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ARTICULATION OF THE ESTONIAN SONORANT CONSONANTS. I. [n] AND [l]

0.1. The peculiar quantitative system of the Estonian language has gained a significant place in special literature. Most of the publications dealing with the degrees of quantity present chiefly theoretical calculations in favour of some particular phonological conception, being only in part based on phonetic facts (for a closer insight, see surveys of literature on quantity in: Kask, 1957; Pikamäe, 1959; Lehiste, 1960; Harms, 1960; Liiv, 1961a, b; Hallap, 1962; and elsewhere).

0.2. Studies of the phonology of consonantal quantity have practically been confined to data from durational analyses of individual sounds (Ariste, 1933a, b, 1939, 1941; Lehiste, 1960, 1966). Materials on qualitative articulatory distinctions of consonants are much scantier (Kettunen, 1913; Ariste, 1938, 1939, 1943, 1953, 1968). Descriptions of the articulation dynamics of consonants are lacking altogether.

0.2.1. Experiments in the perception of consonants (Malécot, 1956; Öhman, 1962; Любимова, 1964; Liiv, 1965a, b, to name only those concerning sonorants) suggest that information on sonorants is carried not only by the segment between their implosion and release but also by the preceding and the following segment. This has made it necessary to base the description of the articulation dynamics of intervocalic sonorants on a speech segment between the culmination phases of the vowels preceding and following the sonorant (for such a possibility of including transitional phases in the description of the articulation of consonants, see also Daniloff et al., 1968).

0.3. The speech segment to be analyzed is presumably too short to use the data for decisions in favour of some particular speech production model (Чистович et al., 1965; Öhman, 1966, 1967a, b; Henke, 1967; Fromkin, 1968). We can only make some indirect allusions here, especially concerning certain coarticulatory effects.

1. Methods and material

1.1. *Lateral cinefluorography*

1.1.1. The cinefluorographic equipment used consisted of the following basic component parts: six-valve X-ray tube TuR D 1000-2 (focal spot 1.2×1.2 mm); five-inch Philips electron optical image intensifier; 35-mm Arriflex X-ray camera operated at a speed of 48—50 frames/sec. Operating conditions for X-raying: 110 kV, 150 mAs, 70—75% of the working capacity of the tube. The informant's head posture was fixed by a head holder. Special brackets were used to place the image intensifier in the immediate vicinity of the informant's face; the X-ray tube was moved to a distance of 2.5 meters from the midsagittal plane of the informant.

Precise synchronization of X-ray frames and spectrograms was guaranteed by a special device attached to the driving shaft of the Arriflex X-ray camera.

The speech produced during X-ray filming was recorded through a G. Neumann & Co. Type UN 61 directional microphone on one track of a Jauza-10 dual-channel tape recorder and the synchronizing pulses on the other.

Spectrograms were obtained by means of a 52-channel dynamic sound spectrograph. The range of analysis of the spectrograph is 40—14 000 cps for frequency and 35 db for intensity, with preamplification of higher frequencies beginning with 1000 cps at a rate of 6 db/octave. The pulses synchronizing spectrograms with cineframes were registered on the upper edge of the dynamic spectrogram in the form of short horizontal lines as an output of the 52nd channel instead of the frequency band between 13 000 and 14 000 cps. (For details of the techniques of cinefluorography synchronized with sound spectrography, see: Лийв et al. 1968a, b; Eek, 1969.)

1.1.2. The cinefluorograms were drawn frame by frame. Before drawing, the film of the word under study was made into a loop and continually projected on a screen. By focusing attention in turn on different articulators (or their parts), a rather good idea of the pronunciation of the word was gained, which was of great help in drawing. The correct magnification power for frame drawing was arrived at from a special metal grid which was fixed in the position of every informant's midsagittal plane in front of the input screen of the image intensifier before each filming.

1.2. *Static roentgenography*

The Diagnomax-125 X-ray tube (focal spot 2×2 mm) with a 1-mm Al filter was used; exposure 0.04 sec; 118 kV, 220 mA; the distance of the tube from the informant's midsagittal plane was 2 meters; the film-holder was placed on the informant's shoulder.

X-ray shots were synchronized with sound recording. One track of the Jauza dual-channel tape recorder was used for recording the sentence pronounced during X-raying, the other for a pulse corresponding to the 0.04 sec exposure. The pulses were taken 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). Oscillograms of the tape recordings provide an opportunity to define the sound segment represented on a given X-ray shot. (For details see Лийв, Ээк, 1968a.)

1.3. *Filming of lip movements*

Motion pictures of the informant's face, both full face and side view, were simultaneously shot on a 16-mm film; film speed 48 frames/sec. Indian ink spots on the lips and in the corners of the mouth facilitate measurement performed on the cineframes.

Frames were synchronized with the speech signal by means of a small neon lamp which was fixed to a spectacle-frame and connected with the synchronous switch of the camera. The blinking of the neon lamp was recorded simultaneously as light spots on the edge of the film and as pulses on one sound track of the dual-channel tape recorder; the other track was used for recording the sentence pronounced. Subsequently produced oscillograms of the recorded material provide an opportunity to compare lip movements with changes in the speech wave (Eek, 1969).

1.4. *Material*

1.4.1. The three techniques described above were applied to one and the same experimental material presented below:

Ka|n|a kaagutab pesa juures.
'A h e n is cackling at her nest.'

Ka|nn|a pealt kulus jälle läbi.
'Again it wore out in the h e e l.'

A|nn|a ta sõita ei jõudnudki.
'But she never managed to leave for A n n a.'

Ta|l|a kukkus pähe.
'A b e a m fell down on (somebody's) head.'

Ta|ll|a paksus on pool tolli.

'The thickness of the s o l e is half an inch.'
Ta|ll|a kasvõi jalad rakku.
'You may t r e a d till you get blisters on your feet.'

The sonorants under study, in the three phonemic degrees of quantity, all occur in the initial word of a sentence and are surrounded by the vowels [a]. The informants were asked to pronounce the whole sentence slowly, whereas the experimenter switched on the X-ray current and the camera only for the initial word. Additional static X-ray shots were made of [n] and [l] pronounced in isolation. One sample of each unit to be analysed was obtained from every informant.

The experimental material under analysis involves 205 cinefluorograms embracing the sonorant with their initial and final transitions (plus a few tracings of remoter frames) and 50 static roentgenograms visualizing the so-called culmination phases of the sonorants.

1.4.2. Two informants were used for cinefluorography: Õ. P. (female), R. T. (male). Static X-ray shots were made of six informants: R. T., A. S., A. E. (male); K. K., H. P., T. K. (female). One informant was used for the filming of lip articulation: Õ. P. All the informants speak perfect Standard Estonian with a Tallinn pronunciation (except A. E. whose speech may contain certain traces of the Western dialect).[1]

1.5. *Palatography*

The traditional procedure was used where the contact surfaces of the tongue were transferred onto blanks from artificial palates (which included the inner surfaces of the teeth). The experimental material here consisted of single words containing [n] and [l] in the three degrees of quantity embedded in the vowel [a] and the same sonorants in a word-final position:

ma|n|a 'exorcise; evoke' (Imperative),
ma|nn|a 'semolina',
pa|nn|a 'put' (Infinitive),
A|nn (Proper name),
a|l|a 'area',
(pilla-)*pa|ll|a* '(higgledy-) piggledy',
a|ll|a 'downwards; under' (Allative),
a|ll 'below; under' (Adessive).

The informants R. T., A. S., A. E. (male), K. K. (female) each pronounced every word 8 times, thus yielding 64 palatograms each, or a total of 256 palatograms.

2. Results

2.1. Articulation of [n]

2.1.1. *Linguopalatal contact*

Thanks to the works of L. Kettunen and P. Ariste, the hitherto most elaborated aspect of consonant articulation is that of linguopalatal contacts. According to these authors (Kettunen, 1913, 3—5; Ariste, 1953, 36—37 and elsewhere) the [n] of Estonian is articulated considerably back of the homorganic plosive [t]; during the production of [n] the tip and the predorsum of the tongue touch either the alveoli or the front part of the hard palate. All this has once again found support in the palatograms and roentgenograms produced for the present study. Furthermore, we can learn from the literature that the longer the nasal segment the wider is the contact area of the tongue on the hard palate (Ariste, 1943, 26). However, it is not known whether the linguopalatal contact area grows (with increasing degree of quantity) through an increase in alveolar or lateral contact. We only learn that a longer [n] is slightly more advanced than a short

[1] The author wishes to express his deep gratitude to the informants Õ. Piir, K. Kolju, H. Palm-Lilleoks, T. Kalmet, R. Trass and A. Sal-Saller for their invaluable assistance.

one (Ariste, 1953, 36; 1968, 65), although the published palatograms (Ariste, 1943, 27) fail to provide convincing proof of this.

