase of vowel duration beyond 4 cs seems to depend on the syntactical structure of the sentence, and the diverging behaviour with respect to voicing of I (+I) and II (+I) in these cases is therefore interpreted as an influence of secondary accent: an increase of stress on the preceding vowel (or a reduction of stress on the following vowel) puts the first consonant of the group in a stronger position and makes consonants of type II more able to resist the assimilatory influence of the second consonant.

1.2. Voiced groups.

Insertion of an [ə] did not occur in groups of stop plus stop or of fricative plus stop, but in groups of stop plus fricative it appeared in 35 out of 199 examples. Usually, the result of preserving the [ə] was that the consonants retained their original glottal articulation, but in /pəz/, /pəʒ/, and /pəv/, all variations of glottal articulation were found: no assimilation (1 ex.), regressive assimilation in spite of [ə] (11 exx.), reciprocal assimilation across the [ə] (3 exx.), and 4 cases of intermediate types.

Voiced groups without [ə]. The surprising result in this section was the high percentage of examples showing disturbance of the vibrations or partial or complete absence of voice in groups of II + II. The following list shows the frequency of occurrence of instances in which the consonant group was incompletely voiced:

	II + II	I + II
stop plus stop	7%	11%
stop plus fricative	31% (!)	25%
fricative plus stop	45% (!)	42%

(Examples of fricative plus fricative were too scanty to give reliable percentages.)

It is true of these groups that if the first consonant is partially unvoiced, and the second voiced, it is always the end of the first consonant which is unvoiced, never its beginning, as claimed by Grammont (4). This seems to indicate that regressive voicing assimilation, rather than being an anticipation of vibrations, is a continuation of the vibrations of the preceding vowel, brought about by the laxness of the following consonant (5). But any effort to give detailed explanations of the assimilatory mechanism in groups of I + II is hampered by the irregularities in the II + II groups.

2. Intra-oral air-pressure.

2.1. Consonants in positions where they are not susceptible to voice assimilation.

a. Single Consonants. Intra-oral air-pressure is primarily determined by the degree of voicing: when the type II consonants are fully voiced, none of the subjects shows any overlapping between corresponding type I and type II consonants. All cases of overlapping are due to partial devoicing or weak amplitude of vibrations in the voiced sounds. /p/, /t/, /s/ have the highest pressure, next come /f/ and /ʃ/, then /z/, followed by the other voiced consonants /b/, /d/, /v/, /ʒ/. In stops and labial fricatives, the pressure of the type II consonant is normally 50 to 70% of its type I counterpart, in s/z and ʃ/ʒ the percentage is higher.

b. Second consonant in groups. Same results as above for 2.1.a.

c. First consonant in groups of I + I and II + II (i.e. no assimilation).

In this section there was some overlapping that could not be explained by deficient voicing. It turned out that the

