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G. LIIV, M. REMMEL

ON THE CLASSIFICATION OF THE ESTONIAN VOWEL SYSTEM: ARTICULATORY MEASUREMENTS

1. Here we present a classification variant of the articulations of Estonian vowels. From what follows below it should become clear that a number of kindred variants exist, which are in a sense equivalent and partly interdependent. Hence preference *vs* rejection of one variant or other is in the main determined by other factors (the domain of such factors is very large and hard to delimit; since we are confining ourselves here to one variant, we shall at present overlook these factors).[1]

2. Materials and Procedures

2.1. Speech Material. The vowel system of Estonian is based on 9 vowel types: *u*, *o*, *a*, *i*, *e*, *ä*, *ü*, *ö*, *ė̮*[2]. The present paper reports on an articulatory analysis of the vowels pronounced in isolation. The subjects were asked to pronounce the isolated vowels in a monotone for a duration of about 1 *sec* each (without any time-controlling signals) at a pitch most convenient for a particular speaker, yet maintaining the same fundamental frequency for all utterances of all the vowels. The speakers were requested to pronounce each vowel several times in succession with pauses of about 1 *sec* between consecutive utterances. The vowel types were arranged in a random order.

The average overall duration of the isolated vowels as pronounced by the three main speakers (yielding a total of 27 samples) turned out to be 1188 *msec*. The X-ray shots were found to be made with the onset of the X-ray flow at an average distance of 594 *msec* from the onset of phonation which is exactly in the middle of the average overall duration (the measurement was performed on oscillograms: see Sec. 2.3).

[1] The present paper is partly a continuation of the preceding one (see G. Liiv, M. Remmel, On Acoustic Distinctions in the Estonian Vowel System. "Soviet Fenno-Ugric Studies" 1970, No. 1, pp. 7—23) where an attempt was made to classify Estonian vowels on the basis of one type of acoustic parameters (viz. formant frequencies) so that the classification procedures themselves were also presented. From the viewpoint of methodology such "decomposition" is in principle possible, but it extends considerably the number of obligatory problems and consequently requires a greater number of assumptions and conventions. Hence an immediate and abrupt extension of conclusions is impossible, and the acquisition of substantial results depends on an ensuing wider formulation of problems.

[2] In the present work we have as a rule made use of a phonetic transcription based on the vowel letters as used in Estonian orthography and on the symbols of the phonetic alphabet employed in transcribing the Fenno-Ugric languages (FUT). With regard to the basic symbols for vowel types one should note the following correspondences to the symbols of the system adopted by the International Phonetic Association (IPA): *ü* = IPA *y*, *ö* = IPA *ø*, *ä* = IPA *æ*, FUT *ė̮* = *õ* (in Estonian orthography) = IPA *ë̞* (an unrounded (central-)back vowel whose quality could be rendered in narrower transcription approximately as *ë̞*-).

Note. For reasons of typographic convenience the vowel symbols in the present paper are given in italics and without brackets.

2.2. Informants. Three speakers (two of them women) participated in X-raying experiments producing the total vowel inventory (each vowel has been X-rayed once); this was supplemented by X-ray shots of three extreme vowels *a*, *i*, *u* as articulated by one male speaker (2×3 shots). The ages of the speakers range between 20 and 44.

All the informants speak perfect Standard Estonian without any dialectal peculiarities. They all are permanent residents of Tallinn.

2.3. Apparatus and Methods. For X-ray shots we have used a Diagnomax-125 X-ray tube (focal spot 2 *mm* × 2 *mm*) with a 1 *mm* Al filter; exposure time 0.04 and 0.06 *sec*; 112 *kV*, 260 *mA* or 118 *kV*, 220 *mA*; the distance of the *X*-ray tube from the midsagittal plane of the informant's head 2 *meters*. The film holder was placed immediately on the informant's shoulder; the head posture of the informant was fixed by a head holder. Barium emulsion was used as a radio-opaque matter for drawing thin stripes along the median lines of the tongue dorsum, the palate, and the lips, and dots in the corners of the mouth. In order to avoid the dispersion of barium in the mouth, the mouth cavity was rinsed and new stripes drawn with a pencil after the pronunciation of every two vowels.

For the purpose of synchronizing the X-ray shots and the uttered speech the following special scheme was employed. The speech produced during X-raying was recorded on one track of a Jauza-10 dual-channel tape recorder; the other track was used to record the pulse corresponding to the duration of the exposure (0.04 or 0.06 *sec*). The pulse was taken immediately from the high-voltage transformer of the control panel of the X-ray apparatus, thus marking the actual beginning and end of radiation and not the switching moments. (With the "Diagnomax" X-ray apparatus utilized the delay of the actual beginning of the X-ray emanation after the switching moment resulting from the inertia of the mechanical relays of the equipment turned out to be 80—100 *msec*.)

The examination of oscillograms made of the tape-recorded material provides an opportunity to determine what phase of pronunciation exactly is depicted on a given X-ray shot. The switching on of the X-ray emanation at the proper moment was performed by the experimenter.

A 12-channel model N-105 oscillograph was used for making the oscillograms at a film speed of 500 *mm/sec*.[3]

The data were processed by means of a "Minsk-22" digital computer.

2.4. Comments upon Procedures

2.4.0. Usually the analysis of articulation from X-ray shots is carried out as follows. The vocal tract or the part of it to be analyzed is formally supplemented with a third dimension (the third dimension is understood here in the ordinary sense; as a matter of fact, the darkness of the film is otherwise a third dimension in itself). The stated supplementation is formal in the sense that two approaches usually employed here reduce the problems linked with the third dimension so that it begins to function just only formally and therefore may be excluded from further treatment. One of the approaches works on the assumption that the values of the third dimension are in a one-to-one or even a one-to-one and monotonous correspondence with the two lower dimensions. In the second case the existence of representative *vs* non-representative regions in the vocal tract is assumed.

The two stated approaches are relatively similar, and they often occur parallel, but they can be (and probably must be) distinguished. The predictability of the values of the third dimension is usually assumed in works reporting on or related to speech acoustics (cf. various functions of cross-sectional areas of the vocal tract), whereas the representa-

[3] For a closer insight into the X-raying technique used, see Г. Лийв, А. Ээк, О проблемах экспериментального изучения динамики речеобразования: комплексная методика синхронизированного кинофлуорографирования и спектрографирования речи. «Изв. АН ЭССР — Биол.», 1968, № 1, pp. 78—102.

tive regions are assumed in works reporting on or related to speech production (this in the final analysis is the source for such classical statements as "X moves considerably more vigorously than Y", "while Y is moving X remains immobile", etc., where X and Y are certain parts of the vocal tract).

The two approaches mentioned above are both approximations, and the acquired results are at best inaccurate. The real solution is probably to be found somewhere else; maybe it lies in a treatment where the predictability is assumed with regard to (some combination of) representative regions.

2.4.1. In the present research we also had to confine ourselves to two dimensions: we are at present not yet in possession of the third dimension. We have tried to build up the two-dimensional case as strictly as possible, consciously ignoring the third dimension throughout the research.

The tongue contour and the lip contours were measured from roentgenograms with reference to the incisors as well as the mandible, the maxilla, and the anterior lower edge of the second cervical vertebra, C_2. The tongue contour was measured with reference to the mandible, the lips with reference to the mandible and the maxilla respectively. As reference points for the mandible and the mouth corner, the upper incisor and C_2 were chosen. For the key diagram of measurements, see Fig. 1.

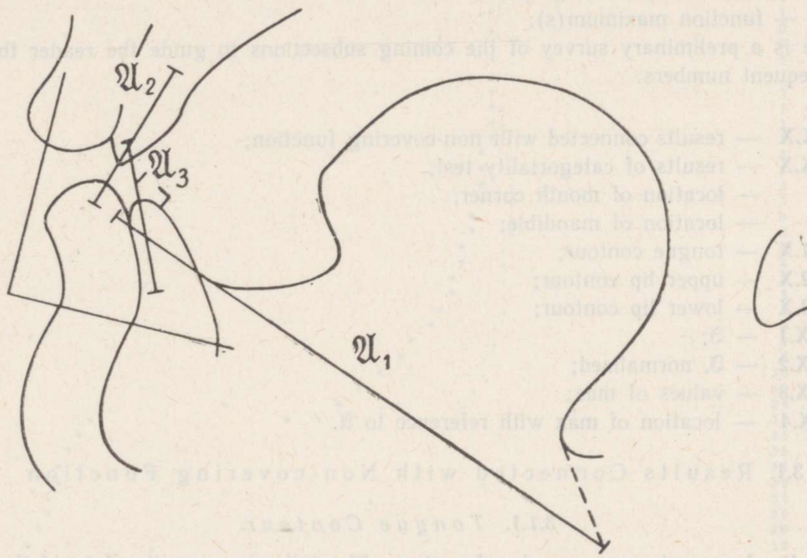


Fig. 1. Key diagram of measurements. The axes in the far left part of the figure show the tilt of the coordinate system used for the measurement of the positions of the mandible and the mouth corners. The small angle under the symbol $\mathfrak{A}_3$ marks the position of the mouth corner. For further explanations see Sec. 2.4.1.

2.4.2. Further processing was carried out by computer. The non-covering in pairs of the lip and tongue contours of all the vowels were computed. Five of such pairs of tongue contours and two pairs of lip contours are exhibited in Fig. 2. In this way a matrix was obtained having $\frac{n(n-1)}{2}$ columns (n — the number of vowels) and m rows (m — the length of the abscissa in millimeters). Thereupon the distances between the columns in this matrix were computed in pairs. This was done on the assumption that there would be a correspondence between these distances and a certain categorical structure: a small distance would testify approximately the same (equivalent?) category, a big distance would denote relatively more different (non-equivalent?) categories.

2.4.3. It should be added that the tongue contours might have been measured with reference to either the maxilla or the mandible. In accordance with our aims we measured them with reference to the mandible.

As may be seen from Fig. 1, of all possible locations of the coordinate system such have been chosen which provide the longest possible abscissas. It stands to reason that all the other coordinate systems having a tilt of up to 90° are also essential (when a tilt exceeds 90° we get dual coordinate systems); this involves respective changes in categoriality; a closer study of these matters cannot be made here (see Sec. 4).

3. Results

3.0. The values treated in the following can be classified in several more or less connected ways. We shall use for this purpose the size (natural and normalized) of the area under the graph of a function (the area in the given case is equal to the total non-covering), and the location and the relative height of the function maximums. The following symbols will be used:

$\mathfrak{A}$ — length of abscissa ($\mathfrak{A}_1$, abscissa for tongue contour; $\mathfrak{A}_2$, abscissa for upper lip contour; $\mathfrak{A}_3$, abscissa for lower lip contour);

$\mathfrak{I}$ — area under function graph;

max — function maximum(s).

Here is a preliminary survey of the coming subsections to guide the reader through the subsequent numbers:

3.1.X.X — results connected with non-covering function;
3.2.X.X — results of categoriality test;
3.3 — location of mouth corner;
3.4 — location of mandible;
3.X.1.X — tongue contour;
3.X.2.X — upper lip contour;
3.X.3.X — lower lip contour;
3.X.X.1 — $\mathfrak{I}$;
3.X.X.2 — $\mathfrak{I}$, normalized;
3.X.X.3 — values of max;
3.X.X.4 — location of max with reference to $\mathfrak{A}$.