2.1.2. We shall present here some data on the location and extent of linguopalatal contact as derived from the palatograms produced for the present study. The distance of the anterior and the posterior edge of the alveolar contact from the upper edge of the incisors was measured along the median line of the palate, *a—a*: the segments *AB* and *AC* respectively (see Fig. 1). In case of an obvious asymmetry of the contact, the same distances were measured from the upper edge of both the left and the right second incisor along the straight lines *a′—a′* and *a″—a″* respectively. An integrated description of the right-hand and the left-hand lateral contact is given by the segment *DE* on the straight line passing between the first and the second molar on either side (the smaller the lateral contact the longer the segment *DE*, and *vice versa*).

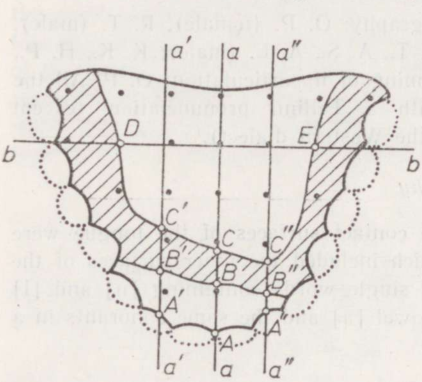

Fig. 1. Coordinate system for measuring palatograms.

2.1.3. Although the contact area has not been measured on the palatograms, it can be estimated indirectly from the length of the alveolar and the width of the lateral contact, measures *BC* and *DE* respectively (see Table 1; for the sake of economy it presents data only on Informant R. T. whose articulation tendencies are similar to those of K. K. and A. E.).[2]

The average measurements for every informant make it obvious that the contact area of the tongue (both the alveolar and the lateral contact) on the palate is larger during the pronunciation of [n] in the second and the third degree of quantity than in the first degree, e. g. R. T.: the average *BC*=6.5, 9.8 and 10.6 mm; the average *DE*=48.8, 46.6, 46.1 mm, for the 1st, 2nd, and 3rd degrees of quantity[3] respectively (see Table 1; cf. also Fig. 2). At that, sounds of Q2 and Q3 make up a uniform group, the two differing considerably less from each other than from sounds of Q1.

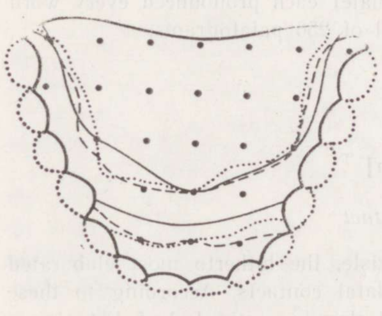

Fig. 2. Superimposed palatograms of Estonian [n] of three degrees of quantity. Informant R. T.
Q1 ———; Q2 — — —; Q3 . . . .

One can see from the data that there are two ways for the tongue to enlarge the alveolar contact area. In one case the alveolar contact increases chiefly on account of an advancement of the anterior edge of the contact, e. g. R. T.: the average *AB*=11.8 in Q1, 9.7 in Q2 and 9.0 mm in Q3, the posterior edge of the contact remaining roughly in the same region for all degrees or retracting a little in Q2 and Q3: R. T's average *AC*=18.3, 19.5 and 19.6 mm respectively. In case of a marked advance in the articulation of [n] in Q2 and Q3 as compared with Q1 (K. K.: the average *AB*=10.8, 6.9, 6.3 mm) the posterior boundary of the contact may even undergo a concomitant advance (K. K.: the average *AC*=16.3, 15.8, 15.1 mm). In the other case (when the anterior boundary of the contact rests in the same place in all degrees of quantity or shifts slightly backwards in Q2 and Q3) the area of the alveolar contact is enlarged through an increasing backward movement of the posterior boundary. An example is Informant A. S.: the average *AB*=9.0, 9.9, 10.3 mm and

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[2] The author is very much indebted to M. Remmel for statistical computations.
[3] Abbreviated as Q1, Q2 and Q3 in the following text.

Table 1

Data from the measurement of palatograms, mm (Informant R. T.)

Word	Alveolar contact										Lateral contact: *DE*			
	Distance of the anterior edge, *AB*				Distance of the posterior edge, *AC*				The length of the alveolar contact, *BC*					
	average	confidence borders of the average at $p=0.95$	limits of individual cases	standard deviation	average	confidence borders of the average at $p=0.95$	limits of individual cases	standard deviation	average	limits of individual cases	average	confidence borders of the average at $p=0.95$	limits of individual cases	standard deviation
mana	11.8	10.6—12.9	10.0—14.0	1.7	18.3	15.8—20.7	14.0—21.5	3.5	6.5	4.0— 8.5	48.8	46.2—51.3	45.0—55.0	3.7
man:a	9.7	8.1—11.3	5.5—11.5	2.3	19.5	17.7—21.3	15.0—21.5	2.6	9.8	9.0—11.5	46.6	44.9—48.2	45.0—50.0	2.3
pan::a	9.0	8.5— 9.5	7.0—10.0	0.7	19.6	18.9—20.2	17.0—20.0	1.0	10.6	10.0—11.0	46.1	45.0—47.1	44.0—48.0	1.5
An::	11.3	10.7—11.8	10.0—13.0	0.8	21.2	19.7—22.7	19.0—24.0	2.2	9.9	8.5—11.0	42.5	40.8—44.2	40.0—44.0	2.4
ala	11.9	10.8—13.0	10.0—13.0	1.5	22.8	21.5—24.1	21.0—25.0	1.8	10.9	8.5—13.0	60.0*	—	—	—
pal:a	11.9	10.9—13.0	10.0—14.0	1.5	26.0	24.4—27.6	23.0—30.0	2.3	14.1	12.5—18.0	54.9	52.9—56.9	50.0—60.0	2.8
al::a	10.3	10.0—10.7	9.5—11.5	0.5	23.3	22.3—24.4	21.5—25.0	1.5	13.0	10.0—15.5	53.5	50.8—56.2	45.0—55.0	3.9
al::	12.0	11.0—13.0	10.0—14.0	1.4	25.4	25.2—25.6	24.5—26.0	0.3	13.4	12.0—15.0	47.4	44.1—50.8	43.0—55.0	4.8

* 60 mm equals the width of the palate in the region between the first and the second molar, i. e. during the pronouncing of [l] in *Q*1 the dorsum leaves no trace on the palate.

the average $AC = 14.9$, 19.9 and 21.1 mm respectively. This is the case also for Informant Õ. P. (although only on the basis of cinefluorograms).

2.1.4. For comparison palatograms were made of the pronunciation of word-final [n] as presumably the most intensive of all [n]'s. Only two informants, K. K. and A. S., provided such data as were expected, viz. the anterior and the posterior edge of the alveolar contact displayed a still stronger development of the moving tendencies that were characteristic of the pronunciation of intervocalic nasals in Q2 and Q3 by these informants. With other informants the location of the alveolar contact is retracted to a position typical of a nasal in Q1 or Q2. The alveolar contact area may even be smaller than that of the same sound in Q3 in the intervocalic position (cf. Table 1); however, this is always compensated for by an appreciably greater width of the lateral contact. The total contact area during the pronunciation of a word-final nasal is the largest in all cases, as expected.

2.1.5. From the viewpoint of the place of articulation [n] is basically an alveolar sound in all degrees of quantity, but individual deviations, both advancement and retraction, do exist. The dispersion of data is rather considerable (cf., e. g., the limits of individual cases, Table 1). A comparison of standard deviations suggests, however, that the tenser and longer a nasal, the less variation there is in the place of its articulation. Histograms drawn for each of the informants and separately for each of the measures (cannot be presented here for lack of space) point to another interesting fact: every informant is characterized by a concentration of the majority of individual cases in a rather narrow region, but the regions differ with the informants. Every informant seems to have his (or her) own restricted locus (centre) of articulation.