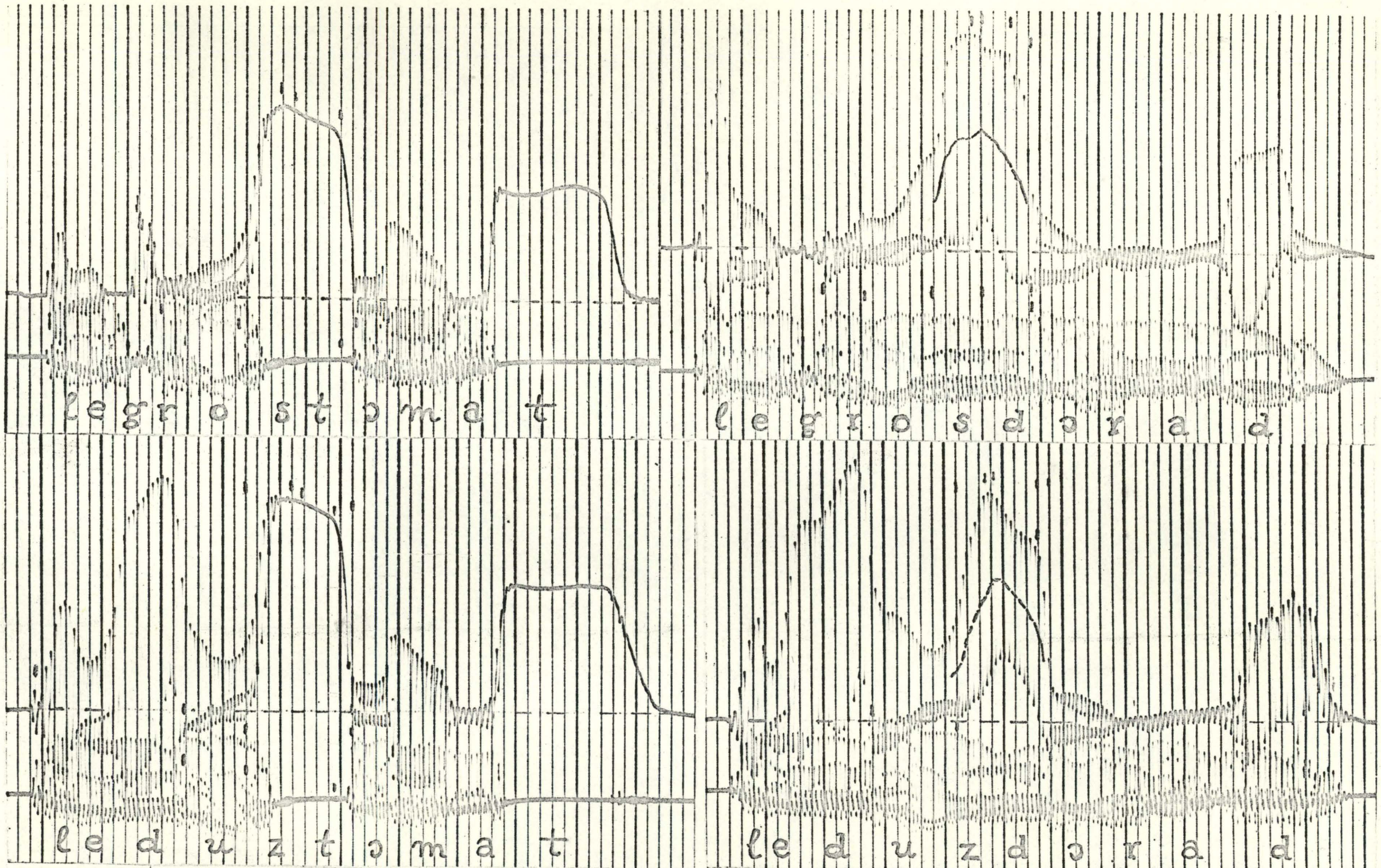

Fig. 1. Lower curve: oscillogram from larynx microphone. Upper curve: intra-oral air-pressure (a line has been drawn to indicate the short time mean value in voiced sounds).
As stated in the text, the air-pressure is a little higher after /u/ than after /o/.
The segmentation indicated is confirmed by or based on spectrograms.

relatively high pressure of the voiced consonant always occurred when the preceding vowel was less open than that found before the corresponding unvoiced consonant (the test sentences did not constitute minimal pairs). A re-examination of the entire material showed that the air-pressure is indeed higher the closer the preceding vowel is. As a close vowel has a higher air-pressure than an open vowel it seems that this difference is somehow carried on through the rest of the syllable.

2.2. Intra-oral air-pressure and voice assimilation.

Comparing all the four combinations of consonants, the findings mentioned above were confirmed: when preceded by vowels that did not differ in aperture, I(+I) and II(+I) had the same (high) air-pressure and II(+II) and I(+II) had the same (low) air-pressure. If the vowel before I + I was more open than the vowel before II + I, the air-pressure of II(+I) was higher than that of I(+I), and so forth.

The inevitable conclusion of this seems to be the following: when voice-assimilation in French is total, it is accompanied by a total assimilation of the intra-oral air-pressure.

3. Lip-pressure.

Lip-pressure is more difficult to explore than air-pressure. The rubber bulb hampers the articulation and must be kept very steady. Some of the subjects had great difficulties with this. As the difference in lip-pressure between /p/ and /b/ is smaller than the difference in air-pressure, there was a good deal of overlapping, and only two of the subjects (GV & JT) made a sufficient number of usable recordings. Furthermore, it turned out that the lip-pressure was smaller after rounded vowels than after unrounded vowels. This influence was not foreseen in the choice of examples for consonantal groups, so that comparison can only be made between unvoiced and voiced /p/, and between voiced and unvoiced /b/.

GV & JT showed a statistically significant difference between /p/ and /b/ in most positions, and in the consonantal groups the result was in most cases a lower pressure for voiced than for unvoiced /p/, and a higher pressure for unvoiced than for voiced /b/. I.e., it seems very probable that voice assimilation is accompanied by an assimilation of lip-pressure as well, but it is impossible to decide on the basis of the present data whether this assimilation is total or partial.

4. Consonant duration.

4.1. Single consonants.

Voiced and unvoiced consonants occurring in the same position show a great difference of duration with practically no overlapping: unvoiced consonants are longer than their voiced counterparts, the difference being greater in fricatives than in stops. For stops in non-final position, the difference in the length of the closed phase was not always quite clear, but the total length was unambiguous.

4.2. Consonant groups.

In the examples with consonant groups, several sources of variation disturbed the comparisons to such a degree that an unvoiced group was sometimes shorter than the corresponding voiced group. So I had to examine the influence of the following factors:

a. rate of speech.
b. emphasis.
c. the distance from the final stressed syllable.
d. sentence rhythm.
e. the number of syllables and sounds in the example.

a. The subjects were asked to keep a constant rate of speech.

b. A consonant is prolonged under the effect of emphasis, but emphasis did not occur among the examples with consonantal groups.

c. A consonant group preceding the final stressed vowel was longer than the same group placed before the penultimate vowel. When occurring before the antepenultimate vowel the group was always shorter than before the stressed vowel, but sometimes longer than before the penultimate.

d. The existence of secondary stress in French, which was doubted by Marguerite Durand (6), became evident from a comparison of the duration of the consonant groups in different syntactical positions. Ceteris paribus, a group consisting of the last consonant of a noun plus the first consonant of a postposited adjective was longer than the same group occurring medially in a word, and also longer than the same group found between the elements of compound words and between adjective plus noun. But if the postposited adjective was monosyllabic, a certain loss of stress sometimes appeared. These findings, and others, were corroborated by measurements of the vowels, and of each consonant in the groups in so far as delimitation was possible.

e. In rather short utterances like the ones used in this investigation, the subjects will have a tendency to shorten the sounds in inverse ratio to the number of syllables. But also the number of sounds in the syllable has an influence on the sound duration: in particular, the consonant group was longer before a short stressed open syllable than before a long stressed vowel plus consonant or before a stressed vowel plus two consonants.

4.3. Consonant duration and voice assimilation.

Taking into account the abovementioned factors, first comparing examples under equal conditions, and then weighing the different conditions against each other, I obtained the following results for the duration of the consonantal groups (all groups, all five subjects):

I + I longer than II + I
II + I longer than I + II
I + II longer than II + II (?)

The differences between unvoiced and voiced groups were greater than the differences between assimilation and non-assimilation, especially in voiced groups.