3.1. Results Connected with Non-covering Function

3.1.1. *Tongue Contour*

3.1.1.1. *Area under non-covering function.* The following are the data of the three speakers taken together:

i : *ü*	2$\mathfrak{A}_1$	*e* : *ä*	8$\mathfrak{A}_1$	*ö* : *o*	14$\mathfrak{A}_1$
ė̮ : *u*	3	*ė̮* : *a*	9	*e* : *u*	15
i : *e*	4	*ä* : *a*	10	*ü* : *ė̮*	16
e : *ü*	4	*ä* : *ü*	10	*i* : *ė̮*	16
e : *ö*	5	*ä* : *o*	10	*e* : *o*	17
ä : *ö*	5	*ä* : *u*	10	*ü* : *u*	18
o : *u*	6	*ö* : *ė̮*	11	*e* : *a*	18
ė̮ : *o*	6	*i* : *ä*	11	*i* : *u*	19
ü : *ö*	6	*a* : *u*	11	*ü* : *o*	19
a : *o*	7	*ü* : *u*	12	*ü* : *a*	20
i : *ö*	7	*e* : *ė̮*	13	*i* : *a*	20
ä : *ė̮*	8	*ö* : *a*	13	*i* : *o*	21

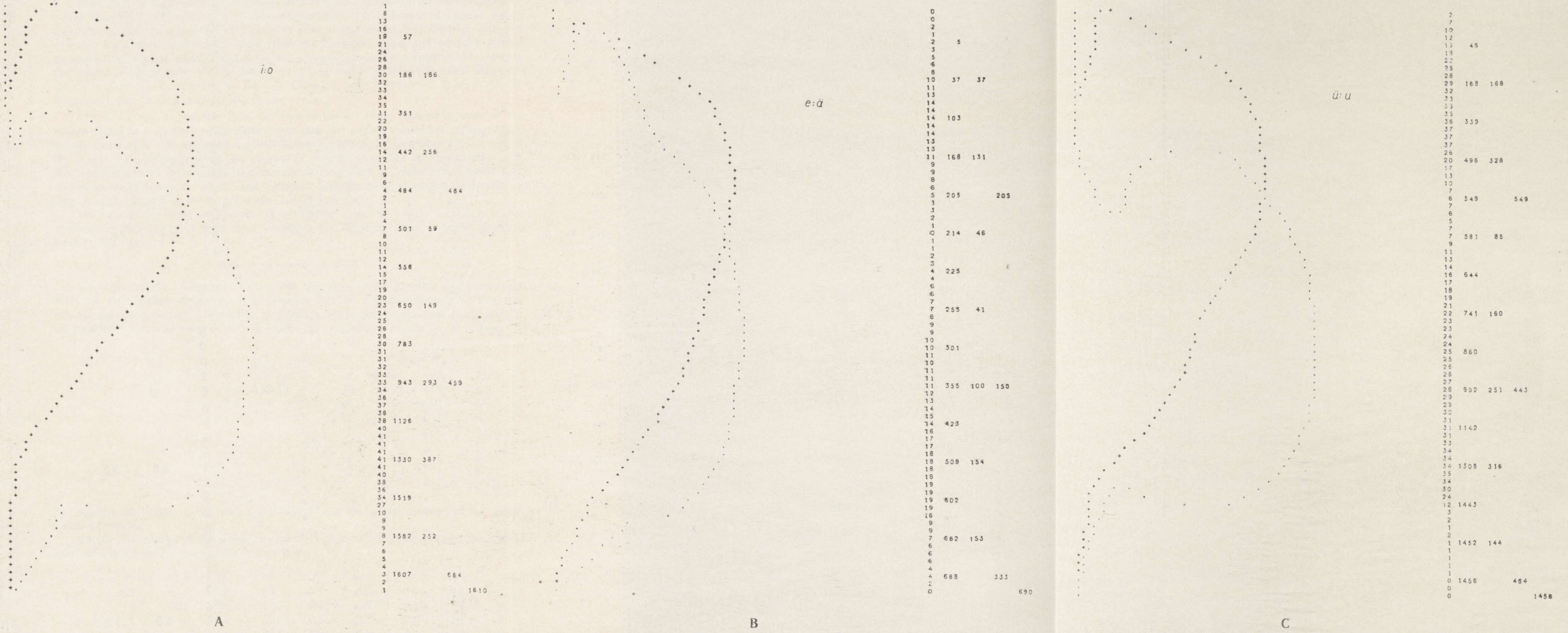
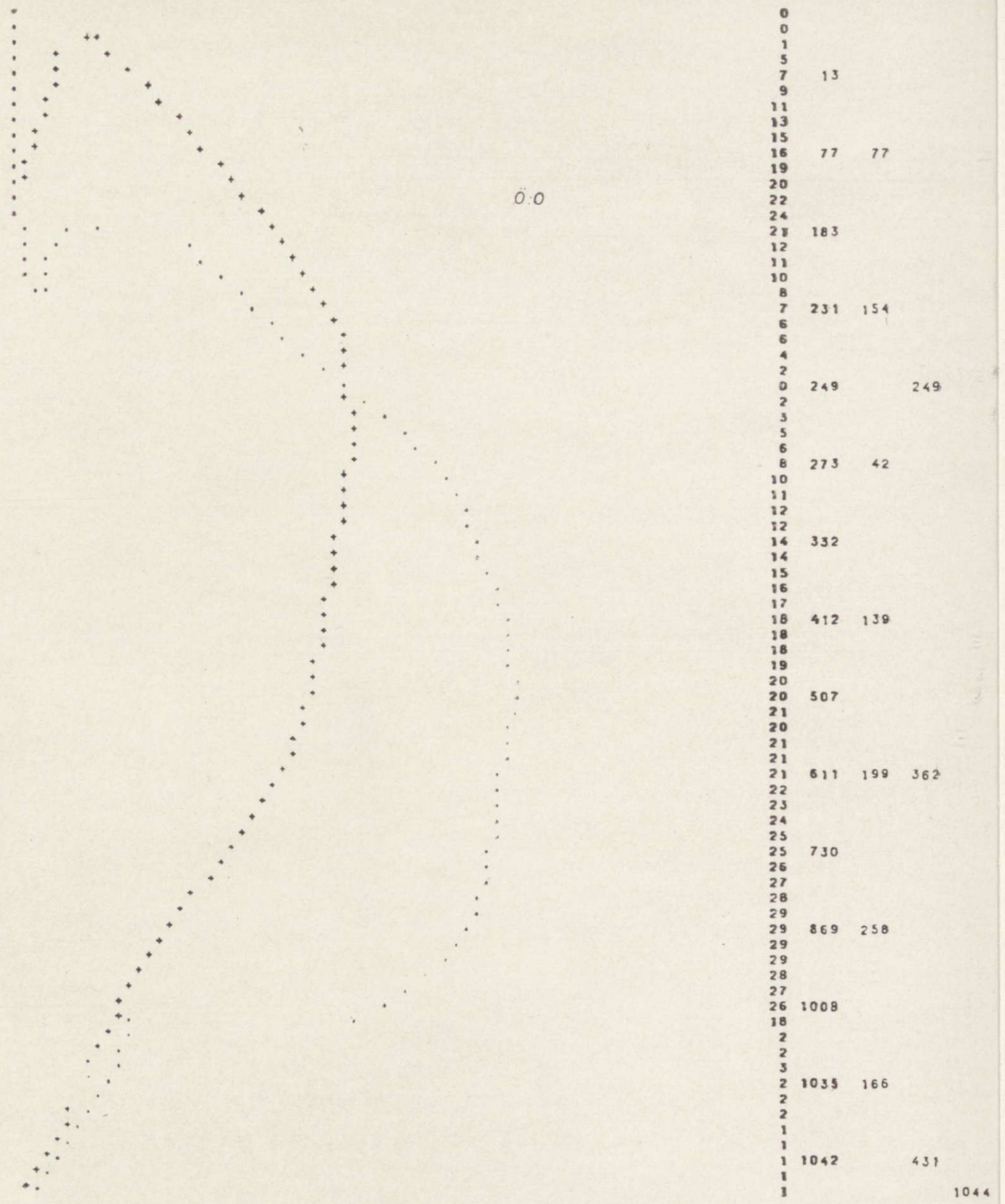
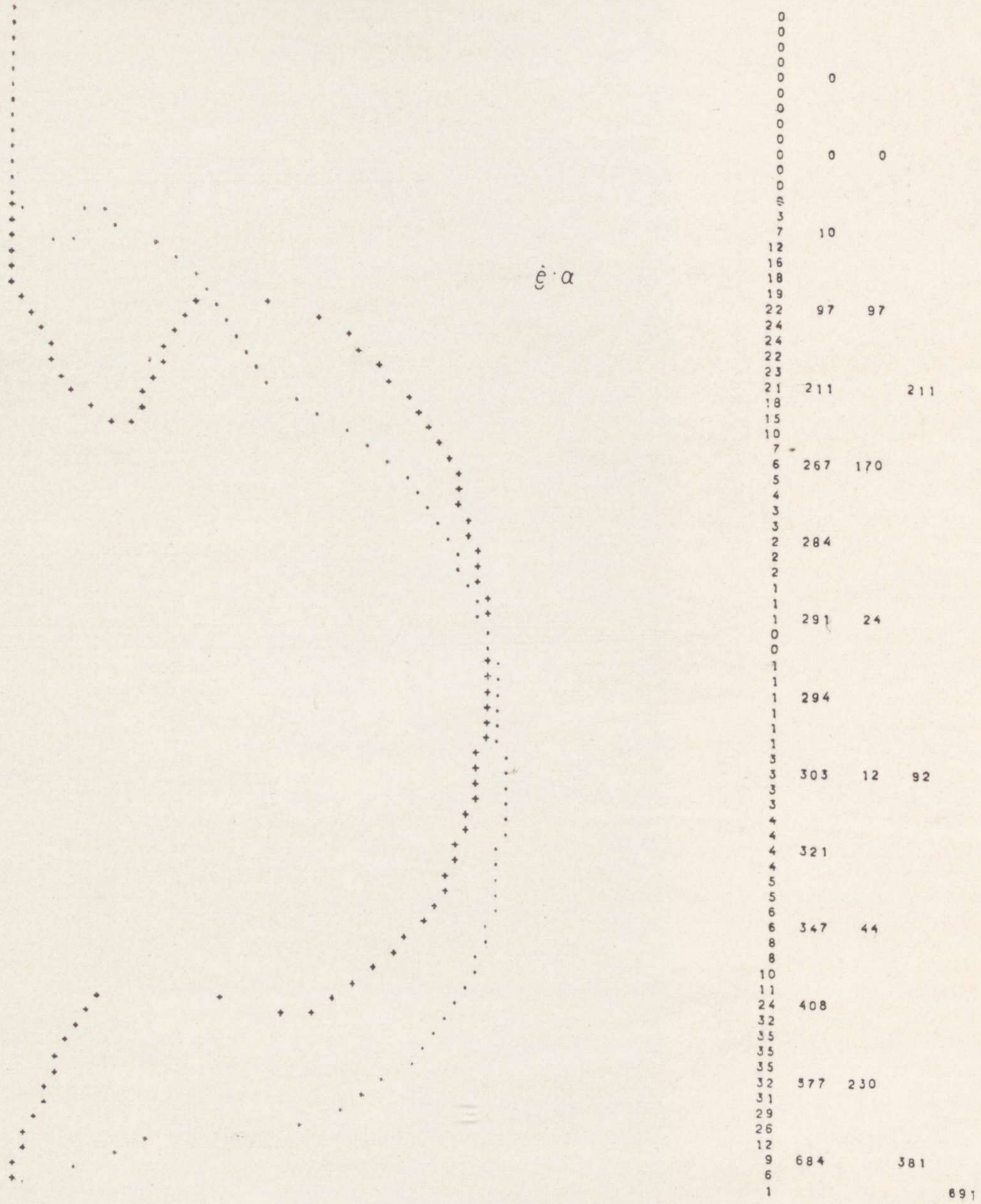