2.1.6. *The configuration of the vocal tract in the so-called quasi-culmination phase of* [n].

A detailed analysis of cinefluorographic films reveals the difficulty (occasionally even impossibility) of finding articulatory steady-stateness. Only when different parts of the tongue (tip, dorsum, root) are examined separately can we speak of a certain amount of steady-stateness. As a matter of fact, the predorsum and the root of the tongue can gain their maximal [n]-ness or [l]-ness, maintain that position, and start for a following sound each at differing moments. Due to these circumstances it is difficult to find an articulatory segment suitable for the comparison of sonorants of the three quantities. Proceeding from the synchronized spectrograms, it is possible to identify stationary segments which might be used as comparable portions of speech flow. Apparently movements of articulators by a few millimeters here are insufficient to produce concomitant changes in the acoustic speech wave. However, the data of speech acoustics would be a misleading basis for a detailed study of speech physiology, since in that way certain tendencies of pronunciation might remain unnoticed.

In the present study of the pronunciation of sonorants in three degrees of quantity, vocal tract configurations and positions of articulators will be compared in so-called quasi-culmination phases of sonorants. In general, a quasi-culmination phase here is defined from roentgenograms as a phase where the predorsum and the mediodorsum have reached the maximum of the movement tendency characteristic of the respective sonorant, though the postdorsum and the root of the tongue may still continue to move towards their maximum points (for 0.5—1.5 mm, as indicated by measured data of R. T. and Õ. P.). The time location of the quasi-culmination phase is more or less in the middle of sonorants in Q2 and Q3, but at the end of sonorants in Q1.

Of static X-ray shots of Q2 and Q3 sonorants only such have been considered where the synchronous oscillogram provides evidence that a shot has been obtained in the medial temporal phase of the sonorant (with permitted deviation of ± 20 msec). Since the duration of Q1 sonorants ranges between 40—70 msec, a static X-ray shot whose exposure is 40—50 msec covers practically the whole of a Q1 sonorant.

2.1.7. For the measurement of roentgenograms a coordinate system was designed which has been described elsewhere (Eek et al., 1969). In this paper the following coordinates are used (Fig. 6):

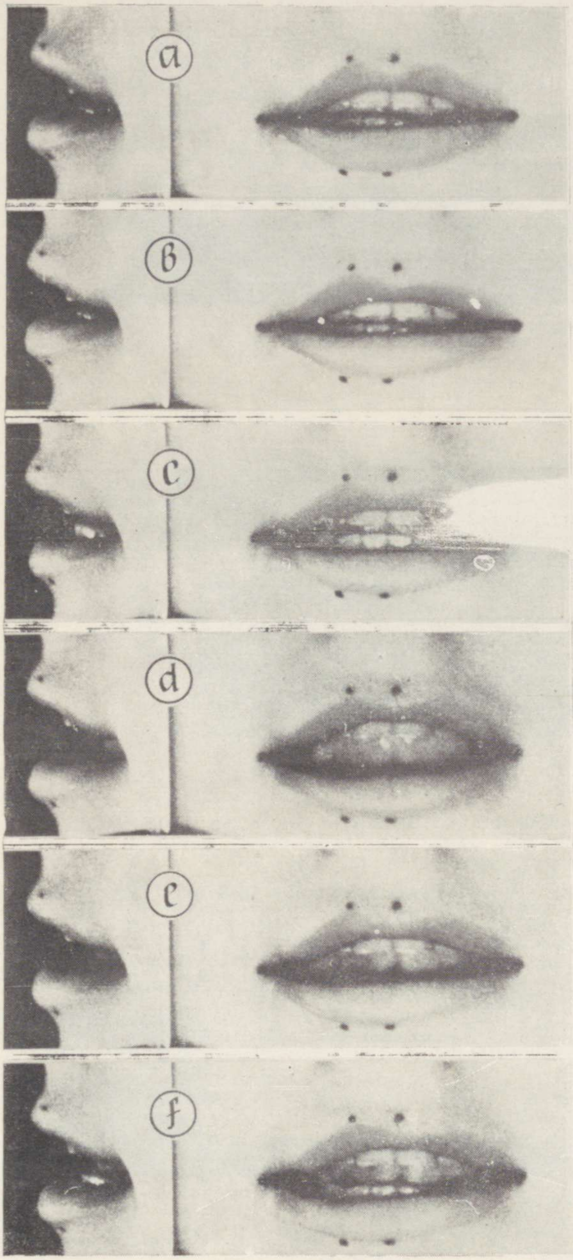


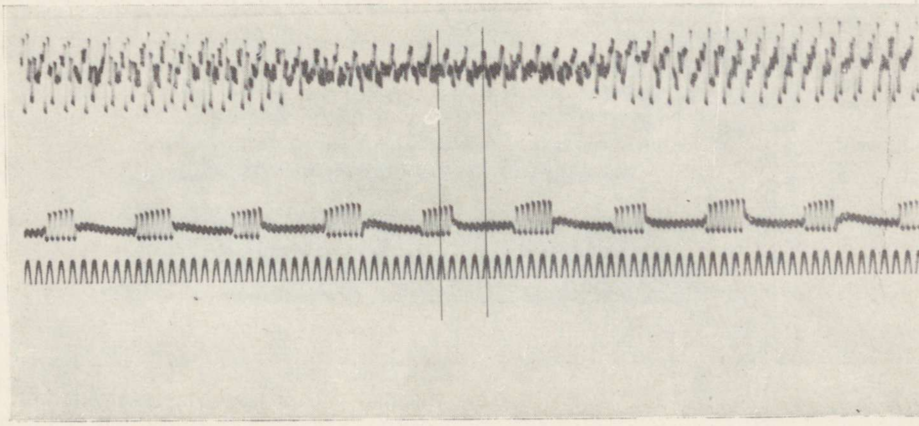
Fig. 3. Lip positions for [n] and [l]. Informant Õ. P.

a, *b*, *c*, — [n] in Q1 (*kana*), Q2 (*kanna*), Q3 (*Anna*, Illative);
d, *e*, *f* — [l] in Q1 (*tala*), Q2 (*talla*, Genitive), Q3 (*talla*, Imperative).

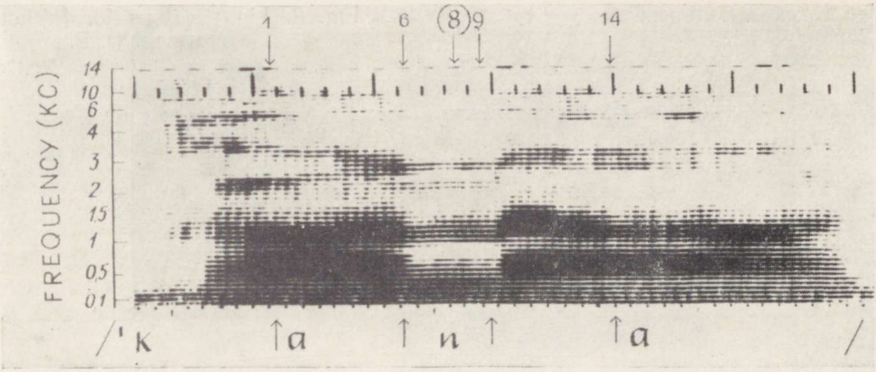
Frames showing the midsonorant phase have been chosen with the aid of comparative analyses of the film of labial articulation and the synchronized oscillograms. See Fig. 4.

Fig. 4. Fragment of the oscillogram of the word *tala* (upper channel) with synchronizing pulses corresponding to cineframes of lips (lower channel).

Depending on the synchronizing switch of the camera and on the open vs closed phase of the shutter, the lip frame presented in Fig. 3*d* covers the speech signal within the time interval enclosed between the vertical lines.