That the second consonant is not exclusively responsible for the differences, will appear from the data about the first consonant in the group. Exact delimitation was possible only in part of the material (MN: in no cases -, GS & MC: only for p/b + s/z, GV & JT: practically everywhere). The duration of the first consonant in the group under maximally similar conditions of rhythm gave the following results:

a. I(+I) longer than II(+II) (and (I+)I longer than (II+)II), i.e. the difference between I and II in non-assimilation groups is clear.

b. II(+I) longer than II(+II) in about 75 per cent of the cases where the durations could be measured and compared directly, i.e., II is longer when devoiced. The second consonant makes the difference between II+I and II+II even greater.

c. I(+I) versus I(+II): the very few directly comparable cases show no clear difference and might indicate that voiced I is not assimilated as to duration. The second consonant brings about a difference in the duration of the entire group: I+I is longer than I+II.

d. I(+I) longer than II(+I) in all comparable cases, i.e., the assimilation of II is only partial.

e. I(+II) longer than II(+II) in practically all comparable cases, i.e., if there is any assimilation of I, it is not total.

f. II(+I) longer than I(+II) in about 60 to 65 per cent of the directly comparable cases, i.e., there is a slight tendency for unvoiced II to be longer than voiced I. This suggests that a greater number of examples under item c might have given a more pronounced shortening of voiced I.

5. Duration of preceding vowel.

Before a single consonant.

In absolutely final position the vowel was longer before voiced than before unvoiced consonant, with no overlapping at all, except for p/b, t/d, f/v in the recording of GS, and t/d, f/v in the recording of MC, and longer before voiced fricative than before voiced stop.

Before a consonant group.

The examples with consonant groups were chosen primarily for the investigation of intra-oral air-pressure, and usually the same vowel was repeated before the same consonant, whether assimilated or not, but a different vowel was found before its partner in the correlation. Moreover, as in the case of consonant duration, secondary stress influenced the vowel duration. Thus the directly comparable cases were not as many as might be desired. Nevertheless, they clearly showed that sonorisation prolongs, and desonorisation shortens, the preceding vowel by about 1 to 2 cs. Owing to the above-mentioned deficiency in the material, the difference of vowel duration before I+I and II+II is difficult to determine: it seems to be about 2 to 3 cs - and nothing can be said as to whether the assimilation is total or partial.

6. Conclusion.

The most important result of the present study has been to demonstrate that regressive voice assimilation in French stops and fricatives is accompanied by an assimilation of

(1) intra-oral air-pressure
(2) lip-pressure
(3) the duration of the assimilated consonant
(4) the duration of the preceding vowel.

This implies that the traditional theory, according to which the assimilation is limited to voicing, is incorrect.

There is still the possibility left that the so-called "force of articulation" which is said to be preserved in spite of the voice assimilation, has nothing to do with intra-oral air-pressure, nor with lip-pressure in the way it has been examined here. It is conceivable that the slight shortening (lengthening) of the vowel together with the slight lengthening (shortening) of the assimilated consonant is in some contexts a sufficient perceptual cue. Another possibility to be considered is that the alleged difference in articulatory force may come out if other methods and instruments be used. Maybe, though, that the difference in force of articulation claimed by so many phoneticians of French, is something that is felt by the speaker, but not communicable to the listener - and maybe the all-important factor in the question of assimilation in French is the context, whether linguistic or extra-linguistic. No Frenchman would misinterpret [lørɔbdənoʒuːr] or [larɔptəvamal] ; but maybe he would misunderstand the intended meaning of [ʒəvjɛ̃tparle] ([t] = 'te' or 'de') if he misunderstands the situation.

There is a lot of investigation to be done, especially in the field of perception tests.

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ACOUSTIC ANALYSIS OF TENSE AND LAX VOWELS IN GERMAN.*)

Hans Peter Jørgensen

For more than half a century it has been discussed what is meant by the terms "tense" and "lax" vowels. With the exception of a paper by A.L. Fliflet (1), who does not measure formant frequencies but rather estimates the different general appearance of the spectrograms, I am not aware of a published analysis of the acoustic differences between tense and lax vowels made with modern apparatus (e.g. the Sonagraph). The main purpose of the research summarized here was, therefore, to attempt to find relevant differences between the acoustic patterns of the tense and the lax vowels in modern German "Hochsprache" with as exact measurements of their formant-frequencies as possible.

The vowel-system of German is usually considered as falling in two groups: 8 "long" and 7 "short" vowel phonemes. In IPA transcription these may be rendered as follows:

I: i: y: u:
e: ø: o:
ɛ: a:

II: ɪ ʏ ʊ
ɛ œ ɔ
a

It is usual to symbolize the latter set of vowels in German as follows:

(II) ì ỳ ù
è ø̀ ò
à

These symbols will be used in the following.

Vowels of group I are usually long, those of group II are always short. Vowels of group I <u>may</u>, however, be short (e.g. ['zi:] but [zi 'kòmt] , but they remain distinct from those of group II.

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*This paper is a brief account of a thesis work (cand.art. degree in German and phonetics) which was carried out at the Institute of Linguistics and Phonetics in 1964. The material will be published in a more detailed form.

A more significant difference seems to be, therefore, the tense/lax-difference, vowels of group I being always tense, those of group II always lax.

(It is doubtful if there is a tense/lax difference between [a:] and [a] , and an opposition of this kind will not be considered in the following.)

Briefly the main theories about the tense/lax-problem viewed from the articulatory and acoustic aspects may be described as follows:

(i) There is a difference in the tongue-form: vowels of group I have a convex tongue-form, those of group II have a more flattened tongue. (2)

(ii) The lax vowels (II) always have a lower tongue-position than the corresponding tense vowels (I) (e.g. [ì] (bitten) lower than [i:] (bieten), [ỳ] (Hütten) lower than [y:] (hüten), etc. (3)

(iii) The lax vowels have less tension in the articulating part of the tongue than the tense ones. (This has given rise to the terminology tense/lax. But as far as I know, this difference has never been examined instrumentally for German vowels, for instance by means of electro-myography.)