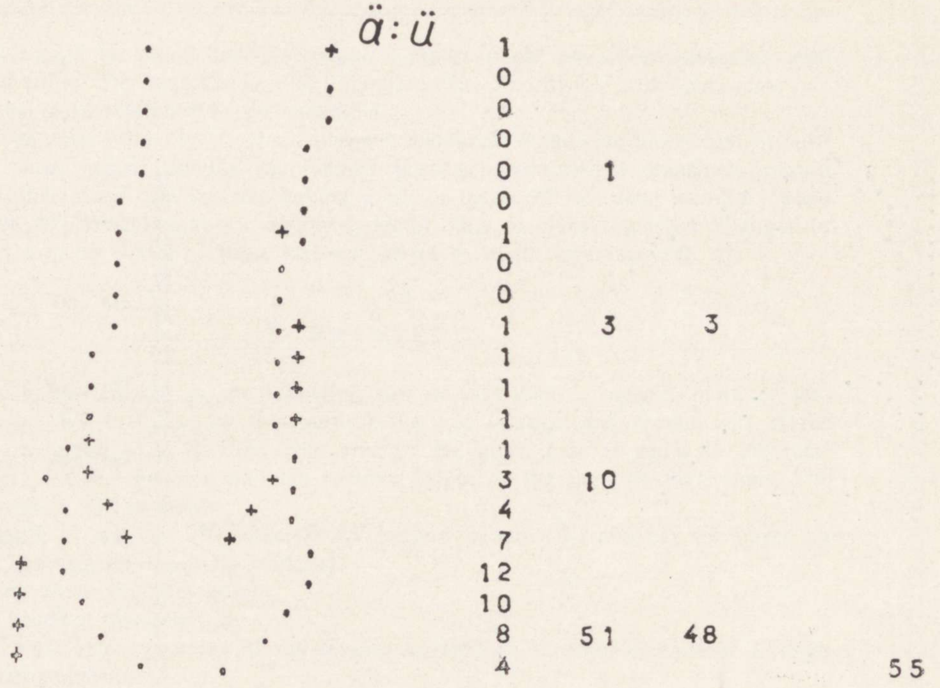
Fig. 2. Some of the pairs of tongue contours (A, B, C, D, E), a pair of upper lip contours (F) and one of lower lip contours (G). The first vowel of a pair is depicted by a sequence of plus signs and the second by a sequence of dots. When the values are equal a dot represents both. Columns of figures indicate non-covering for one, five, ten, twenty-five and 𝔄 ordinate values respectively. Only the first and the last of these columns were used in the present paper. A female Speaker.


ö:o

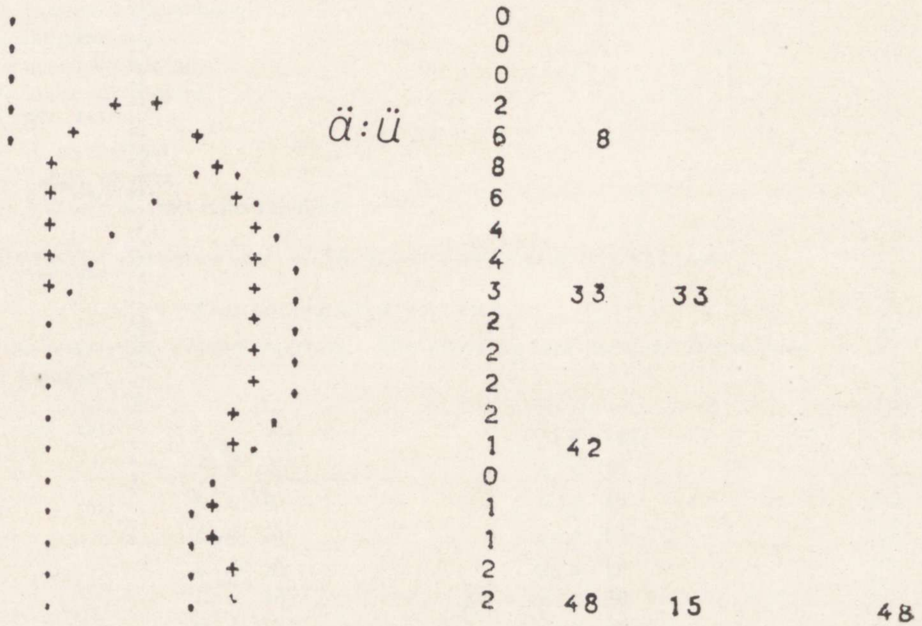
D


ẹ:a

E


ä:ü
1
0
0
0
0 1
0
1
0
0
1 3 3
1
1
1
1
3 10
4
7
12
10
8 51 48
4
55

F


ä:ü
0
0
0
2
6 8
8
6
4
4
3 33 33
2
2
2
2
1 42
0
1
1
2
2 48 15
48

G

Here the value of $\mathfrak{J}$ displays the size of the area under the graph constructed for the non-covering function of the tongue contours in a given pair of vowels, with $\mathfrak{A}_1$ as a unit. Of course, any other unit of absolute value can be used instead of $\mathfrak{A}_1$. The values of $\mathfrak{J}$ are presented as the means of the three speakers.

The values of $\mathfrak{J}$ are in strict correspondence with the number of function maximums: values from $2\mathfrak{A}_1$ to $7\mathfrak{A}_1$ relate to a non-covering function of 3 or more max whereas values from $8\mathfrak{A}_1$ to $21\mathfrak{A}_1$ to a function of 2 max. In essence this means that relatively "closer" contours have more intersections than relatively "remoter" ones, and actually it also means that such pairs where contours do not intersect are absent altogether. In principle the tongue is likely to be able to behave in a way which would yield pairs with non-intersecting contours. However, at least in Estonian (and probably in most if not all languages) such a mechanism is not in use.

3.1.1.2. As will be apparent from the data of the preceding subsection, some of the vowels (such as *i*, *ü*) may stand either "very near to" or "very far from" others; other vowels (such as *ä*) are placed at a relatively more uniform distance from all the rest of the vowels. This has to be taken into account in order to generalize the classification, and the "distances" have to be normalized in some fashion. Such a normalization would help us find for every vowel its "closer" and "remoter" partners; in an unnormalized system we may as well (depending on the criterion) fail to find them.

The data of the three informants taken together rank the vowels according to the evenness of their distances from other vowels in the following order, evenness growing from left to right:

i—ü—e—a—o—u—ė̮—ö—ä

We converted the "distances" to one and the same scale ($0 \div 10$) and normalized them for each speaker separately. It is probable that the results arrived at in this way are not absolutely correct (assumption of linearity, etc.); but for the time being there is no possibility to prefer some other procedure. The *normalized results* are as follows:

i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
x	1	7	0	5	9	10	10	10	*i*
	x	4	0	0	7	10	9	8	*e*
		x	8	0	10	5	6	6	*ä*
			x	3	9	10	9	9	*ü*
				x	6	7	10	7	*ö*
					x	2	2	0	*ė̮*
						x	0	3	*a̮*
							x	1	*o*
								x	*u*

The smaller the number in the matrix, the "closer" are the tongue contours of the corresponding vowels.

3.1.1.3. The *values of the maximums* for 3 speakers taken together (only the highest maximum has been considered; the unit is $\mathfrak{A}_1$):

i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
x	0.2	0.4	0.2	0.2	0.5	0.5	0.5	0.5	*i*
	x	0.2	0.1	0.2	0.5	0.5	0.5	0.4	*e*
		x	0.3	0.2	0.3	0.3	0.4	0.3	*ä*
			x	0.2	0.5	0.4	0.5	0.5	*ü*
				x	0.3	0.4	0.4	0.4	*ö*
					x	0.4	0.4	0.2	*ė̮*
						x	0.3	0.4	*a̮*
							x	0.3	*o*
								x	*u*

3.1.1.4. *The location of maximums.* The abscissas of two higher maximums are presented; the upper number refers to the higher one. The unit is $\mathfrak{A}_1$.

	i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*
i	x	0.04 0.79	0.80 0.10	0.03 0.78	0.12 0.80	0.18 0.74	0.13 0.81	0.20 0.77	0.19 0.73
e		x	0.83 0.11	0.04 0.78	0.12 0.82	0.19 0.68	0.16 0.85	0.23 0.78	0.20 0.70
ä			x	0.82 0.17	0.70 0.18	0.19 0.80	0.17 0.90	0.21 0.77	0.20 0.80
ü				x	0.17 0.82	0.18 0.70	0.84 0.16	0.20 0.78	0.20 0.74
ö					x	0.20 0.67	0.18 0.84	0.22 0.75	0.20 0.68
ė̮						x	0.88 0.24	0.27 0.86	0.22 0.86
a							x	0.92 0.26	0.24 0.88
o								x	0.26 0.84
u									x

3.1.2. *Upper Lip Contour*

3.1.2.1

e : ä	0.9 $\mathfrak{A}_2$	*ö : ė̮*	1.8 $\mathfrak{A}_2$	*i : ö*	2.7 $\mathfrak{A}_2$
ė̮ : a	0.9	*ü : u*	1.8	*ä : ü*	2.7
ä : a	0.9	*i : ė̮*	1.9	*a : u*	2.8
e : ė̮	1.0	*a : o*	1.9	*ė̮ : u*	2.9
ä : ė̮	1.0	*ü : o*	1.9	*i : o*	3.0
e : a	1.2	*ö : a*	2.0	*ö : u*	3.0
i : e	1.3	*e : ö*	2.0	*ü : ė̮*	3.1
i : ä	1.3	*i : a*	2.1	*e : ü*	3.2
ä : ö	1.5	*ü : ö*	2.1	*e : u*	3.4
o : u	1.6	*ü : a*	2.3	*ä : u*	3.5
ö : o	1.7	*e : o*	2.4	*i : ü*	3.8
ė̮ : o	1.8	*ä : o*	2.5	*i : u*	4.0

3.1.2.2

	i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*
i	x	0	1	10	6	3	4	8	10
e		x	0	8	4	0	1	5	10
ä			x	5	2	1	0	6	10
ü				x	3	10	4	1	0
ö					x	3	4	0	10
ė̮						x	0	3	7
a							x	3	10
o								x	0
u									x

3.1.2.3

	i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
	x	0.2	0.3	0.5	0.5	0.3	0.3	0.5	0.6	*i*
		x	0.2	0.5	0.3	0.2	0.2	0.4	0.5	*e*
			x	0.4	0.3	0.1	0.1	0.4	0.5	*ä*
				x	0.3	0.4	0.4	0.2	0.2	*ü*
					x	0.2	0.3	0.2	0.3	*ö*
						x	0.2	0.3	0.5	*ė̮*
							x	0.3	0.5	*a*
								x	0.2	*o*
									x	*u*

3.1.2.4

	i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
	x	0.75	0.80	0.85	0.80	0.80	0.80	0.80	0.80	*i*
		x	0.80	0.85	0.80	0.80	0.80	0.85	0.85	*e*
			x	0.85	0.85	0.80	0.75	0.85	0.90	*ä*
				x	0.90	0.85	0.80	0.85	0.80	*ü*
					x	0.80	0.85	0.75	0.90	*ö*
						x	0.85	0.90	0.90	*ė̮*
							x	0.90	0.85	*a*
								x	0.85	*o*
									x	*u*