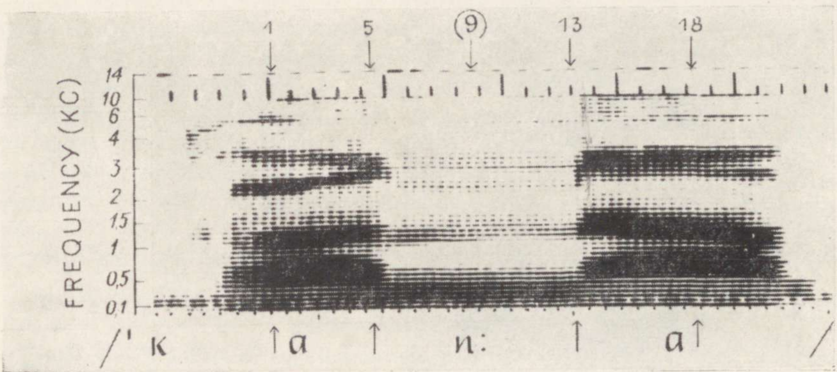


a



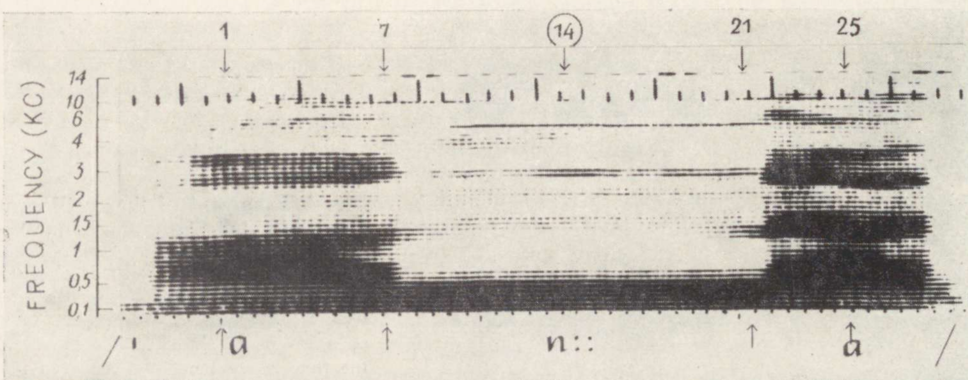
1 6 (8) 9 14
FREQUENCY (KC)
14 10 6 4 3 2 1.5 1 0.5 0.1
/'k ↑a ↑ n ↑ ↑a /

b



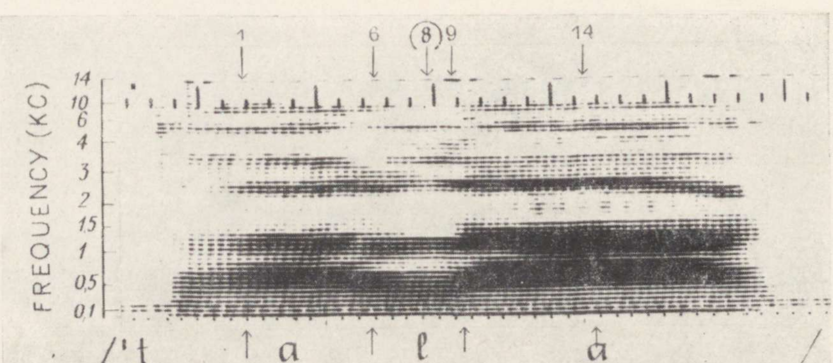
1 5 (9) 13 18
FREQUENCY (KC)
14 10 6 4 3 2 1.5 1 0.5 0.1
/'k ↑a ↑ n: ↑ a↑ /

c



1 7 (14) 21 25
FREQUENCY (KC)
14 10 6 4 3 2 1.5 1 0.5 0.1
/' ↑a ↑ n:: ↑ ↑a /

d



1 6 (8) 9 14
FREQUENCY (KC)
14 10 6 4 3 2 1.5 1 0.5 0.1
/'t ↑ a ↑ l ↑ ↑a /

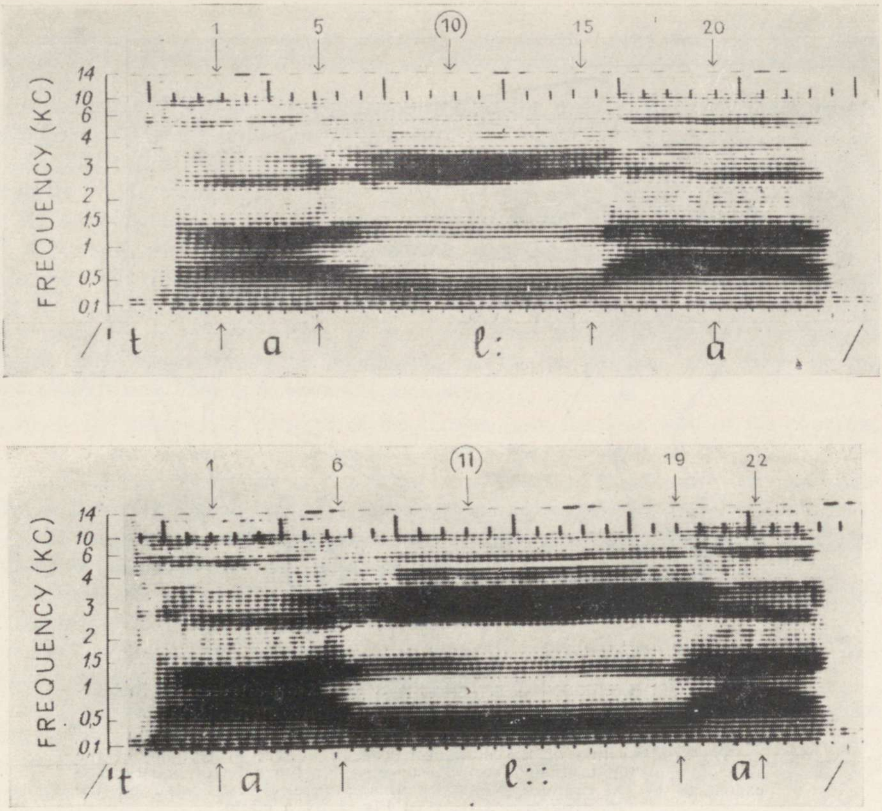


Fig. 5. Dynamic spectrograms, synchronized with cinefluorograms, of the Estonian words *kana* (*a*); *kanna* (*b*); *Anna*, Ill. (*c*); *tala* (*d*); *talla*, Genitive (*e*); *talla*, Imperative (*f*). Informant R. T.

Vertical lines in the upper part of the spectrograms indicate time intervals, the distance between two shorter lines represents an interval of 20 msec and the distance between two longer lines an interval of 100 msec. X-ray frame exposures (10 msec) have been registered on the upper edge of the spectrograms in the form of horizontal lines; as a facility for frame counting every tenth and every first frame have been marked with darker lines. The first vertical arrow in the uppermost edge of the spectrogram indicates the first frame that has been traced; the second arrow designates the first closure frame of the sonorant; the third arrow (encircled) marks the so-called quasi-culmination phase of the sonorant; the fourth is for the last frame of the closure; the fifth indicates the last frame that has been traced.

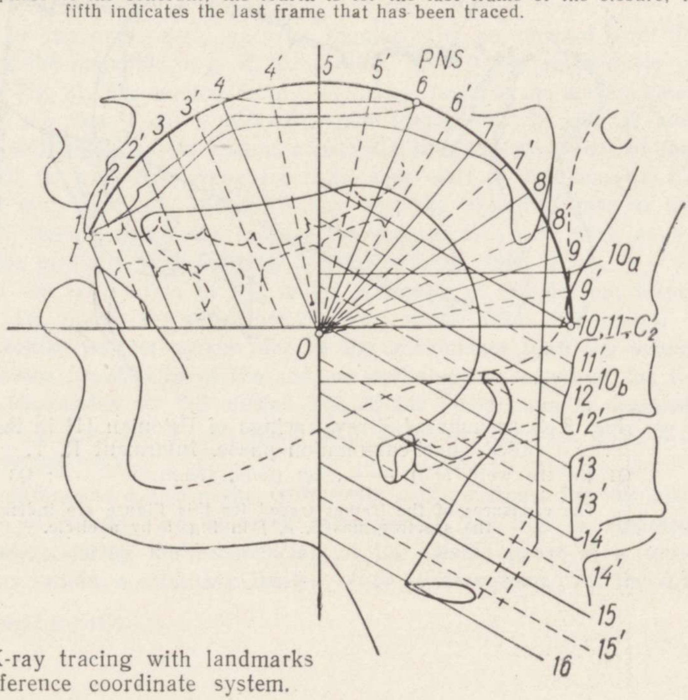


Fig. 6. X-ray tracing with landmarks and reference coordinate system.