(iv) The consumption of air is greater in the articulation of lax vowels than in the articulation of tense vowels, this being caused by a lesser tension in the vocal chords in the articulation of the lax ones. (4)

(v) By visual examination of spectrograms of German tense and lax vowels Fliflet (1) claims that there are general differences in the appearances of the spectrograms, such as a more equal dispersion of intensity throughout the spectrum in the lax than in the tense ones, and furthermore blurred formant contours and a less regular formant structure in the lax compared with the corresponding tense vowels, and a couple of other differences. Summarizing Fliflet claims that the lax vowels exhibit a general indistinctness or blurring of the features that normally serve to define the quality of a vowel.

(vi) According to the views of Roman Jakobson, Gunnar Fant and Morris Halle (5,6) the tense/lax difference can be described in terms of articulation as a greater tension and deviation of the vocal tract from the 'neutral position' for group I than for group II, and acoustically as a higher overall intensity throughout the spectrum and a greater deviation of the formants of group I away from the formants of a vowel pronounced with the tongue in the 'neutral position'.

My intention was to measure the exact formant frequencies of the tense and the lax vowels and on the basis of the formant values to try to find out if and how the formant frequencies differ between the two vowel groups and, furtheron, perhaps to be able to conclude something about the way of articulation. I partly used spectrograms of German vowels (in words) spoken by native speakers and made by Eli Fischer-Jørgensen (though primarily made for other purposes) and partly measured formants on spectrograms from a material especially made for this investigation. The latter material consisted of German vowels in words spoken by native male speakers from the northern part of Germany, where the tense/lax-difference is regarded as being most marked.

Six such speakers were recorded on tape each pronouncing the 15 vowel phonemes six times (in natural words). Among these six speakers I chose four, having the best voices for spectrography. My first problem was to find words in which the vowel formants were minimally influenced by the consonantal surroundings. I made two lists each pronounced twice by the speakers: A: [h]/0 + vowel + labial consonant for the back rounded vowels and [h]/0 + vowel + dental consonant for the front vowels and for [a:] and [à] , and B: [h]/0 + vowel + velar stop.

A: The dental consonants should minimally influence the second formant of front vowel, and the labials should minimally influence the second formant of back rounded vowels. B: The velar stops should not heavily influence the formants, because the place of articulation differs according to the preceding vowel. The words were thus of the types A: <u>hiessen</u>, <u>hüten</u>, <u>hupen</u>, <u>hissen</u>, <u>Hütten</u>, <u>hupfen</u>, etc. and B: <u>Igel</u>, <u>Hügel</u>, <u>Huker</u>, <u>Hickel</u>, <u>Tücke</u>, <u>Hucken</u>, etc.

The presentation of vowels in an acoustic chart raises a difficult problem for languages with both rounded and unrounded front vowels. It is not adequate just to plot F_1 versus F_2 , as F_3 seems to be of importance for the distinction between rounded and unrounded vowels. One must somehow take F_3 into account. I did

so, using Gunnar Fant's formula to calculate the "effective F_2":
$F_2' = F_2+1/2(F_3+F_2)\ \frac{F_2-F_1}{F_3-F_1}$ but apparently without obtaining a significant improvement in the separation of the vowels. For the back rounded vowels I preferred not to use the formula. F_1 and F_2 (respectively F_2') were plotted in a chart using the 'mel'-scale, which is nearly logarithmic above 1000 c/s and linear below 1000 c/s.

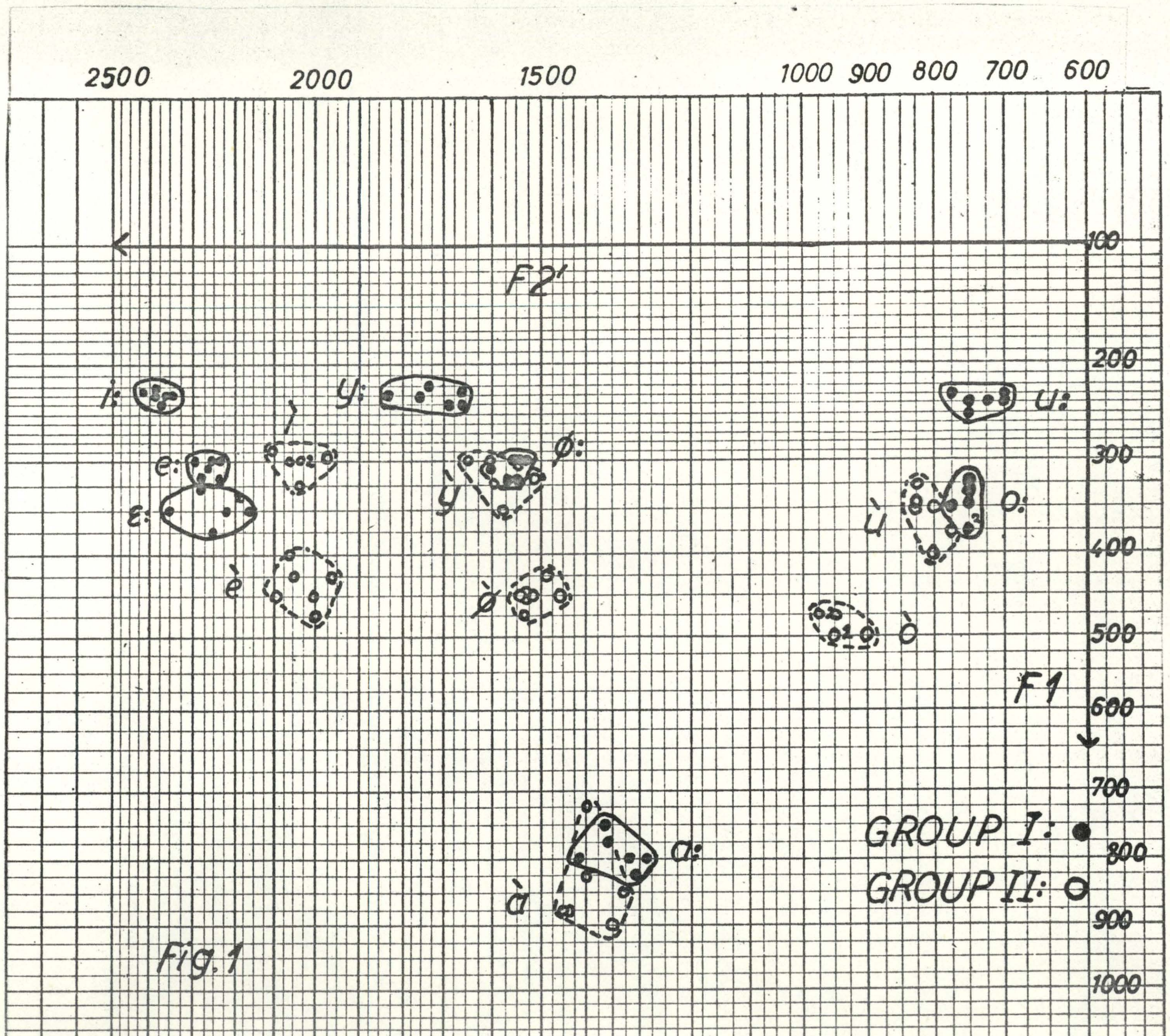
Fig. 1 shows the F_1 versus F_2 plotting for one person. (For the front vowels and the a-sounds the x-axis represents the F_2'-value, for the rounded back vowels the x-axis represents the F_2-value. The y-axis always represents F_1-values). Each dot stands for one vowel. In some cases the values of two samples were identical and are thus marked with a small figure (2).