3.1.3. *Lower Lip Contour*

3.1.3.1

i : *ė̮*	1.2$\mathfrak{A}_3$	*e* : *a*	2.7$\mathfrak{A}_3$	*i* : *ü*	3.5$\mathfrak{A}_3$
ä : *a*	1.4	*ü* : *o*	2.7	*a* : *u*	3.8
i : *e*	1.5	*ü* : *a*	2.7	*i* : *ö*	3.9
ü : *ö*	1.5	*ö* : *o*	2.8	*ä* : *u*	4.0
e : *ä*	1.6	*a* : *o*	2.9	*i* : *a*	4.0
e : *ė̮*	1.7	*ö* : *a*	2.9	*e* : *u*	4.0
e : *ü*	2.2	*i* : *ä*	3.0	*ö* : *ė̮*	4.0
ä : *ė̮*	2.3	*ä* : *o*	3.0	*ė̮* : *u*	4.0
ü : *u*	2.3	*ė̮* : *a*	3.1	*ė̮* : *o*	4.1
ä : *ü*	2.4	*o* *u*	3.2	*ė* : *o*	4.2
ä : *ö*	2.5	*ü* : *ė̮*	3.2	*i* : *u*	4.5
e : *ö*	2.6	*ö* : *u*	3.5	*i* : *o*	5.2

3.1.3.2

	i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
	x	1	5	10	8	0	10	10	9	*i*
		x	0	3	5	2	5	8	10	*e*
			x	4	4	4	0	4	10	*ä*
				x	0	7	5	0	0	*ü*
					x	10	6	5	8	*ö*
						x	6	8	9	*ė̮*
							x	3	8	*a*
								x	3	*o*
									x	*u*

3.1.3.3

i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
x	0.3	0.5	0.5	0.5	0.2	0.6	0.6	0.6	*i*
	x	0.3	0.4	0.5	0.3	0.4	0.5	0.5	*e*
		x	0.3	0.3	0.3	0.3	0.4	0.4	*ä*
			x	0.2	0.5	0.3	0.4	0.3	*ü*
				x	0.5	0.4	0.3	0.4	*ö*
					x	0.5	0.5	0.5	*ė̮*
						x	0.4	0.4	*ă*
							x	0.3	*o*
								x	*u*

3.1.3.4

i	*e*	*ä*	*ü*	*ö*	*ė̮*	*a*	*o*	*u*	
x	0.45	0.35	0.40	0.35	0.40	0.35	0.35	0.35	*i*
	x	0.30	0.30	0.30	0.35	0.30	0.30	0.30	*e*
		x	0.30	0.25	0.30	0.30	0.20	0.25	*ä*
			x	0.30	0.35	0.25	0.15	0.20	*ü*
				x	0.35	0.20	0.25	0.35	*ö*
					x	0.30	0.25	0.30	*ė̮*
						x	0.20	0.20	*ă*
							x	0.10	*ó*
								x	*u*

3.2. Since in the general case $\mathfrak{I}$ is unsuited for the representation of local peculiarities of the non-covering function, an addition has been made by the point by point calculation of the distances between pairs of pairs. The results are presented in Table 1 regarding

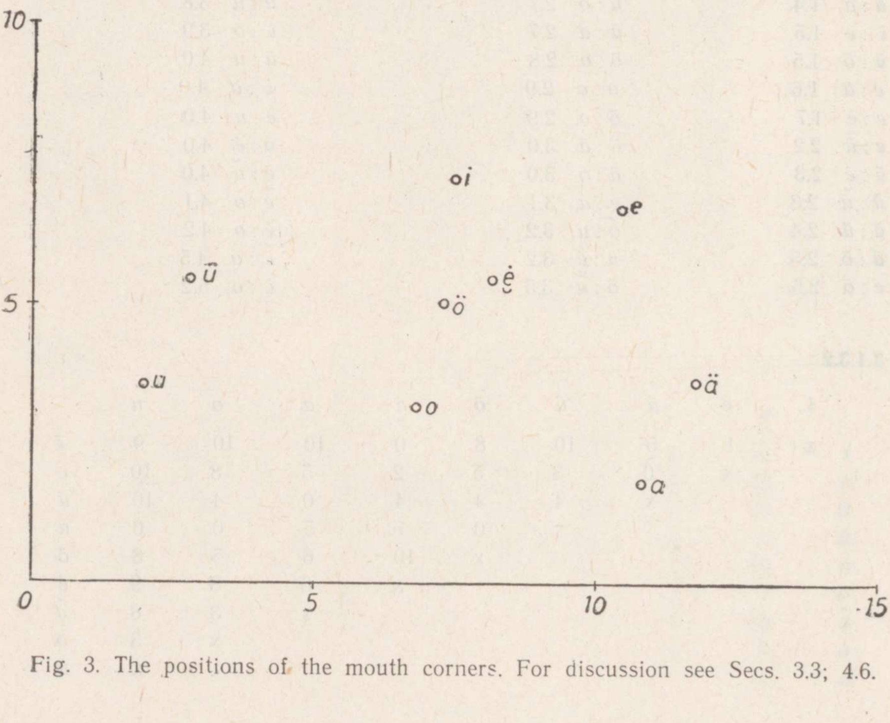


Fig. 3. The positions of the mouth corners. For discussion see Secs. 3.3; 4.6.

tongue contours and in Table 2 whose upper part is reserved for upper lip and lower part for lower lip contours.

3.3. The *positions of the mouth corners* were measured with reference to C_2 and to the upper incisors. The obtained values were normalized first with respect to coordinate systems and then between the speakers. The method of least squares was used. The results can be seen in Fig. 3.

3.4. The *positions of the mandible* were dealt with in much the same way; they were measured at the tip of the lower incisors. The results can be seen in Fig. 4.

4. Discussion

4.1. In the present paper our chief aim was to analyze the categoriality expected for the positions of articulators.

It was decided to regard the articulators (the tongue, the mandible, the lips, the mouth corners) in as strict and as general a manner as possible. As was mentioned before, we have confined ourselves to two dimensions and to the longest abscissas. The latter restriction requires more detailed explanation.

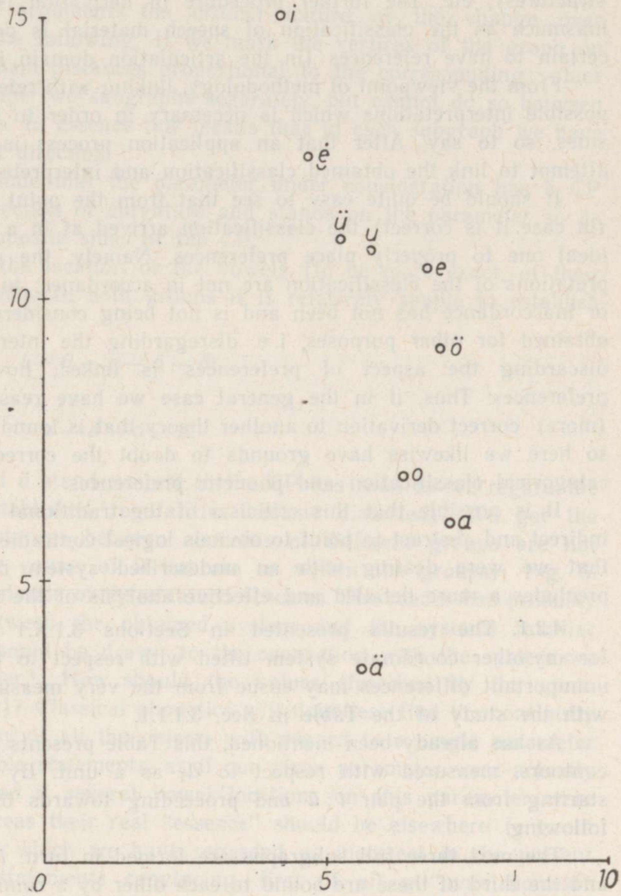


Fig. 4. The positions of the mandible. For reference to this figure see Secs. 3.4; 4.7.

Since we regard the tongue and the lips as certain contours on a coordinate plane, it is necessary to start (as in the general case) with a choice of coordinates which would grant the distribution of ordinate values along an abscissa of the greatest possible length. For objects concerning which any more detailed information is lacking, such a principle is common although absolutely heuristic. Hence the system used in the present paper is capable of being generalized, which we actually intend to do in future.

In addition, a glimpse is needed into how tradition has treated categoriality. Since only (exclusively) such definitions and treatments are to be found that are nonformal, it is improbable that a unique reference could be established. This limits us here to a general derivational analysis which unfortunately also has to be performed in nonformal terms.

It is widely claimed, particularly in linguistic folklore, that Pāṇini's system corresponds to more detailed systems of classical phonetics (with the exception, perhaps, of Pāṇini's categories relating to connected speech), Brücke's system to that of distinctive features, etc. Such relating of classifications to each other expresses, first and foremost, trivial facts like the division of speech material into classes (classifiability), occurrence of certain universal principles (classifications appearing to have partly similar structures), etc. The further procedure of derivation is based on the assumption that inasmuch as the classification of speech material is possible, the classes obtained are certain to have references (in the articulation domain inclusively).

From the viewpoint of methodology, linking with references is naturally one of several possible interpretations which is necessary in order to tie up the classification on both sides, so to say. After that an application process is embarked upon, comprising an attempt to link the obtained classification and interpretations with preferences.

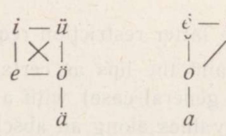
It should be quite easy to see that from the point of view of derivational analysis (in case it is correct) the classification arrived at in a way mentioned above is not an ideal one to properly place preferences. Namely, the general structure and the interpretations of the classification are not in accordance; to be more exact, their accordance or inaccordance has not been and is not being considered. The classification, which was obtained for other purposes, i. e. disregarding the interpretations in question and fully discarding the aspect of preferences, is linked, however, with "alien", "external" preferences. Thus, if in the general case we have reason to prefer a theory having a (more) correct derivation to another theory that is found to have been derived incorrectly, so here we likewise have grounds to doubt the correctness of linking the traditional categorical classification and phonetic preferences.

It is possible that this criticism of the traditional approach to categoriality is too indirect and abstract to point to obvious logical contradictions; but it should be considered that we were dealing with an undescribed system reconstructed in analysis, which precludes a more detailed and effective analysis of the system's contradictions.

4.2.1. The results presented in Sections 3.1.X.1 and 3.1.X.2 are equally valid for any other coordinate system tilted with respect to the given one (however, certain unimportant differences may ensue from the very measurement procedure). Let us begin with the study of the Table in Sec. 3.1.1.1.

As has already been mentioned, this Table presents the $\mathfrak{I}$ values for pairs of tongue contours, measured with respect to $\mathfrak{A}_1$ as a unit. By binding the pairs into graphs, starting from the pair *i* : *ü* and proceeding towards bigger values of $\mathfrak{I}$, we find the following.