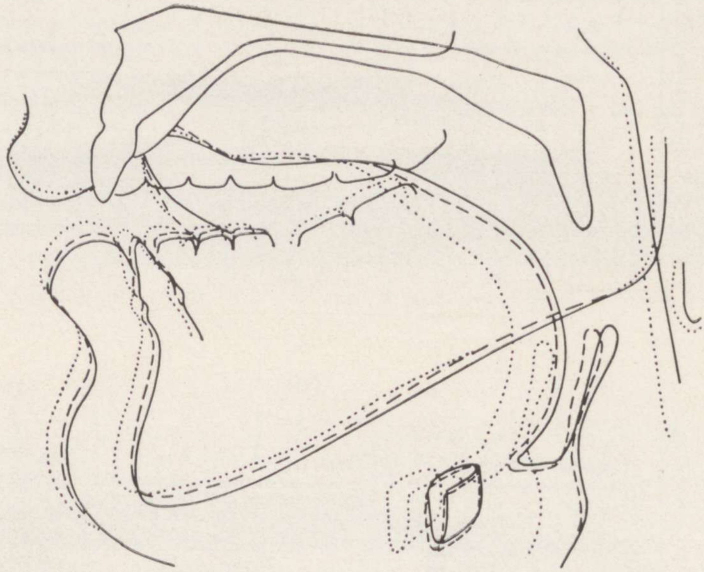


Fig. 7. Superimposed X-ray tracings of Estonian [n] in the so-called quasi-culmination phase. Informant R. T.

Q1 (in the word *kana*) ———; Q2 (*kanna*) — — —; Q3 (*Anna*, Illative). . . . .
The median line of the dorsum has been drawn; projections of the side edge of the tongue have been omitted for the sake of clarity. The exposures of the frames traced for this Figure are indicated on the spectrograms *a*, *b*, *c* in Fig. 5 by a circle.

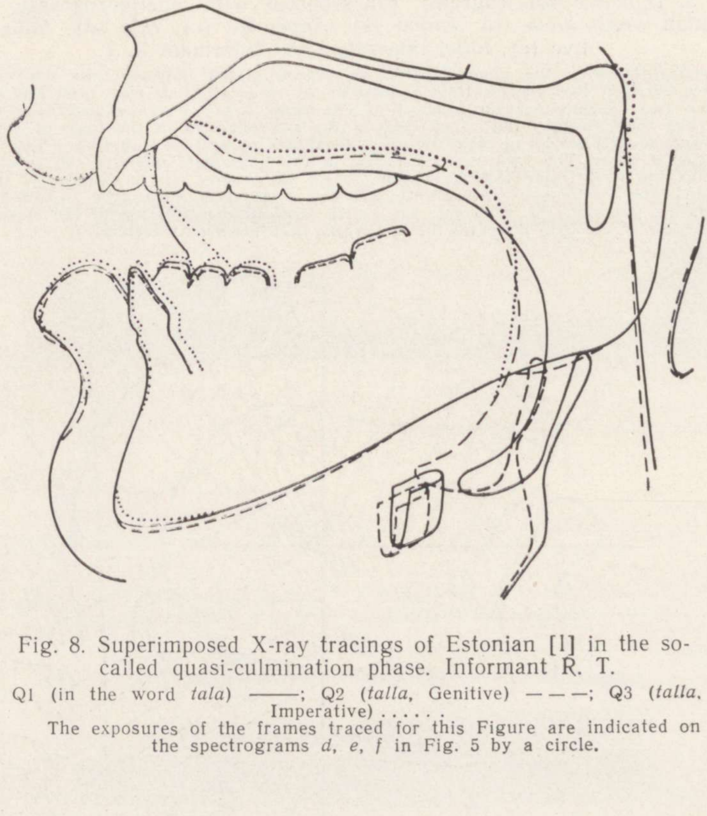


Fig. 8. Superimposed X-ray tracings of Estonian [l] in the so-called quasi-culmination phase. Informant R. T.

Q1 (in the word *tala*) ———; Q2 (*talla*, Genitive) — — —; Q3 (*talla*, Imperative) . . . . . .
The exposures of the frames traced for this Figure are indicated on the spectrograms *d*, *e*, *f* in Fig. 5 by a circle.

L_h — the height of the lip aperture; measured as the distance between the tangents (perpendicular to *5*) to the upper and lower lip;

I_d — the distance between the tips of the anterior upper and lower incisors (describes the movements of the mandible);

2 or *2'* — the distance of the predorsum from the alveoli or the prepalate;

4, *4'*, *5*, *6* — the distance of the mediodorsum from the medio- and postpalate;

$6'_0$, 7_0, 8_0 — the distance of the postdorsum from the origin of the coordinate system (describes the movement of the tongue dorsum in the velar and uvular region); *6'*, *7*, *8* giving an otherwise valuable measure of the vocal tract are discarded here because of the difficulty of distinguishing the movements of the postdorsum and those of the velum and uvula which both may vary this measure;

10a, *10* — the distance of the root of the tongue from the rear wall of the pharynx;

12 or *13* — the distance of the epiglottis from the rear wall of the pharynx; the choice between *12* and *13* depends on individual peculiarities of informants (the coordinate system being normalized with respect to immovable structures);

U_h — the height of the uvula; measured as the distance between the tangent (perpendicular to *5*) to the upper curve of the uvula and *10*;

U_w — the distance between the back wall of the uvula and the rear wall of the pharynx; measured along the perpendicular to *5* from *7* or *7'*;

H_f — the distance of the body of the hyoid bone from the prolongation of *5* (describes the forward-and-back movement of the hyoid bone);

H_u — the distance of the body of the hyoid bone from *10* (describes the up-and-down movement of the hyoid bone);

Lar_f — the distance of the anterior end of the ventricle from the prolongation of *5* (describes the forward-and-back movement of the larynx);

Lar_u — the distance of the anterior end of the ventricle from *10* (describes the up-and-down movement of the larynx).

2.1.8. The following is a comparison of vocal tract configurations in the quasi-culmination phase of the pronunciation of [n] in Q1, Q2 and Q3 (Fig. 7). The corresponding measured data are presented in Table 2.

The labial articulation is hardly significant for distinguishing between the quantities of [n]. The lip aperture may show decrease with growth of quantity (Informants R. T., K. K., T. K.), in the main probably an attendant phenomenon to the upward movement of the mandible; or it may show slight widening, mainly on account of the retraction of the lower lip (Informants Õ. P., A. E.).

The front part of the oral cavity narrows regularly by an upward and slightly forward movement of the mandible, e. g. R. T.: I_d=8.5, 7.5, 5.0 mm respectively in Q1, Q2 and Q3 (Table 2; Fig. 3). The mediodorsum rises higher towards the mediopalate, e. g. Õ. P.: *4'*=11.0, 10.5, 9.5 mm, *5*=11.5, 10.5, 10.0 mm respectively in Q1, Q2 and Q3.

In contrast, the pharyngeal cavity widens constantly with the movement of the root of the tongue and of the epiglottis away from the rear wall of the pharynx (Õ. P.: *10a*=17.5, 18.5, 19.5 mm; *10*=13.5, 16.0, 17.5 mm; *13*=7.0, 10.5, 12.5 mm in Q1, Q2 and Q3 respectively), during which the root of the tongue does not move as a unit, but is depressed more medially than laterally (cf. Rothenberg, 1968, 97).

Characteristic of the articulation of [n] is the concavity of the dorsum (especially of the postdorsum). The higher the degree of quantity of the nasal, the greater is the withdrawal of the median barium-marked line of the postdorsum from the velum and uvula, with simultaneous broadening of the shadow outlining the edges of the tongue. The increase of the depression on the median line of the postdorsum is demonstrated by the coordinates $6'_0$, 7_0, 8_0 (R. T.: $6'_0$=28.0, 26.5, 23.5 mm, 7_0=28.0, 26.5, 22.5 mm for Q1, Q2 and Q3 respectively).