Only for [ỳ]/[ø:] and [a:]/[à] you find true overlapping, and only in the case of [a:]/[à] the overlapping concerns corresponding vowels from different groups. (The position of [ε:] quite close to [e:] reflects the frequent merging of [ε:] and [e:] in the northern part of Germany).

In a vowel-chart like this, F_1 seems to represent in articulatory terms the degree of opening (the higher F_1, the larger the opening), and F_2 to a certain extent represents the place of articulation, front vowels having a rather high F_2 (F_2') and back vowels having a low F_2. The vowels of group II are all placed lower than the corresponding vowels of I, which is without doubt caused by a lower tongue-position. For instance [ì], [ỳ] and [ù] are not only lower than [i:], [y:] and [u:]; they are in fact found on the same F_1-level as [e:], [ø:] and [o:], or even lower (cf. Fig. 3).

Another obvious difference between the two groups of vowels is the centralization of the lax vowels in proportion to the tense ones, [ì] and [è] being to the right of [i:], [e:] and [ε:] and [ù], [ò] being to the left of [u:] and [o:]. Because of the placing of the rounded front vowels in between the other groups on the x-axis you cannot speak of a centralization (in that sense) of the lax [ỳ] and [ø̀] in proportion to the tense [y:] and [ø:].

What could this general centralization (see also Figs. 2 and 3) be referred to in articulation? It is clear that it might be possible to regard it as an expression of less accurate articulation. The lax vowels do not reach the extremes of articulation as the tense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F2'
F1
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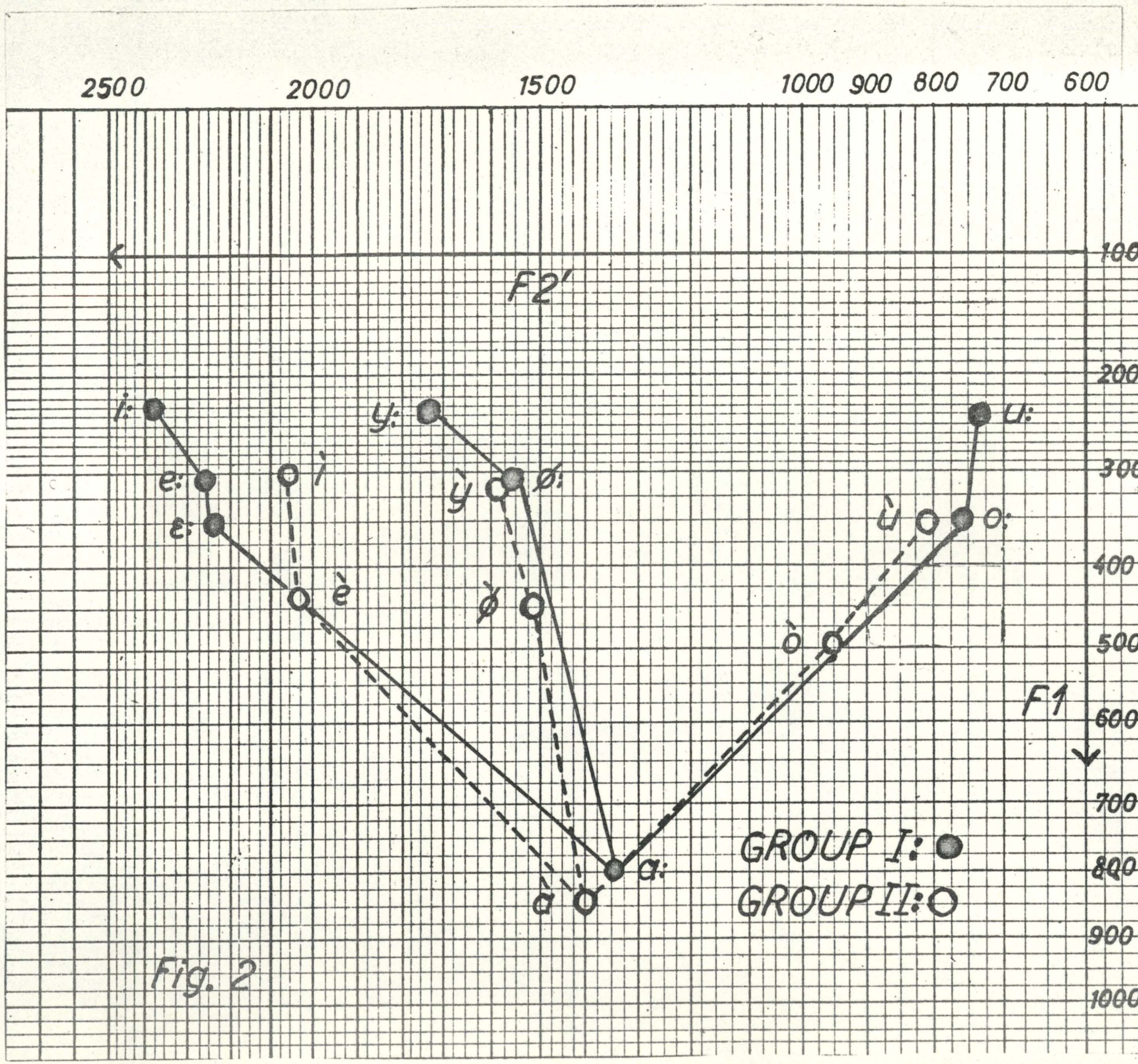
e:
ε:
y:
ø:
u:
o:
a:
GROUP I: ●
GROUP II: ○