The next three full subgraphs are formed in turn: *i* : *ü* : *e*, *ė* : *u* : *o*, *e* : *ü* : *ö*. The first and the third of these are bound to each other by a common edge. At the distance of $7\mathfrak{A}_1$ the two full subgraphs just mentioned combine into one four-vertex one and the full subgraph *ė* : *u* : *o* gets another element, *a*, bound to its *o* vertex. Now there are two connected subgraphs:



At the distance of $8\mathfrak{A}_1$ the subgraphs are bound into one, and proceeding in this manner a nine-vertex full graph is finally obtained. Let us once more concentrate our attention on the mentioned two subgraphs. The distance $\mathfrak{I} = 7\mathfrak{A}_1$ is peculiar in several respects. First, as we see, the two subgraphs may in a sense be called "isomorphous" (although formally they are not), one containing a three-vertex full subgraph, another a four-vertex one. Further note that this is the second time (the first was at the distance of $3\mathfrak{A}_1$) where we can speak of a certain "isomorphism"; at the same time it is the last time because at the next distance the subgraphs are bound into one. At the distance $\mathfrak{I} = 7\mathfrak{A}_1$ the given parameter has a critical point (CP) in still another respect — which was referred to already in Sec. 3.1.1.1 —, viz. that a non-covering function having three or more max corresponds to $\mathfrak{I}$ values from $2\mathfrak{A}_1$ to $7\mathfrak{A}_1$ and a function with 2 max to values from $8\mathfrak{A}_1$ to $21\mathfrak{A}_1$. The normal interpretation here is as follows: a two-max case implies "opposite" contours whereas a case of three or more max implies contours "tracking each other".

In addition to the given arguments the critical nature of the change over $\mathfrak{I} = 7\mathfrak{A}_1 - 8\mathfrak{A}_1$ reveals itself in the following. If we mark the vertices of the graph on a plane and maintain between them distances proportional to the corresponding values of $\mathfrak{I}$, we can do so for either of the two subgraphs separately, but cannot do so between elements from different subgraphs. In essence this means that in each subgraph we have to do with curvatures of different direction.

From the aforesaid we conclude that the parameter under consideration has a CP which marks a change in the direction of curvature and stands on the parameter so as to locate the above groups on opposite sides of the CP.

It remains now to consider the location of the vowels (to be more exact, of their projections) on the given parameter. In both groups it is relatively simple to establish this, thus in the first

i — *ü* — *e* — *ö* — *ä*;

in the second

u — *ė̮* — *o* — *a*.

u and *i* are extreme values; *a* and *ä* stand nearest to the CP (as soon as we regard the distances across the CP the established regularities become distorted). We get the following scheme (where the distances between elements of different groups are not proportional to the corresponding values of $\mathfrak{I}$ but are so within the groups): Fig. 5.

Let us now consider the logical side of the obtained schemes. The reader has probably already noticed a connection between the obtained system and the systems familiar in phonetics. Besides, attention should be drawn to the connection with the system we arrived at in the preceding paper [4]. How should the values classified by the given parameter be treated (and denoted)? Classical phonetics will doubtless find the continuity of the values and the classifiability of all the objects with regard to a single parameter unusual. But note that such possible statements, as if our given parameter were actually a composition of parameters or as if several vowel locations on this parameter were just attending circumstances whereas their real "essence" should be elsewhere (e. g., in the lips), are in fact of the kind which we have regarded as incorrect in the present paper. In order to make such statements convincing, first of all a "more normal" parameter ought to be practically designed. This is without doubt feasible, at least to some extent; nevertheless we are convinced that continuous or single parameter classifications are also expedient and "normal".

Apparently the symbols to be used in this case are also somewhat unusual. On one side of the CP we apply "+", on the other side "−", with the denotation of a corresponding region by either a real number or, after classification, an integer (e. g., "+4"). Note that the signs "+" and "—" mark a fact of the inner structure of the parameter here (viz. the direction of curvature), and not the presence or absence of a feature.

4.2.2. Sec. 3.1.2.1 presents the values of the same parameter ($\mathfrak{I}$) for the upper lip. If these be depicted again in a graph, the derivation of this graph would be even as to its connectedness, beginning with the formation of the full subgraph *e* : *ä* : *a* : *ė̮* whereupon the two first vertices of the subgraph bind *i*. At the distance of $1.8\mathfrak{A}_2$ all the 9 vertices are combined into one graph, and the addition of the remaining 20 edges is performed evenly over the graph. Thus a peculiar radix of a graph makes its appearance which is formed from the mentioned 4-vertex subgraph (perhaps together with *i* bound to the vertices *e* and *ä*). Hence the given radix seems to contain two (or possibly three) categorical elements:

— the fact of being a radix as such;

— the connectedness of *i* with the vertices *e* and *ä* in the absence of the edges *i* : *a* and *i* : *ė̮*;

[4] See G. Liiv, M. Remmel, On Acoustic Distinctions in the Estonian Vowel System. "Soviet Fenno-Ugric Studies" 1970, No. 1, pp. 7—23.

(— the radix has in essence two cores, viz. *ä* : *a* and *e* : *ė*); the second of these coincides with the one established by the analysis presented before. The values are located on the parameter as follows:

$$\begin{array}{c}\ddot{a}\\ \Big| \\ a\end{array} - \begin{array}{c} e \\ \Big| \\ \dot{e}\end{array} - i - \ddot{o} - o - u - \ddot{u}$$

4.2.3. The Table in Sec. 3.1.3.1 contains the same information concerning the lower lip. But the derivation of the graph is somewhat specific. To begin with, separate vertices bind up with one another, the resulting edges are combined into a graph in such a way as to produce three vertices (in essence two, since two vertices duplicate each other) which bind to themselves all the other vertices. These three are on the one hand *e* and *ä* (binding to the graph the vertices *a*, *i*, *ė*) and on the other hand *ü* (binding *ö*, *u*, *o*). The structure of the parameter is portrayed in the following scheme:

$$\left.\begin{array}{l} a - \\ \dot{e} - \\ i - \end{array}\right\} \begin{array}{c} e \\ \Big| \\ \ddot{a}\end{array} - \ddot{u} \left\{\begin{array}{l} - u \\ - \ddot{o} \\ - o \end{array}\right.$$

4.3. The matrix presented in Sec. 3.1.1.2 is, as previously noted, a normalized variant of the Table of Sec. 3.1.1.1. The normalization was linear and meant to provide each vowel with at least one "very close" and at least one "very remote" partner. Thus the continuity has been reduced to a choice between "close" and "remote", with the intermediate values graduated proportionally to their original distribution. Accordingly the whole distribution has been made more algorithmic so it may be used as a certain operational scheme. The distribution becomes more algorithmic in the sense that all operands are brought into use within one and the same step, and likewise all derivations come to an end within one and the same step.

Exactly the same is the relation between Secs. 3.1.2.1 and 3.1.2.2 as well as 3.1.3.1 and 3.1.3.2.

4.4.0. The values and the location of the maximums presumably ought to convey information about the "normality" (or something like that) of the non-covering function, and they should also indicate how far the number of measurements can be reduced to leave the necessary and sufficient set.

4.4.1. Let us first consider the values of maximums.

One can see from the values in the matrix of Sec. 3.1.1.3 that in 90% of the cases the value of the highest maximum alone suffices to calculate $\mathfrak{I}$ accurate to 0.25, with nearly linear relationship. Such predictability is at any rate too low, and although the general correlation is positive, the presentation of incongruities practically amounts to the presentation of a list. Hence the possibility of a substantial reduction of the number of measurements must probably be dismissed, and it should be noted that the non-covering function is apparently not "simple". The same must be said about lip contours where the corresponding numbers are 95% for the upper lip and 90% for the lower lip within the same accuracy (see Secs. 3.1.2.3 and 3.1.3.3).

4.4.2. Now about the location of maximums.

As a rule the higher maximum of the non-covering function of tongue contours is located in front, except for the vowels next to the CP: *ä* is in this respect different from all the rest of the vowels which lie on the same side of the CP as *ä*, whereas in the case of *a* there is a different location in the pairs *a* : *ė*, *a* : *o*, *a* : *ü* (see Sec. 3.1.1.4).

The location of maximums seems to be a parameter of relatively low classifiability. There might be a certain point of interest, however, in the location of the front maximum which is basically a duplication of $\mathfrak{I}$. This seems to be confirmed by data from lip contours as well (see Secs. 3.1.2.4 and 3.1.3.4).

Fig. 5. Scheme of the location of the vowels (of their projections) on the (non-covering function of the tongue contours) parameter. Note, e. g., that the distances between elements of the groups *i—ü—e—ö—ä*, and *u—ė—o—a* are not proportional to the corresponding values of $\mathfrak{I}$ but are so within each group. Text concerning this figure is presented in Sec. 4.2.1.

4.5.0. Next we shall discuss problems connected with categoriality tests. The term "categoriality test" as such also calls for some explanation. It usually refers to a certain decision procedure. But decision procedures themselves are categorical for their derivation; from the methodological point of view there are no procedures without at least one heuristic interpretation. This elementary truth results directly from the fact that a category (or categories or systems of categories) is (are) embedded in another category (or categories or systems of categories). This is why the so-called "God-discovering" procedures are impossible.

In view of the aforesaid one must admit that despite seemingly utter triviality there is a formal necessity of at least fixing the objects that are to be dealt with in a categoriality test. For classical phonetics this really is a naive problem, but — we are convinced — it may turn out to be rather complicated when one has to perform operations of the type and complexity of articulatory synthesis, in particular when the model of articulation is realized logically, e. g. by means of a digital computer. It seems that in such a case, for instance, besides the classes "immovable structure" and "movable structure" an intermediate class should be defined whose composition depends on preassigned criteria, and so forth. It is also possible that the objects are located in space in a fashion different from that in the list of classes. Therefore the statement that we test the tongue and the lips is at present apparently not incomprehensible, but, for instance, for the purpose of articulatory synthesis it is obviously insufficient, even given Fig. 1.

The generalization of the categoriality test applied in the present paper is to be designed as a continually tilted coordinate system along with appropriate computation of correlations. The latter is used to find a sufficient system of the variants, tilted with respect to each other, of the coordinate system. Such a system may finally serve as a source of preferences which can be taken into account in the construction of "more normal" and "more natural" reference systems.

It should be added that the mathematical interpretation of the categoriality test is very involved indeed and must for obvious reasons be dismissed in the present case. Nonetheless it is necessary to explain the logic aspect of the interpretation of the categoriality test. The smaller the numbers in Tables 1 and 2, the "closer" (in the local sense) are the values of the non-covering function of the corresponding contour pairs. Since we are dealing with a sum, it is conceivable to transform the values proportionately to the non-covering of the contour pairs; likewise acceptable (and even more preferable from the viewpoint of this investigation) is another manner of treatment where a 0-separation, i. e. covering, is also allowed at any given distance.

It is necessary to distinguish between the following three situations:

(1) all the four vowels in a pair of vowel pairs are different (e. g., *ü/a* : *o/e*);

(2) two of the four vowels are different and one occurs in both pairs simultaneously (e. g., *a/o* : *a/e*);

(3) a given distance is satisfied by certain two different vowels which combine with all the other vowels according to situation (2) (e. g., *i/u* : *ü/u*; *i/o* : *ü/o*; *i/a* : *ü/a*, etc.).