The qualitative differences between the vocal tract configurations for the nasals of the different degrees of quantity are, however, rather small (see Fig. 7). Apparently a specified vocalic context during the pronouncing of the closure phase of a consonant constrains the tongue within a relatively limited range of movement. Yet the material at hand reveals a consistent tendency: the higher the quantity degree of a nasal, the farther away the tongue has moved from the articulation place of the surrounding [a]. The growth of the degree of quantity with the surmisable higher tension in the linguopalatal contact is accompanied by a higher degree of compression of the total mass of the tongue (the rise of the mediodorsum towards the prepalate and mediopalate; the withdrawal of the postdorsum and of the root of the tongue from the velum and the rear wall of the pharynx). A forward movement of the hyoid bone can also be pointed out in the same connection (R. T.: H_f=7.5, 6.0, 1.0 mm for quantities 1, 2, 3 respectively).

2.1.9. When the movements of articulators are not restricted by the context, they have a greater latitude of movement (within certain limits of tolerance). This can be made highly evident by the analysis of static roentgenograms of [n] pronounced in isolation. The most persistent of the characteristics here is the enlargement of the tongue-median concavity and the simultaneous widening of the pharyngeal cavity (K. K.: $6'_0$=24.0, 22.5 mm; 7_0=23.5, 20.5 mm; 8_0=23.0, 18.5 mm; 10=19.5, 23.5 mm for [n] in Q3 and in isolation respectively). The pharyngeal cavity shows consistent lengthening owing to the downward movement of the larynx (R. T.: Lar_u=42.0, 48.5 mm for [n] in Q3 and in isolation respectively). In case of an especially intense enlargement of the concavity of the dorsum there simultaneously occurs a vigorous downward pull of the hyoid bone (T. K.: H_u=25.0, 35.0 mm for [n] in Q3 and in isolation respectively). The velopharyngeal passage is wider (R. T.: U_w=8.0, 10.5 mm for [n] in Q3 and in isolation respectively). Such lengthening of the pharyngeal cavity and widening of the velopharyngeal passage was not observed in different degrees of quantity when [n] was embedded in [a]. This can be well understood when the specific features of the articulation of [a] are taken into account: (1) [a] is an oral sound produced with the velopharyngeal passage normally closed; (2) the tenser the [a], the higher is the location of the larynx (cf. Liiv, 1961b). Thus quite oppositely directed gestures are necessary to produce [n] and [a]; this has levelled down the corresponding gestures of [n] in different degrees of quantity to an extent where it is impossible to detect in this region any consistent difference between the degrees of quantity.

Within the oral cavity, there are no characteristics common to all the informants pronouncing [n] in isolation. Data give additional evidence that labial articulation is immaterial: in some cases the lip aperture is still narrower than in Q3 (Informants R. T., K. K., H. P.), in others it is wider (Õ. P., T. K., A. S., A. E.). Various tongue configurations (with special reference to the oral cavity) provide descriptions of three individual pronunciation usages of isolated [n]. The first: the differences in the movement of various parts of the tongue that served as a basis for a qualitative distinction between the pronunciation of [n] in Q1, Q2 and Q3 progress in the same direction for [n] in isolation (Informants K. K., A. S.). The second: in case the postdorsum and the root of the tongue have been withdrawn from the velum, uvula and rear wall of the pharynx with particular intensity, the mediodorsum does not rise to a position as high as in Q3, that is, the total mass of the tongue is forced to move in a forward-and-downward direction (Informants T. K., H. P., A. E.). The third: in case the mediodorsum is observed in the movement of particular effort towards the palate the pharyngeal cavity retains the same width as in Q3 but with the rise of the mediodorsum the concavity on the postdorsum is reduced (Informant R. T.).

2.2. Articulation of [l]

2.2.1. *Linguopalatal contact*

According to L. Kettunen and P. Ariste [l] is usually produced in a medio- and postalveolar or a prepalatal position (Kettunen, 1913, 6; Ariste, 1939, 223, and elsewhere). P. Ariste's extensive palatographic study gives the same information about [l] as in the case of [n]: the higher the degree of quantity, the wider the area of the palate touched by the tongue (Ariste, 1943, 30). Again there are no data concerning the direction of the increase of the linguopalatal contact area with the increase of the degree of quantity.

2.2.2. P. Ariste's calculations of contact areas of laterals in different degrees of quantity are corroborated by the data of the present paper, for example the average BC=10.9, 14.1, 13.0 mm and the average DE=60.0, 54.9, 53.5 mm for Q1, Q2 and Q3 respectively (cf. Table 1, Fig. 9). The sounds in Q2 and Q3 again make up a uniform group, the two quantities differing far less from each other than from quantity 1. It is quite regular (in nearly one half of the cases) that the alveolar contact of [l] in Q3 is slightly smaller than in Q2. On such occasions we again come across the phenomenon of articulatory compensation. Namely, the scantiness of the alveolar contact is compensated for by a larger lateral contact area. In most of the cases laterals in Q1 lack the lateral contact altogether; in Q2 it never reaches farther back than up to the first or the second molar, which is less than in Q3. Thus the [l] of Q3 is a lateral with the narrowest side passages.

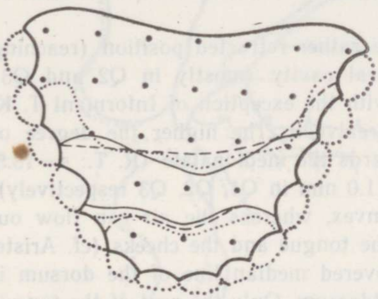


Fig. 9. Superimposed palatograms of Estonian [l] of three degrees of quantity. Informant R. T. Q1 ———; Q2 — — —; Q3 . . . . . .

The anterior boundary of the alveolar contact has a location equal for the Q1 and Q2 (R. T.: the average AB=11.9 mm for both) or slightly advanced for Q2, as with Informant K. K.: the average AB is 13.1 mm for Q1 and 12.2 mm for Q2. The alveolar contact area in Q2 reveals a regular increase by means of a strong retraction of the posterior boundary (e. g. R. T.: AC=22.8 mm for Q1 and 26.0 mm for Q2). In Q3 the anterior edge of the alveolar contact has moved still more forward, whereas the posterior edge often does not reach as far back as in Q2. Instead, the dorsum has risen higher towards the palate, and the contact area on lateral teeth and gums has notably increased. An interesting circumstance is revealed here. During the production of more intensive sounds the tongue as a whole seems to participate more strenuously in articulation. This will probably explain the retraction of the alveolar contact of a word-final variant of both [n] and [l] (and in many cases also of the intervocalic sounds in Q3) and the main emphasis on the lateral contact (for proper examples see Table 1).

Although [l] is usually a bilateral sound, it is possible to describe a case of monolaterality with a right-hand side passage. The asymmetric alveolar contact increases in higher degrees of quantity through the lengthening of its left-hand part in the forward-backward line and the retraction of the posterior edge of its right-hand part (Informant A. E.: the average $A'B'$=10.8, 9.0, 8.1 mm; $A'C'$=18.8, 20.4, 19.6 mm; $A''B''$=14.3, 15.4, 15.9 mm; $A''C''$=22.6, 25.0, 26.6 mm for Q1, Q2 and Q3 respectively). Here, too, the relative scantiness of the alveolar contact in the word-final variant is compensated for by a larger lateral contact.

There is a high dispersion of data. Yet histograms of separate measures for each coordinate show that the majority of individual cases is concentrated in quite a narrow region, which again differs for each informant.

2.2.3. From the viewpoint of the place of articulation [l] is an alveolar-prepalatal lateral pronounced in every degree of quantity in a more backward position than that of [n] in the corresponding degree of quantity. An especially consistent approach to the prepalate is seen in the case of the posterior boundary of the contact which makes the alveolar contact longer for [l] than it is for [n]. The side contact of the laterals of the same degrees of quantity is usually shorter and fails to reach as far back as for [n] (mostly in Q1 and Q2).

2.2.4. *The configuration of the vocal tract in the quasi-culmination phase of* [l]

Labial articulation is of little importance in distinguishing between the quantities of [l]. Common to all the informants is only the fact that, compared with [l] in Q1, the lip aperture for [l] in Q2 is either equal (R. T.: $L_h=14.5$ mm in Q1 and 14.5 mm in Q2) or narrower (Õ. P.: $L_h=13.0$ mm in Q1 and 12.0 mm in Q2). In Q3 greater articulatory effort is manifested differently for each informant. In one case lip aperture is narrower than in Q2. In another case greater tension of facial muscles (deeper withdrawal of the corners of the mouth, retraction of the lower lip) exerts a widening effect on lip aperture (see Table 2 and Fig. 3 *d*, *e*, *f*).