Fig.1



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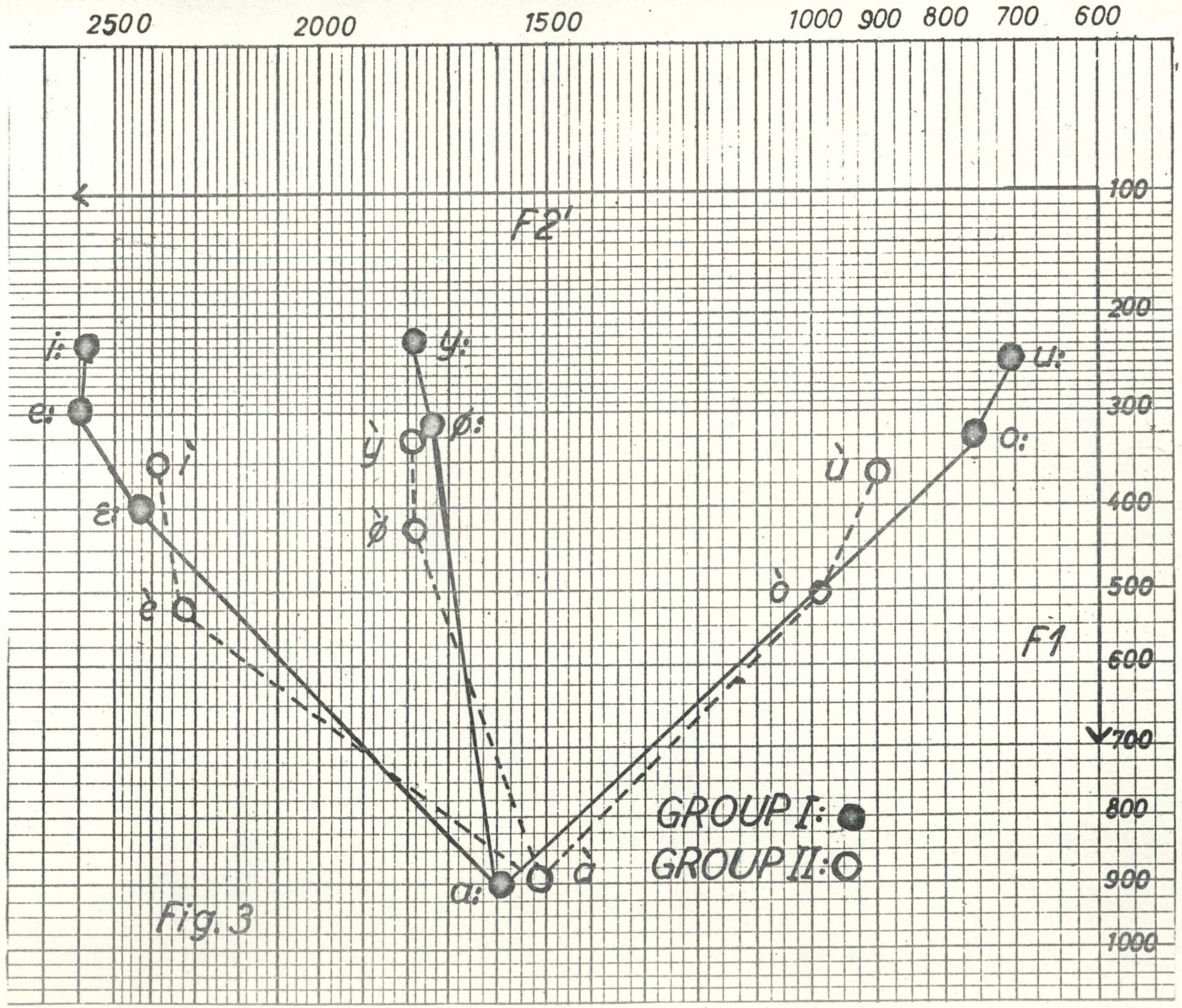
GROUP II:
Fig. 2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GROUP I:
GROUP II:

Fig. 3

ones do. Compared to this they approach the 'neutral tongue position', perhaps because of a certain laxness in the tongue-muscles involved.

Fig. 2 shows the average formant-values for one person. They naturally show the same tendencies as described above, maybe even clearer.

Fig. 3 is an illustration of the average formant-values for another person. The same tendency of lowering and centralization of the lax vowels compared with the corresponding tense ones is obvious. [ì] and [ù] even lie somewhat lower than [e:] and [o:]! This fact seems in a way to prove E.A. Meyers results based on his method of plastrography (3). The degree of centralization is almost the same as in Fig. 2 (less for [ì] and more for [ù]). It is of importance to mention, comparing Fig. 2 with Fig. 3, that it is not the exact placement of each vowel in the chart, but rather the relations between the vowels that seem to be important: Fig. 3 has, for instance, [ì] and [è] almost in the same F_2'-area where Fig. 2 has [i:], [e:] and [ɛ:], but Fig. 3 has still higher F_2'-values for [i:], [e:] and [ɛ:], and thus the relations between the vowels look almost the same.