When moving from one of the extreme values to the other, heed should be given to such essential cases where cycles come into play; i. e. when the difference of a distance between given pairs from a pre-assigned distance is represented by the edge of a graph; a cycle means that if we proceed along the edges of a graph in one and the same direction, we may return to the point where the movement began.[5]

4.5.1. Now let us regard Table 1 and specifically those values in it that are equal to, or smaller than, 6.0 (this boundary is naturally conventional). Let us move from the smallest values (*i/ü* : *i/e* = 1.5) to bigger ones. At the distance 2.3 the first cycle appears between paired combinations of the vowels *i*, *ü*, *e*. Thus at the distance 2.3 *i*, *ü*, *e* are in equivalence relation (with one another, but not with regard to the other vowels: in

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[5] In mathematical terms the appearance of cycles indicates a conversion from tolerance to equivalence.

essence this is a matter of being separated or not). With regard to the other vowels the three vowels are equivalent beginning with the distance 3.8 (*ü, i* from the distance 2.3; *ü, e* and *i, e* from 3.8). Now the pairs which are equivalent with regard to the rest of the vowels within the distance 6.0 (the first left-hand column presents distances at which members of a given pair are equivalent with regard to the remaining seven vowels taken together; it is followed by the presentation of such distances for each of the seven vowels separately):

		i	*e*	*ä*	*ü*	*ö*	*ė*	*a*	*o*	*u*
i, ü	2.3	—	2.1	2.3	—	2.3	2.1	2.2	2.3	2.3
u, ė	3.3	3.3	2.9	3.1	3.3	3.0	—	3.1	3.0	—
ü, e	3.8	1.5		3.7		3.7	3.7	3.8	3.8	3.5
i, e	3.8	—	—	3.7	2.3	3.7	3.7	3.7	3.8	3.6
ö, e	4.1	2.8	—	3.5	3.5	—	3.6	3.8	4.1	3.9
o, u	4.7	4.5	4.1	3.9	4.4	3.5	4.1	4.7	—	—
ö, ä	5.1	5.1	5.1	—	5.1	—	5.0	5.0	4.9	5.1
a, o	5.9	5.9	5.7	4.8	5.9	5.6	5.5		—	5.6
o, ė	5.9	5.9	5.9	5.2	5.7	4.9	—	3.9	—	4.1

Upon adding the pairs *ö, ü* 6.6 and *ö, i* 7.1, we get the same system at which we arrived in the Table of Sec. 3.1.1.1 at the distance of $7\mathfrak{A}_1$, the derivation being also essentially similar. The analogy is continued towards bigger values.

The stated analogy between the values of $\mathfrak{I}$ and the values of the categoriality test is not accidental: it is explicable on the basis of the parameter described above. Minor differences have emerged, however (the derivations do not coincide exactly, and the coincidence decreases towards bigger values); this is one of the reasons why it is also necessary to compute a test of tilted coordinates.

4.5.2. The situation involving the values of the categoriality test for the upper lip (see Table 2) is similar (with the boundary distance chosen at 1.0):

		i	*e*	*ä*	*ü*	*ö*	*ė*	*a*	*o*	*u*
ä, e	0.8	0.7	—	—	0.7	0.6	0.7	0.8	0.7	0.7
a, ė	0.8	0.8	0.8	0.7	0.7	0.6	—	—	0.8	0.7
ä, ė	0.9	0.9	0.9	—	0.7	0.9	—	0.7	0.8	0.7
a, ä	0.9	0.9	0.8	—	0.8	0.7	0.8	—	0.8	0.8
a, e	1.0	0.9	—	0.7	0.9	0.8	1.0	—	1.0	1.0
e, ė	1.0	0.8	—	0.7	0.7	0.9	—	0.7	1.0	0.8

These numbers should suffice for the purpose of comparison with the derivation presented on the basis of the $\mathfrak{I}$ values in Sec. 4.2.2.

4.5.3. All the aforesaid is entirely valid for the lower lip (see Table 2 and Sec. 4.2.3).

Table 1

Values obtained through the categoriality test for tongue contours

	i/e	*i/ä*	*i/ü*	*i/ö*	*i/ė̮*	*i/a*	*i/o*	*i/u*	*e/ä*	*e/ü*	*e/ö*	*e/ė̮*	*e/a*	*e/o*	*e/u*	*ä/ü*	*ä/ö*	*ä/ė̮*	*ä/a*	*ä/o*	*ä/u*	*ü/ö*	*ü/ė̮*	*ü/a*	*ü/o*	*ü/u*	*ö/ė̮*	*ö/a*	*ö/o*	*ö/u*	*ė̮/a*	*ė̮/o*	*ė̮/u*	*a/o*	*a/u*	*o/u*
i/e	X	7.7	1.5	2.8	12.7	17.0	16.9	14.7	5.1	2.1	4.2	9.8	14.3	13.9	11.9	7.3	2.9	5.3	7.5	7.5	7.8	4.5	12.3	16.7	16.4	14.1	8.1	10.8	10.7	10.5	8.5	7.1	4.3	6.9	10.7	6.5
i/ä		X	9.3	5.1	6.9	9.7	9.9	9.2	3.7	7.9	8.1	5.5	7.8	8.0	7.5	2.3	6.4	6.3	7.3	7.5	6.5	5.8	6.7	9.6	9.9	9.0	5.5	5.1	6.3	6.5	10.7	9.8	9.3	10.3	12.2	9.9
i/ü			X	5.3	14.2	18.5	18.5	16.1	6.2	2.3	3.9	11.1	15.7	15.3	13.0	8.9	4.1	6.2	8.7	8.8	8.9	4.7	13.7	18.1	17.9	15.3	9.3	12.1	12.3	11.4	8.7	6.7	3.7	6.5	10.8	6.4
i/ö				X	10.3	16.8	13.8	12.4	3.5	4.5	3.7	8.1	10.9	10.9	9.8	5.5	4.3	4.9	4.9	5.8	6.1	2.3	10.1	13.2	13.3	11.9	6.7	7.6	8.4	8.3	8.6	6.8	5.4	7.7	10.7	6.8
i/ė̮					X	7.7	5.9	3.3	9.4	13.0	13.1	3.7	8.6	7.1	4.7	7.7	11.7	9.9	12.0	9.9	9.2	11.0	2.3	8.3	6.9	4.5	6.4	8.9	7.0	6.3	15.7	14.3	13.9	15.6	16.9	14.9
i/a						X	5.9	7.7	12.7	17.2	16.6	9.8	3.7	7.5	9.1	10.5	15.7	14.1	10.8	12.1	11.7	14.2	8.9	2.2	7.0	9.1	11.7	6.8	9.5	10.5	13.5	16.0	17.3	15.5	13.7	15.9
i/o							X	4.5	13.1	17.1	16.7	9.1	7.9	3.8	6.9	10.7	15.6	14.1	13.5	10.8	12.0	14.6	7.0	6.8	2.3	5.8	10.9	10.0	7.1	9.0	17.2	15.1	17.5	17.7	16.9	16.1
i/u								X	11.6	15.0	14.6	5.9	9.0	6.1	3.6	10.1	13.9	12.1	12.9	10.7	10.3	13.4	4.3	8.5	5.7	2.3	7.7	10.3	6.9	6.5	16.9	15.4	15.0	16.1	17.7	16.2
e/ä									X	5.5	5.1	6.7	9.9	9.9	8.7	3.7	3.5	4.7	5.6	6.1	5.3	3.8	8.9	12.4	12.6	11.0	6.1	6.7	7.8	7.4	8.3	7.3	5.8	7.8	10.5	7.4
e/ü										X	3.7	10.1	14.3	13.9	12.0	7.7	3.3	5.0	7.3	7.4	7.5	3.5	12.3	16.7	16.4	14.2	8.3	10.9	10.8	10.5	7.4	6.3	3.9	6.0	9.9	5.7
e/ö											X	9.9	13.6	13.3	11.4	8.1	5.1	5.3	6.5	7.1	6.7	3.7	12.7	16.3	16.2	14.0	8.3	10.4	10.6	9.9	7.5	5.5	3.1	5.7	9.5	5.1
e/ė̮												X	7.5	5.9	2.9	5.6	8.8	6.9	9.3	7.7	6.7	8.5	3.7	8.9	8.8	5.7	3.6	7.1	5.7	4.5	10.0	11.9	10.8	12.8	14.4	12.5
e/a													X	5.7	7.1	8.2	12.8	11.3	7.7	9.3	9.4	11.4	8.2	3.8	7.5	8.9	9.3	3.9	7.2	8.3	10.7	12.9	14.3	12.3	11.1	12.9
e/o														X	4.1	8.2	12.3	11.1	10.5	7.6	9.1	11.5	6.5	7.4	3.8	5.7	8.0	7.5	4.1	6.4	14.5	11.8	14.1	14.5	14.3	13.1
e/u															X	7.7	10.8	9.0	10.1	8.0	7.5	10.6	4.5	8.9	6.7	3.5	5.0	7.9	4.6	3.9	17.6	12.8	12.1	13.2	15.3	16.9
ä/ü																X	6.0	6.0	7.0	6.9	5.8	5.1	6.8	9.7	9.9	9.2	5.1	5.3	6.1	6.3	10.1	9.3	9.0	9.9	11.4	9.3
ä/ö																	X	5.1	6.5	7.1	6.8	4.6	11.2	15.2	15.1	13.3	6.9	9.1	9.2	9.1	8.0	6.3	4.7	6.3	9.9	6.4
ä/ė̮																		X	5.6	5.2	3.1	4.5	9.4	13.5	13.7	11.6	5.0	8.3	8.7	7.4	8.5	7.1	5.9	7.3	9.7	7.4
ä/a																			X	4.8	5.1	5.2	11.5	10.5	12.8	12.5	7.9	5.0	8.3	8.3	6.5	7.3	7.2	6.4	8.3	7.5
ä/o																				X	3.9	5.8	9.8	12.1	10.4	10.2	6.3	7.1	4.9	6.5	9.5	6.5	7.5	8.3	10.1	8.3
ä/u																					X	5.9	8.7	11.6	11.4	9.7	5.1	7.1	6.6	5.1	7.4	7.5	6.9	7.0	8.8	7.6
ü/ö																						X	10.3	13.6	13.8	12.5	7.0	7.7	9.0	8.5	7.7	6.1	5.0	6.8	9.7	6.1
ü/ė̮																							X	7.6	5.7	3.3	5.8	8.3	6.3	5.7	15.1	13.8	13.5	15.1	16.2	14.2
ü/a																								X	5.9	7.9	11.1	6.3	9.0	9.9	16.4	15.8	16.9	15.1	13.2	15.7
ü/o																									X	4.4	10.2	9.4	6.6	8.3	16.3	14.5	16.9	17.1	16.1	15.2
ü/u																										X	7.5	9.9	6.3	5.9	16.3	14.7	14.7	15.5	17.2	15.5
ö/ė̮																											X	6.6	4.9	3.0	11.3	9.8	9.4	10.3	12.5	10.7
ö/a																												X	5.6	6.3	9.2	10.7	10.9	9.9	10.6	10.9
ö/o																													X	3.5	12.1	9.9	11.2	15.1	12.5	11.3
ö/u																														X	11.5	10.3	10.4	10.4	12.4	11.1
ė̮/a																															X	5.5	6.3	3.9	3.1	4.2
ė̮/o																																X	4.1	5.9	6.3	3.0
ė̮/u																																	X	4.1	8.0	4.1
a̮/o																																		X	4.7	5.5
a/u																																			X	5.6
o/u																																				X