Thus the changes in lip position for the quasi-culmination phase of the different degrees of quantity are similar for [n] and [l]. The sounds differ in the size of lip aperture. One and the same informant always has a bigger lip aperture for [l] than for [n] of the same degree of quantity. Similarly, the passage between the maxilla and the mandible is always wider for [l]. But the upward movement of the mandible accompanying the growth in degree of quantity is less consistent than was revealed in the study of [n] (see Table 2).

Since the linguopalatal contact of [l] occurs in a rather retracted position (reaching as far as the prepalate) the anterior part of the oral cavity (mostly in Q2 and Q3) is narrower than the same when [n] is pronounced, with the exception of Informant T. K. whose linguopalatal contact for [l] is located on prealveoli. The higher the degree of quantity, the higher the rise of the mediodorsum towards the mediopalate (R. T.: $4=18.5$, 16.0, 14.5 mm, $4'=17.5$, 15.5, 14.5 mm, $5=15.0$, 13.0, 11.0 mm in Q1, Q2, Q3 respectively).

During the articulation of [l] the dorsum is convex, whereas the air can flow out through the passage between the depressed sides of the tongue and the cheeks (cf. Ariste, 1953, 45). Roentgenograms reveal that the barium-covered median line of the dorsum is the highest part of both the mediodorsum and the postdorsum. Only the root of the tongue has visible shadows of its side-edges above the epiglottis, and the concavity of the medial part of the root of the tongue increases with the effort for linguopalatal contact. The postdorsum under such conditions is pressed with increasing force towards the velum and uvula, whereas the root of the tongue and the epiglottis move forward, away from the rear wall of the pharynx, thus widening the pharyngeal cavity (R. T.: $6'_0=33.5$, 35.5, 37.0 mm, $7_0=33.0$, 34.0, 36.0 mm, $10=17.0$, 21.5, 22.5 mm, $12=13.0$, 19.0, 20.0 mm for Q1, Q2, Q3 respectively; see Fig. 8). A steady tendency to a more advanced location is seen in the movement of the hyoid bone (Õ. P.: $H_f=14.0$ mm in Q1, 13.5 mm in Q2, 12.0 mm in Q3). On occasions when the forward movement of the root of the tongue is especially pronounced there is a possibility in Q2 and Q3 for the postdorsum to make a concurrent movement away from the velum and uvula instead of moving towards them, maintaining its medial convexity as it does this (T. K.: $10=12.0$, 20.5 mm, $6'_0=34.0$, 32.0 mm, $7_0=34.0$, 30.0 mm in Q1 and Q3 respectively. See also Informant H. P., Table 2). Consequently, unlike the [n] sounds, the movement of the postdorsum towards the velum and uvula or in the opposite direction is generally inessential for distinguishing between the degrees of quantity of [l] (although it may prove relevant in terms of idiosyncrasies of informants).

The velopharyngeal passage is closed. Presumably as a result of a difference in the supraglottal air pressure during the pronouncing of [l] and [a], there is an abrupt shift of the velum 1—2.5 mm upwards from its location for the preceding [a]. Even more upwards along the rear wall of the pharynx is the movement of the velum during word-initial [t]. The following measurements might be characteristic though with some doubt imposed by the vagueness of the contour of the velum and uvula on the film: R. T., the word /tal::a/ where $U_h=53.5$ mm for [t], 50.0 mm for [a], 52.5 mm for [l]. This kind of movement is clearly observable, however, during the motion-picture projection of the film. The rise of the velum is minimal in the articulation of [l] in Q1 (see Table 2, measure U_h).

2.2.5. When [l] is pronounced in isolation the anterior part of the oral cavity is still narrower than for [l] in Q3. The movements of the postdorsum and the tongue root here also show similarities with those described above. If owing to a particularly vigorous forward movement of the root of the tongue the pharyngeal cavity happens to be wider, the postdorsum does not rise so much towards the velum and uvula as in the intervocalic Q3, and hence the posterior part of the oral cavity is also wider (Informants K. K., T. K., A. E.). In other cases the postdorsum rises still farther towards the velum and uvula than in Q3, thus narrowing the posterior part of the oral cavity and the oral pharynx (Informants R. T., H. P., A. S.). The pharyngeal cavity grows consistently longer due to the downward movement of the larynx. The hyoid bone is likewise pulled much more downwards (H. P.: $H_u = 33.5$ and 38.0 mm, $Lar_u = 42.0$ and 51.0 mm for [l] in Q3 and in isolation respectively). Such regular lengthening was not observed in the comparison of the samples of [l] in three degrees of quantity, obviously due to the environmental influence of [a].

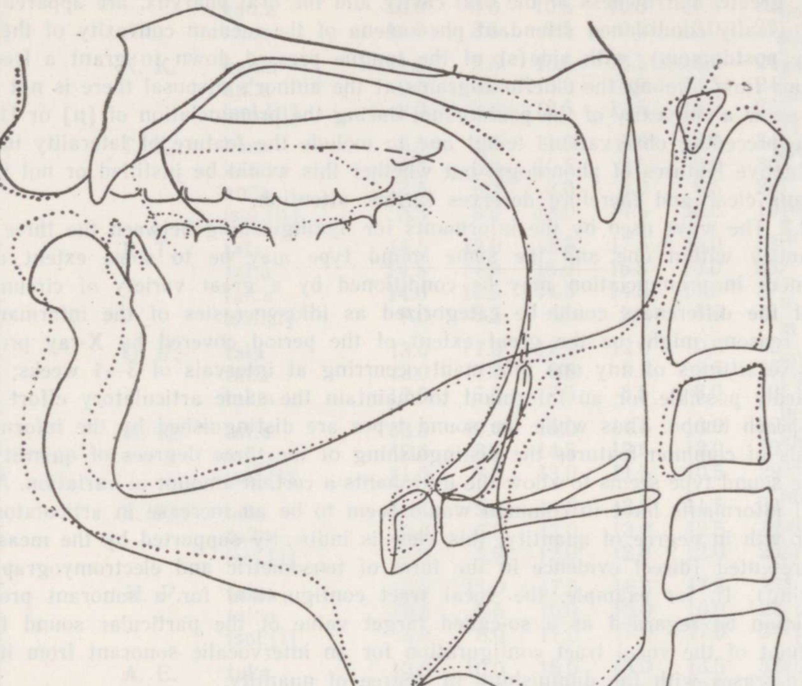


Fig. 10. Static roentgenograms of [l] and [n] pronounced in isolation. Informant R. T.

[l]: —— tongue median line; — — — projection of a side edge of the tongue;
[n]: . . . . . tongue median line: —•—•—•— projection of a side edge of the tongue.

2.2.6. In spite of idiosyncrasies of different informants articulating [l] and [n] in three degrees of quantity and in isolation, it is still possible to outline features that may be used for distinguishing between [l] and [n] in one and the same degree of quantity pronounced by any informant. The following is a summarizing list of the features differentiating [l] from [n]: wider aperture between the lips and jaws; more posterior contact of the tongue and the palate; higher location of the medio- and postdorsum with regard to the palate, the velum and uvula; convexity of the postdorsum; depression of side(s) of the tongue to grant a free egress to the air flow; narrower oral pharynx; the velopharyngeal passage closed (cf. Fig. 10). Obviously these features common to all the informants are just the ones determining the general outlines of the vocal tract configurations characteristic of [l] and [n]. It is worth mentioning that there are regions of certain coordinates (such as L_h, I_d, $6'_0$, 7_0, 8_0, U_h, U_w; for some informants also *4'*, *5*, *10a*) where the vocal tract configurations for [l] and [n] reconstructed on the basis of these general articulatory distinctive features will never coincide. In the regions of other coordinates that underlie articulatory distinctions common to all informants, such as measures of the linguopalatal contact, *4*, *4'*, *5*, *10a*, *10*, there may be partial overlapping of the vocal tract configurations of [l] and [n], but differences exist between [l] and [n] in one and the same degree of quantity. On a more abstract level it is possible to state that there are mainly two articulatory features essential for distinguishing between the Estonian [l] and [n]: laterality (convex *vs* concave dorsum) and nasality (open *vs* closed velopharyngeal passage). The rest of the above-mentioned features differentiating [l] from [n], such as larger mouth opening, more posterior location of the linguopalatal contact, greater narrowness of the oral cavity and the oral pharynx, are apparently mere physiologically conditioned attendant phenomena of the median convexity of the dorsum (mainly postdorsum), with side(s) of the tongue pressed down to grant a free egress to the air flow. Among the cinefluorograms at the author's disposal there is not a single one to show a convexity of the postdorsum during the pronunciation of [n] or [t].