To sum up: the acoustic data plotted in the charts presented here seem to be the acoustic result of an articulation, by which the group II-vowels approach the 'neutral tongue position' (i.e., are centralized). This is perhaps due to a certain laxness of the tongue-muscles. But to <u>prove</u> a connexion of this kind more detailed investigations both of the articulatory and the acoustic phenomena are obviously necessary.

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RESEARCH ON THE PHYSIOLOGICAL CORRELATE TO THE TWO VOWEL TYPES IN GERMAN.

W. W. Schuhmacher

The occurrence versus non-occurrence in open and closed syllable divides the category of the German vowels into two classes: one type occurring both in open and closed syllable, and another type occurring in closed syllable only. The purpose of the research reported here is to find the physiological correlate to these two types, our hypothesis being that the functional criterion has some physiological counterpart.

The vocoids manifesting the two vowel types have often been defined as "tense" and "lax". The two attributes should then refer to different degrees of tongue tension, in accordance with the traditional conception dating back to Bell's and Sweet's opposition "narrow - wide".

A pilot study was carried out to verify or falsify Ernst A. Meyer's conclusion from 1913 that "bei den gespannten vokalen eine stärkere pressung der stimmbänder und ein verhältnismässig geringerer atemverbrauch stattfindet als bei den ungespannten vokalen" (1). We recorded sub- and supraglottal air pressure and oral air flow (plus the oscillogram from a throat microphone) on a 4-channel Mingograph during a subject's articulation of the 15 German vowels. The vowels were pronounced in the following consonantal environments: /l-l/, /v-l/, /g-l/, /l-k/, /b-t/. In our laboratory setup sub- and supraglottal air pressure are at present picked up by means of manometers of the type manufactured in Edinburgh. Each manometer is connected to a rubber tube which is passed through the nose: one tube goes into the pharynx, the other - with a balloon at the end - in the oesophagus, i.e. the subglottal air pressure is measured indirectly according to Ladefoged's method. The mean air flow is measured by means of the flow meter (aerometer) constructed by Svend Smith and Børge Frøkjær-Jensen.

On the basis of 150 recordings (each vowel pronounced 10 times by the author) the following preliminary results can be stated:

Our experiments verify Meyer's result in that we have found a difference in the mean air flow (1 1/3 times higher for the lax vocoids manifesting the vowels occurring only in closed syllable - a slightly lower figure compared with Meyer's 1 1/2 times higher ratio), and no difference in the subglottal pressure. On the other hand, the tense vocoids (manifesting the vowels occurring both in open and closed syllable) are characterized by the supraglottal pressure being 1 1/2 times higher than that for the other vocoids. As the tense type is characterized by a higher supraglottal air pressure and a lower mean air flow at the lips, we must assume a greater resistance somewhere in the vocal tract in between.

In order to investigate a possible correlation between mean air flow and abduction-adduction of the vocal cords Fabre's glottographic method was also tried in a brief experiment. The morphology of these glottograms is, however, complicated as we are far from knowing exactly what we measure (see this report, p. 22ff.). Measurements by means of the type of glottograph recording the amount of light passing through the glottis from a light source are planned.

As possible future methods one might think of the application of radio-isotopes in order to get information about the air passing through the glottis, and of high-speed cineradiographic technique.

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PERCEPTUAL DIMENSIONS OF SPEECH SOUNDS.

Eli Fischer-Jørgensen

A closer investigation of the perceptual dimensions of speech sounds must be expected to throw some light on the general laws governing the structure of phonemic systems, the general tendencies of sound development, and the facts of sound symbolism. The closer we come to central processes the better will we understand the essential characteristics of speech.

Starting from Roman Jakobson's hypothesis *) that vowels are perceived in two dimensions (corresponding to the normal $F_2 - F_1$ diagram) and that these dimensions are closely related to the colour dimensions bright-dark and saturated-non-saturated, the author carried out a number of tests in the years 1949-51, 1952-54, and 1964-65 (with generally from 40 to 200 students without previous phonetic training participating in each test) asking the subjects to group the Danish long vowels i: y: u: e: ø: o: ɛ: œ: ɔ: æ: ɑ: in three groups (bright-neutral-dark or saturated-neutral-nonsaturated) and (in later tests) according to a seven-point scale. A number of other adjective-pairs were also tried out using the seven-point scale, (1 a) bright-dark, pointed-blunt, hard-soft, light-heavy, thin-thick, (1 b) narrow-broad, small-big, tense-lax, close-open, (2) tight-loose, compact-diffuse, and (3) flat-round, but in most cases only with the vowels i y u ɛ œ ɔ. Moreover, subjects were asked to match each of the vowels with one of a series of nine achromatic colours, and with one shade from a set of colour charts comprising 11 different hues each represented by an Ostwald colour triangle containing ten different shades of brightness and saturation.

The testing conditions were mostly so arranged that an auditory reaction was favoured, but several of the experiments with seven-point scales were made both with conditions favouring an auditory reaction and with conditions favouring a motoric reaction. The results of these two series showed only slight differences.

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*) Roman Jakobson, "Kindersprache, Aphasie und allgemeine Lautgesetze", Språkvetenskapliga Sällskapets i Uppsala Förhandlingar 1940-42 (1941).

The main result was that there seems to be a dominating perceptual dimension which, when compared to the traditional vowel triangle, can be said to run obliquely downward from the upper left corner (i) to the lower right corner (ɒ), corresponding approximately to F2 - F1. This dimension is covered by the adjectives mentioned under (1), but in such a way that the first 4 pairs (1 a) show a somewhat stronger dominance of F2. A second dimension covered by compact-diffuse and tight-loose is found to be more closely correlated with F1 (but in the sense that i y u were considered as tighter and more compact than the group ɛ œ ɔ with i as the most compact vowel). For saturated - non saturated no clear answer could be obtained. Answers to flat-round were only elicited for the six-vowel group giving the order i-ɛ-y-œ-ɔu.