Table 2

Values obtained through the categoriality test for upper lip contours (above the diagonal) and for lower lip contours (below the diagonal)

	i/e	*i/ä*	*i/ü*	*i/ö*	*i/ė̮*	*i/a*	*i/o*	*i/u*	*e/ä*	*e/ü*	*e/ö*	*e/ė̮*	*e/a*	*e/o*	*e/u*	*ä/ü*	*ä/ö*	*ä/ė̮*	*ä/a*	*ä/o*	*ä/u*	*ü/ö*	*ü/ė̮*	*ü/a*	*ü/o*	*ü/u*	*ö/ė̮*	*ö/a*	*ö/o*	*ö/u*	*ė̮/a*	*ė̮/o*	*ė̮/u*	*a/o*	*a/u*	*o/u*	
o/u	X	0.7	2.7	1.7	0.8	0.9	2.1	3.1	1.1	2.8	2.2	1.5	1.5	2.3	3.0	2.5	2.1	1.1	0.9	2.1	2.9	2.1	2.6	2.4	2.2	1.9	1.9	1.9	1.6	2.4	1.3	1.7	2.8	2.0	2.2	1.8	*i/e*
a/u	2.3	X	2.6	1.6	0.9	0.9	2.4	3.4	0.8	2.7	2.1	1.8	1.2	2.3	3.0	2.5	2.0	1.1	1.1	1.9	2.7	2.2	2.6	2.4	2.0	1.4	2.0	1.9	1.5	2.3	1.1	1.7	2.4	1.8	2.3	1.8	*i/ä*
a/o	2.7	1.8	X	1.9	2.3	2.0	1.3	1.2	3.2	1.1	2.7	3.2	2.9	2.1	1.6	1.2	2.8	3.2	3.2	2.0	1.4	2.1	1.5	1.8	2.6	2.7	3.0	2.7	3.0	2.3	2.8	2.3	1.6	2.5	1.7	2.7	*i/ü*
ė̮/u	3.1	1.8	3.0	X	1.3	1.7	1.2	2.2	2.1	2.1	1.0	2.0	2.0	1.3	2.1	2.0	1.2	1.9	2.2	1.2	1.9	1.9	1.8	2.0	1.9	1.9	1.6	1.3	2.2	2.1	1.9	1.8	1.9	1.6	1.9	2.0	*i/ö*
ė̮/o	3.4	3.6	2.0	2.3	X	0.8	1.7	2.7	1.2	2.5	1.8	1.1	1.3	1.8	2.7	2.2	1.8	1.0	1.3	1.8	2.4	1.8	2.2	2.1	1.8	1.6	1.6	1.4	1.7	2.0	1.5	2.0	2.2	1.9	2.4	1.7	*i/ė̮*
ė̮/a	3.3	2.8	2.8	1.7	2.0	X	1.8	2.7	1.3	2.5	2.3	1.7	1.1	2.3	2.8	2.3	2.2	1.4	1.2	1.9	2.3	2.1	2.4	2.5	2.2	1.6	2.0	1.6	1.7	2.1	1.4	1.9	2.2	2.0	2.3	2.1	*i/a*
ö/u	2.5	2.1	2.3	2.5	3.5	3.1	X	1.2	2.7	2.0	1.8	2.4	2.4	1.1	1.7	1.6	1.9	2.5	2.6	1.2	1.7	1.8	1.6	1.9	2.4	2.5	2.1	1.8	2.4	2.0	2.5	1.7	1.6	1.8	1.9	2.2	*i/o*
ö/o	1.5	2.1	1.9	2.8	3.3	2.6	2.3	X	3.6	1.9	2.8	3.2	3.3	2.0	1.1	1.7	2.9	3.5	3.5	2.3	1.3	2.4	2.0	2.2	3.1	3.2	3.0	2.9	3.3	2.4	3.6	2.6	1.6	2.8	1.9	2.8	*i/u*
ö/a	2.0	2.2	2.3	3.1	3.7	3.1	2.5	1.7	X	2.4	1.4	0.9	0.8	2.0	2.8	2.3	1.4	0.7	0.7	1.8	2.7	1.9	2.4	1.9	1.7	1.2	1.4	1.4	1.3	2.2	0.9	1.5	2.3	1.5	2.3	1.4	*e/ä*
ö/ė̮	3.4	3.2	2.8	1.5	1.7	2.2	2.6	3.4	3.1	X	1.9	2.3	2.1	1.2	1.0	0.7	2.0	2.5	2.4	1.6	1.3	1.5	0.7	0.9	1.9	2.2	2.3	2.0	2.4	1.9	2.3	1.8	1.2	1.8	1.2	1.9	*e/ü*
ü/u	2.0	2.4	2.2	2.7	3.8	2.8	2.8	1.3	1.7	3.1	X	1.3	1.5	1.1	2.0	1.8	0.6	1.4	1.8	1.3	2.2	1.6	1.7	1.5	1.4	1.5	0.9	0.8	2.1	2.3	1.6	1.6	1.9	1.3	1.9	1.3	*e/ö*
ü/o	1.5	3.0	1.6	3.5	3.1	3.2	2.5	1.4	1.5	3.8	1.8	X	0.8	1.6	2.6	2.2	1.1	0.7	1.0	1.9	2.7	1.5	2.1	1.6	1.3	1.3	1.2	1.2	1.4	2.1	1.0	1.8	2.3	1.8	2.4	1.1	*e/ė̮*
ü/a	2.1	2.2	2.2	2.5	3.6	2.6	2.3	1.3	1.5	3.3	1.4	1.8	X	1.7	2.5	2.1	1.4	0.9	0.8	1.8	2.5	1.7	2.1	1.9	1.5	1.1	1.4	1.2	1.5	2.1	0.7	1.7	2.2	1.6	2.1	1.3	*e/a*
ü/ė̮	3.4	3.1	2.8	1.5	2.2	1.5	3.0	3.1	3.6	1.2	2.8	3.4	2.5	X	1.2	1.3	1.1	1.8	2.0	0.7	1.5	1.3	1.1	1.1	1.7	1.8	1.4	1.2	1.7	1.6	1.9	1.0	1.2	1.0	1.4	1.6	*e/o*
ü/ö	2.2	2.9	2.2	3.0	3.7	3.0	2.2	2.2	2.4	3.0	1.8	2.3	2.3	2.8	X	1.1	2.2	2.8	2.8	1.6	0.7	1.6	1.2	1.4	2.2	2.4	2.4	2.1	2.6	1.7	2.8	2.0	0.8	2.0	1.0	2.1	*e/u*
ä/u	2.7	1.2	3.0	1.4	3.2	2.2	1.7	2.9	2.6	2.4	2.2	3.2	2.2	2.5	3.0	X	1.9	2.3	2.2	1.3	1.2	1.2	0.7	0.8	2.0	2.2	2.0	1.9	2.3	1.9	2.2	1.6	1.1	1.8	1.3	1.8	*ä/ü*
ä/o	2.4	2.7	1.1	2.6	1.8	2.6	2.5	2.0	2.6	2.5	2.6	2.0	2.5	2.6	2.3	2.8	X	1.2	1.7	1.3	2.3	1.5	1.7	1.4	1.4	1.4	0.9	0.7	1.9	2.0	1.4	1.4	2.0	1.1	1.9	1.3	*ä/ö*
ä/a	2.5	2.7	2.1	3.1	3.3	2.0	2.8	1.8	2.3	3.3	1.7	2.1	1.7	2.6	1.8	3.0	2.0	X	0.7	1.6	2.7	1.7	2.2	1.8	1.4	1.2	1.1	1.2	1.2	1.9	0.8	1.6	2.3	1.5	2.4	1.4	*ä/ė̮*
ä/ė̮	2.9	3.2	2.7	2.5	2.7	1.6	2.9	2.3	3.5	2.2	2.4	3.1	2.8	1.6	2.2	3.0	2.7	1.9	X	1.8	2.7	1.7	2.3	2.1	1.8	1.4	1.5	1.4	1.1	2.1	0.7	1.5	2.5	1.7	2.5	1.3	*ä/a*
ä/ö	2.5	2.6	1.9	2.5	3.0	2.9	2.4	2.1	3.6	2.3	1.9	2.3	1.9	2.7	2.0	2.4	1.8	2.0	2.9	X	1.2	1.4	1.3	1.5	1.7	1.6	1.5	1.3	1.5	1.4	1.8	0.8	1.2	0.8	1.2	1.8	*ä/o*
ä/ü	2.5	1.9	2.0	2.0	3.2	2.2	1.9	1.8	2.4	2.4	1.6	2.3	1.4	1.8	1.7	1.9	1.9	1.6	2.1	1.5	X	1.6	1.4	1.7	2.2	2.1	2.4	2.1	2.4	1.4	2.8	1.9	0.7	1.8	0.8	2.1	*ä/u*
e/u	3.1	1.6	3.1	1.2	3.1	2.5	1.8	2.6	3.0	2.3	2.3	3.4	2.5	2.3	3.0	0.7	2.8	3.1	3.0	2.6	2.0	X	1.2	1.3	1.2	1.6	1.5	1.2	1.5	1.3	1.7	1.6	1.4	1.5	1.6	1.1	*ü/ö*
e/o	3.0	2.5	1.7	2.4	1.6	2.7	2.7	2.4	2.9	2.5	3.1	2.4	2.7	2.0	3.4	2.5	1.3	3.1	3.5	2.3	2.5	2.2	X	0.7	1.5	2.0	1.8	1.6	2.0	1.8	2.1	1.5	1.1	1.6	1.3	1.9	*ü/ė̮*
e/a	2.9	2.1	2.5	2.4	3.0	1.5	2.5	1.6	2.4	2.9	1.8	2.4	1.5	2.4	2.7	2.2	2.3	1.5	2.3	2.0	1.6	2.1	2.0	X	1.5	1.8	1.6	1.6	2.1	2.0	2.0	1.5	1.3	1.3	1.4	1.4	*ü/a*
e/ė̮	2.5	3.3	2.5	3.0	3.5	2.2	2.8	2.4	3.0	3.0	2.8	2.5	2.4	2.2	2.0	3.0	2.8	1.9	1.1	2.4	1.9	3.3	3.6	2.2	X	1.2	1.6	1.3	1.8	1.9	1.9	2.1	2.2	1.5	1.9	1.3	*ü/o*
e/ö	3.2	2.9	2.2	2.2	2.3	2.6	2.6	2.9	2.6	1.5	2.4	3.1	2.7	1.9	2.1	2.5	1.7	2.3	2.3	1.4	1.7	2.2	2.0	2.2	2.7	X	1.4	1.3	1.5	1.6	1.2	1.7	2.0	1.3	1.7	1.2	*ü/u*
e/ü	3.2	2.5	2.5	2.1	3.0	2.3	2.5	2.7	3.3	2.4	2.5	3.1	2.1	1.4	1.8	2.3	2.1	2.1	2.1	2.2	1.1	2.0	2.5	1.8	2.3	1.4	X	0.6	1.4	1.6	1.6	1.6	2.0	1.5	2.1	1.2	*ö/ė̮*
e/ä	2.7	2.9	2.3	3.1	3.5	2.4	2.8	2.1	2.6	3.4	1.7	2.3	2.0	2.6	1.9	3.1	2.5	1.5	1.6	1.9	1.6	3.0	3.1	1.7	1.4	2.3	2.0	X	1.5	1.5	1.4	1.5	1.8	1.3	1.8	1.2	*ö/a*
i/u	3.8	2.2	3.6	1.1	2.9	2.4	2.5	3.5	3.8	2.3	3.2	4.0	3.2	2.2	3.6	1.7	3.3	3.8	3.2	3.3	2.6	1.0	2.7	2.9	3.6	2.8	2.5	3.5	X	1.3	1.4	1.6	2.1	1.8	2.3	1.8	*ö/o*
i/o	3.5	3.1	2.7	2.1	1.2	2.6	3.7	3.1	3.7	2.1	3.9	3.2	3.5	2.7	4.3	2.8	2.4	4.1	3.6	3.2	3.4	2.5	1.2	3.0	4.0	2.8	3.4	4.1	2.2	X	2.1	1.7	1.5	1.7	1.7	1.5	*ö/u*
i/a	3.4	2.3	2.5	1.6	2.9	1.1	3.0	2.7	3.4	2.7	3.0	3.5	2.4	2.1	2.5	2.0	2.3	2.8	2.5	3.2	2.5	2.2	2.8	1.6	2.8	3.2	2.7	2.8	1.7	2.1	X	1.4	1.3	1.4	2.4	1.4	*ė̮/a*
i/ė̮	2.6	3.3	2.6	3.3	4.2	2.8	2.9	2.0	2.6	3.5	1.7	2.2	2.1	2.8	1.6	3.3	2.8	1.6	2.0	2.2	1.7	3.4	3.5	2.0	1.1	2.6	2.3	1.2	4.0	4.5	3.1	X	1.3	0.8	1.6	1.6	*ė̮/o*
i/ö	4.0	3.9	3.1	2.0	2.0	2.5	3.0	3.9	3.8	1.0	3.6	4.0	3.8	1.4	3.0	3.0	2.6	3.5	2.5	3.0	2.9	2.6	2.7	3.5	3.2	1.6	2.2	3.7	2.2	2.1	2.7	3.9	X	1.6	0.7	1.6	*ė̮/u*
i/ü	3.8	3.3	3.5	1.8	2.7	2.0	2.9	3.5	4.0	1.7	3.3	3.9	3.1	0.9	2.8	2.6	3.1	3.1	2.1	3.4	2.2	2.2	3.3	3.0	2.8	2.2	1.4	3.1	1.8	2.8	2.0	3.4	1.2	X	1.3	1.5	*a/o*
i/ä	3.0	2.8	3.0	2.1	3.1	1.7	2.7	2.5	3.4	2.3	2.4	3.1	2.5	1.8	2.7	2.3	3.1	2.5	1.1	2.9	2.0	2.3	3.0	2.0	1.7	2.7	2.3	1.6	2.5	2.8	1.7	2.2	2.4	1.9	X	1.7	*a/u*
i/e	2.9	3.4	2.9	3.0	3.6	1.9	2.9	2.7	3.5	2.9	2.2	3.0	2.7	2.2	1.7	3.1	2.8	1.9	1.2	3.0	2.1	3.2	3.7	2.6	0.9	2.7	2.2	2.0	3.7	4.2	2.8	1.6	2.8	2.4	1.5	X	*o/u*
	o/u	*a/u*	*a/o*	*ė̮/u*	*ė̮/o*	*ė̮/a*	*ö/u*	*ö/o*	*ö/a*	*ö/ė̮*	*ü/u*	*ü/o*	*ü/a*	*ü/ė̮*	*ü/ö*	*ä/u*	*ä/o*	*ä/a*	*ä/ė̮*	*ä/ö*	*ä/ü*	*e/u*	*e/o*	*e/a*	*e/ė̮*	*e/ö*	*e/ü*	*e/ä*	*i/u*	*i/o*	*i/a*	*i/ė̮*	*i/ö*	*i/ü*	*i/ä*	*i/e*	