An interesting detail of the results is that the two variants included in the vowel list (namely [ɑ:] and [ɒ:] which are variants of [æ:] and [ɔ:] respectively before /r/-ɑ also after /r/), have their separate placings, ɑ being often rather far removed from æ. This seems to indicate that subjects confronted with isolated vowels may be inclined to react to them as sounds, not as phonemes. The results should thus probably be in better agreement with the general symbolic values of sounds than with the distinctive features of the given language.

A somewhat longer summary of the results will appear in the Proceedings of the Seminar on Speech Production and Perception held in Leningrad in August 1966, and in the Festschrift for Roman Jakobson. A detailed account with documentation will be given in a book to be published by the Philological Society in London.

Further tests involving pure similarity judgments according to the methods used by Göte Hanson*) are in preparation.

A much more restricted number of tests have been applied to consonants. A major preliminary result is that a grouping of the consonants according to manner of production seems much more obvious to the subjects than a grouping according to place of articulation. It is also found that the subjective similarity between consonants (e.g. between p, t, and k) varies according to the following vowel.

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*) cp. e.g. The Scand. Journal of Psych. 4 (1964) and 6 (1965).

EXPERIMENTS WITH SHARP FILTERING OF DANISH AND GERMAN VOWELS.

Eli Fischer-Jørgensen and Jørgen Rischel

Some three years ago we started some experiments with sharp highpass filtering of vowels. These experiments were first undertaken in order to throw light on a problem that had arisen in spectrographic measurements, viz. the difficulty in determining the exact F1 peak in spectrograms of vowels with a pronounced "subformant", i.e. an intensity concentration below the first formant pole (perhaps due to nasal coupling or the like). This low-frequency peak, which is often found in German lax vowels, may or may not merge with the F1 envelope, partly depending on the F1 location, and thus raises a methodical problem in sound spectrography. In cases where the F1 envelope is just broadened we face the problem whether to try to determine the actual pole frequency (which cannot in principle be done in any simple fashion with our present methods) or whether to take the centre of gravity observed on the spectrogram (which will be inconsistent with the principles followed in all cases where the subformant is distinguishable from F1).*)

The error that can be introduced when F1 is measured in the presence of a merging subformant, is appreciable. It has, however, been generally claimed that the ear is not very sensitive to differences in the low-frequency region of the speech signal. In order to evaluate whether the contribution of low-frequency energy to the vowel quality is negligible, we have prepared a rather extensive material consisting of Danish and German vowels, long and short, occurring in contexts and isolated, with sharp highpass filtering at different frequencies. The cutoff frequencies used for each vowel

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*) A comparison with standard spectrum envelopes for different types of vowels suggests itself in such cases. - A number of precision analyses of vowels synthesized by JR on OVE II and analysed with the 51 channel analyser were recorded at the Speech Transmission Laboratory in Stockholm in 1965, see STL-QPSR-3/1965, pp. 25f. Envelopes drawn from these spectrograms and provided with indications of the actual pole frequencies will probably be useful in defining the shape of F1 proper in our natural vowel spectra.

are (approximately) 200, 250, 340, 400, 500, 630, 800, and 1000 c/s. (With narrow vowels we did not use the highest cutoff frequencies, since the experiment was to throw light on phenomena associated with the F1 region only.)

A preliminary listening made by ourselves clearly indicated that the distribution of spectral energy below some 200 c/s does indeed not contribute to define the phonetic quality of the sound. Certain other results concerning the quality of vowels with removal of a greater or lesser portion of the F1 region are suggested.

AUDITORY INVESTIGATION OF GERMAN TENSE AND LAX VOWELS.

Eli Fischer-Jørgensen

It has been maintained (e.g. by E.A. Meyer and by R.M.S. Heffner) that in spite of the fact that the short German vowels ɪ ʏ ʊ often have a lower tongue position than long e ø o (and, as it appears from Hans Peter Jørgensen's acoustic investigations, also a higher F1) they are normally perceived as sounds of the i y u-type. - Now it can be argued that people who hear them as i y u-sounds may be influenced either by the spelling or by the status of these sounds as the highest short vowels of the vowel system, and that people who have not got this knowledge hear them as sounds of a more open type. In order to test this hypothesis German long and short vowels (spoken by the same persons as those used in the acoustic analysis by HPJ) were cut out of words so that the central part (with a duration of 6-9 cs) was used and transitions avoided as far as possible. These vowels were combined into a test, which also included Danish vowels. The vowels of each subject were presented as a special group of vowels in the test, to prevent interferences between different subjects with different relative formant positions. For each subject the order was random. - The test tape was presented to two groups of Danish students (each comprising about 4o subjects) and one group of Danish phoneticians (1o subjects). As the students did not have sufficient training in cardinal vowels, all listeners were asked to allocate each of the vowels they heard to a position in a two-dimensional diagram containing the Danish long vowels

i	y	u
e	ø	o
ɛ	œ	ɔ

The answers were in close correspondence with the acoustic measurements. ɪ ʏ ʊ were heard as slightly higher than e ø o for the subject HL who had rather close ɪ ʏ ʊ, and as lower than e ø o, and often somewhat centralized for the other subjects.

In some cases the vowels had been influenced strongly by surrounding consonants, not only in their marginal sections close to the consonants (in the form of transitions), but also in the central section which was cut out and used in these experiments. This happened for ʊ and ɔ between dentals (relatively high F2) and for ɪ between l and p (relatively low F2). In such cases both ʊ and ɪ were heard as front rounded ø or œ.

Similar results have been obtained in a previous test with some Dutch and English vowels (e.g. ʊ in "soot" when isolated was heard as [ø]).

It is intended to use the same test tape with German listeners. The results will be published in a somewhat more detailed form later.

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