4.6. The data concerning the positions of the mouth corners were represented in Fig. 3. Here we add the distances of the points from one another (in conventional units):

ö : ė̮	5	*a : o*	21	*ö : u*	26
ö : o	9	*i : o*	21	*ü : ė̮*	27
i : ė̮	10	*ė̮ : a*	22	*i : ä*	28
i : e	10	*ü : ö*	22	*ė̮ : u*	31
ä : a	10	*ü : o*	23	*i : a*	32
i : ö	11	*ä : ö*	24	*i : u*	32
ü : u	11	*ö : a*	24	*e : ü*	38
e : ė̮	13	*o : u*	24	*e : u*	44
ė̮ : o	13	*e : a*	24	*ü : a*	44
e : ä	17	*i : ü*	25	*a : u*	45
e : ö	18	*e : o*	25	*ä : ü*	45
ä : ė̮	20	*ä : o*	25	*ä : u*	48

Beginning again with the pair *ö : e* and proceeding toward greater distances, we shall obtain a graph with following derivation.

At the distance 11 there is at least one edge in every vertex. The "root" of the graph is the full subgraph *e : ö : i*; linked to it are *e* in the vertex *i* and *o* in the vertex *ö*. The edges *a : ä* and *u : ü* lie apart. At the distance 13 there are at least two edges in every vertex of the basic part of the graph; the edges *a : ä* and *u : ü* are still apart. At the distance 20 the vertices *a* and *ä* are bound to the basic part of the graph through the vertex *ä*. At the distance 22 there are at least three edges in every vertex of the basic part of the graph, and the vertices *u* and *ü* are bound to the rest of the vertices through the vertex *ü*. Now the graph is connected. At the distance 24 there are two edges in the vertex *u*. The further derivation is carried out uniformly all over the graph; finally *a* and *ä* are linked to *u* and *ü*. A schematic representation (with proximity of neighbouring vowels maintained) will be like this:

u–ü–o–ö–ė̮–i–e–ä–a

This sequence corresponds to the succession of vertices projected (at right angles) on the curved parameter shown in Fig. 3. If the curvature is assumed to be uniform, its center ought to be in the point with coordinates (approximately) (10; 1).

When projected on the maximum abscissa, the given sequence would alter into one where *a* would change places with *ä* and *i* with *ė̮*.

4.7. The data on the positions of the mandible were represented in Fig. 4. The distances of the points from one another (measured in conventional units) were as follows:

ü : u	2	*ä : a*	14	*ü : a*	27
e : u	5	*ö : a*	15	*ä : ö*	29
a : o	5	*ä : o*	16	*ė̮ : o*	30
e : ü	7	*ö : ė̮*	19	*i : ö*	31
e : ö	7	*e : o*	19	*e : ä*	35
ü : ė̮	8	*i : ü*	20	*ė̮ : a*	35
ö : o	8	*i : u*	21	*ä : ü*	37
ė̮ : u	9	*o : u*	22	*ä : u*	37
ö : u	10	*ü : o*	22	*i : o*	42
ü : ö	12	*e : a*	23	*ä : ė̮*	45
i : ė̮	13	*i : e*	25	*i : a*	46
e : ė̮	14	*a : u*	25	*i : ä*	57

The corresponding graph is derived in the following way.

At the distance 12 the "core" of the graph is the full subgraph ü : u : ö : e which in the vertices ü and u is connected with the vertex e and through the vertex ö with the vertex o, the latter in its turn binding the vertex a. In the vertices i and ä there are no edges. At the distance 14 there is at least one edge in every vertex, and at the same distance the graph is connected. Further the addition of new edges takes place uniformly all over the graph; the last linking is between the vertices ä and i.

The following sequence is formed:

ä—a—o—ö—e—u—ü—ė̌—i

This sequence may appear as a projection on a parameter having a curvature variable within wide limits. The optimal center (in terms of least squares) of the curvature is in the point with coordinates $\approx(-5; 8)$. With regard to the longest abscissa the succession remains unchanged.

5. Summary Considerations

Above we have tried to examine, though perhaps in a somewhat fragmentary fashion, the problems which essentially govern the inner structure of phonetics. The established categorialities are valid, as has been mentioned, only for the system of the used assumptions and conventions, although the major part of what has been ascertained is probably true to an appreciably wider extent. As we have seen, the system of categories derived by the procedures used in our research is somewhat different from traditional systems. In our case single-parameter distributions of values were formed; only to a certain degree are they similar to those of classical phonetics. As yet there is no possibility of preferring either of the two systems, but at this stage a closer consideration should be undertaken of the logical aspects of categoriality.

In classical phonetics the relation of objects and categories is expressed by statements of the type $x \in A_Y$, where x is an object and A_Y is a class A determined by some category Y. In the case of single-parameter distributions such statements are to be replaced by statements either of the type $x \in A_{Y/z}$ or of the type $x \in A_{Y/B}$, where $A_{Y/z}$ stands for a class A determined by a category Y with respect to some object z and $A_{Y/B}$ the same with respect to some class B. The two types, viz. a reference to an object and a reference to a class, are maybe not exhaustive of the necessary and/or sufficient number of types; maybe the references are also inaccurate; nevertheless the formal structure of the statement should remain as proposed. All the more so in view of a widespread practice in methodology of fixing similar situations.

The doubts that we have expressed here stem from the fact that the inner structure of the parameters itself (as described in some arbitrary system of measurement; the aforeused normalization of $\mathfrak{J}$ is unsuited for the purpose) is at present excluded from the classification. What we were able to say in this paper about the $\mathfrak{J}$ used in the analysis of the tongue and lip contours proceeded from just a single possibility, viz. from the structural classification of the parameter on the basis of the value distributions by themselves; naturally this is not the general case, moreover, it is one of the most specific cases. The general case is built up outside the scope of phonetics.

Academy of Sciences of the Estonian SSR,
Institute of Language and Literature

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G. LIIV, M. REMMEL

EESTI KEELE VOKAALIDE ARTIKULATOORNE KLASSIFIKATSIOON

Resümee

Esitatakse eesti keele vokaalide artikulatsioonil põhinev klassifikatsioon. Selle tuletamiseks viidi elektronarvutisse keele- ja huulte kontuurid ning alalõua ja suunurga koordinaadid. Arvutati välja mitmesugused vastavate kontuuride ja mõõtepunktide eristatusega seotud klassifikatsioonilised parameetrid ning saadi nende artikulaatorite positsioonide klassifikatsioon kõikide kasutatud parameetrite suhtes. Formaalselt võttes on eristatuse väärtuste jaotustel klassikalise foneetika klassifikatsioonidest erinev kategoriaalne sisu. Nimelt on neil kuju $x \in A_{Y/z}$ (või $x \in A_{Y/B}$), kus $A_{Y/z}$ ja $A_{Y/B}$ tähistavad kategooria Y poolt objekti z või klassi B suhtes määratud klassi A (klassikalistes süsteemides kasutatakse $x \in A_Y$-tüüpi lauseid). Käsitletakse ka mõningaid teisi metodoloogilisi probleeme.

Eesti NSV Teaduste Akadeemia
Keele ja Kirjanduse Instituut

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Г. ЛИЙВ, М. РЕММЕЛЬ

О КЛАССИФИКАЦИИ СИСТЕМЫ ЭСТОНСКИХ ГЛАСНЫХ (НА МАТЕРИАЛЕ АРТИКУЛЯТОРНЫХ ИЗМЕРЕНИЙ)

Резюме

В статье представлен вариант классификации эстонских гласных с точки зрения их артикуляции.

В ЭЦВМ вводились контуры языка, контуры губ и координаты нижней челюсти и углов рта. Вычислялись различные классификационные параметры, связанные с отделимостью соответствующих контуров и точек измерения (в случае нижней челюсти и углов рта). Получены классификации позиций названных артикуляторов по всем использованным параметрам. С формальной точки зрения полученные распределения соответствующих значений отделимости имеют категориальный смысл, отличный от известных в классической фонетике классификаций, а именно, категории задаются по форме $x \in A_{Y/z}$ (или $x \in A_{Y/B}$), где $A_{Y/z}$ и $A_{Y/B}$ обозначают класс A, определенный категорией Y по отношению к объекту z или к классу B (в классических системах используются высказывания типа $x \in A_Y$). Кроме названной, обсуждается ряд других методологических проблем.

Институт языка и литературы
Академии наук Эстонской ССР

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