The preceding observations tempt one to include the feature of laterality in the list of distinctive features of phonology, but whether this would be justified or not is yet by no means clear and therefore deserves further attention.

2.2.7. The ways used by the informants for distinguishing between the three degrees of quantity within one and the same sound type may be to some extent different. Differences in pronunciation may be conditioned by a great variety of circumstances. Part of the differences could be categorized as idiosyncrasies of the informants. One of the reasons might be the great extent of the period covered by X-ray procedures, successive sittings of any one informant occurring at intervals of 3—4 weeks; hence it was hardly possible for an informant to maintain the same articulatory effort and the same speech tempo. Thus while the sound types are distinguished by the informants on the basis of common features the distinguishing of the three degrees of quantity within a single sound type seems to allow the informants a certain amount of variation. A feature that all informants have in common would seem to be an increase in articulatory effort with growth in degree of quantity; this view is indirectly supported by the measurement data presented (direct evidence in the form of tensometric and electromyographic data is lacking). If, for example, the vocal tract configuration for a sonorant pronounced in isolation be regarded as a so-called target value of the particular sound type, the undershoot of the vocal tract configuration for an intervocalic sonorant from its target value increases with the diminishing of degree of quantity.

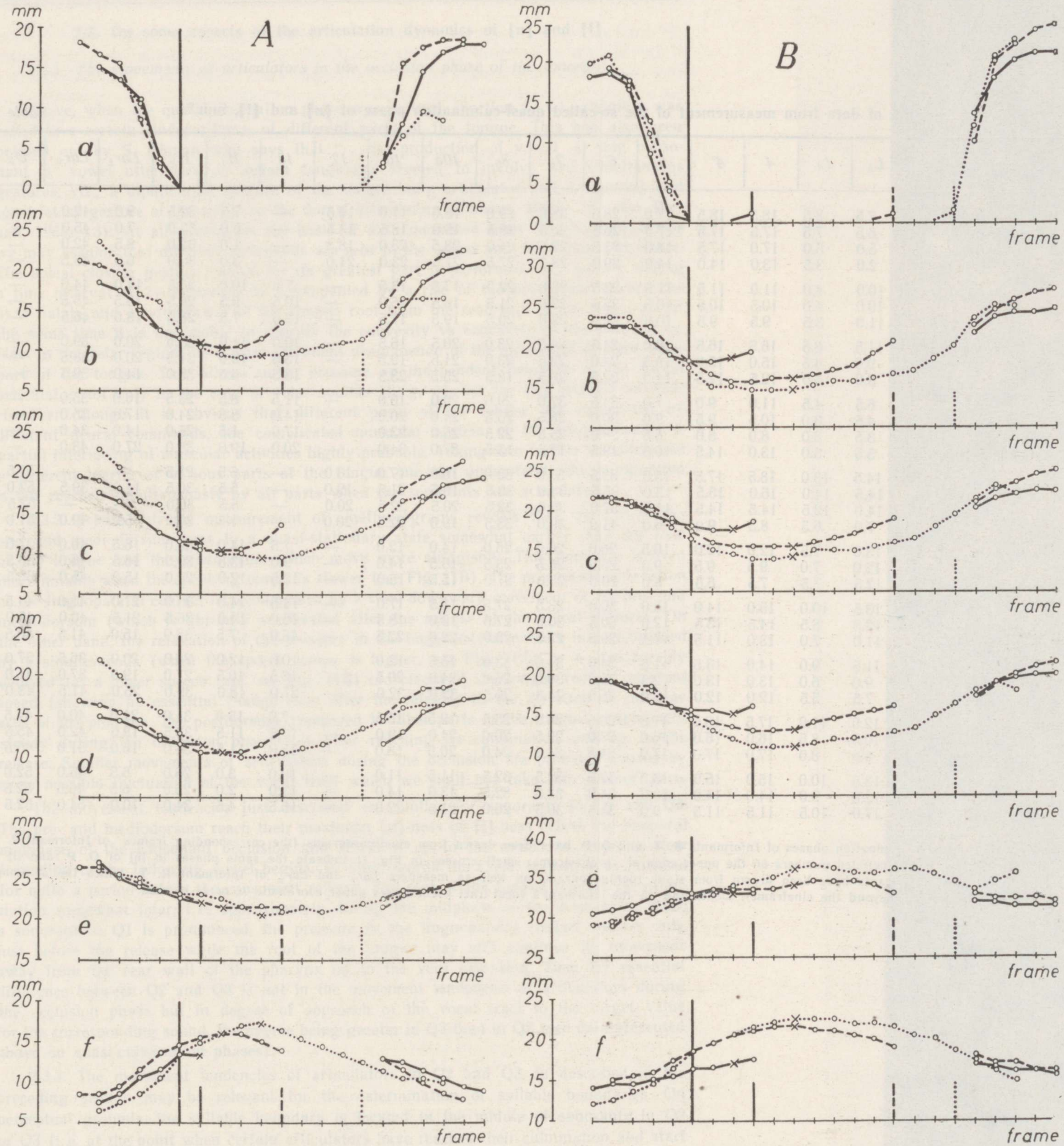
So far, we have described the sonorants only in their quasi-culmination phase. Certain aspects of speech dynamics are presumably also essential for distinguishing between the degrees of quantity.

Fig. 11. Graphs of the measurements of the Estonian words (A): *kana* (———), *kanna* (— — —), *Anna* (Ill.; . . . . . ; Informant Õ. P.) and (B): *tala* (———), *talla* (Gen.; — — —), *talla* (Imp.; . . . . . ; Informant R. T.).

a — the distance of the predorsum from the alveoli (coordinate *2'*); *b* — the distance of the mediodorsum from the borderline of prepalate and mediopalate (coordinate *4*); *c* — the distance of the mediodorsum from mediopalate (coordinate *4'*); *d* — the distance of the dorsum from the borderline of medio- and postpalate (coordinate *5*); *e* — the distance of the postdorsum from the origin of the coordinate system (coordinates 8_0, 7_0 respectively); *f* — the distance of the tongue from the rear wall of the pharynx (coordinate *10*).

The abscissa plots time (the succession of frames). The ordinate plots measurements of cinefluorograms in millimeters. The first vertical line marks the onset of the consonants, the next verticals mark the end of corresponding consonants. Frames marked with a cross represent the so-called quasi-culmination phase of the sonorant of the given degree of quantity.

In order to give a clearer presentation of post-sonorant vocalic transitions, the initial frames of the word-final vowels of words in Q1 and Q2 have been temporally aligned with the initial frame of the word-final vowel of the word in Q3.



A
B
mm
frame
a
b
c
d
e
f

Selection of data from measurement of the so-called quasi-culmination phase of [n] and [l], mm.*

Table 2

		L_h	I_d	4	4′	5	$6'_0$	7_0	8_0	10a	10	12	13	H_f	H_u	Lar_f	Lar_u	U_h
R. T.	kana	7.5	8.5	18.5	18.5	17.0	28.0	28.0	29.0	18.0	17.0	11.5	—	7.5	32.5	9.0	42.0	—
	kan:a	6.5	7.5	17.5	17.5	17.0	26.5	26.5	28.5	19.0	18.5	13.5	—	6.0	33.0	7.0	45.0	—
	an::a	5.0	5.0	17.0	17.5	18.0	23.5	22.5	24.0	23.5	23.0	18.5	—	1.0	32.0	8.5	42.0	—
	isol.[n]	2.0	3.5	13.0	14.0	14.0	29.0	28.5	27.5	21.5	23.0	21.0	—	3.0	30.0	6.5	48.5	—
Õ. P.	kana	10.0	4.0	11.0	11.5	11.5	23.5	23.0	22.0	17.5	13.5	—	7.0	10.0	27.5	14.0	44.0	—
	kan:a	10.0	4.0	10.5	10.5	10.5	22.5	22.0	21.5	18.5	16.0	—	10.5	9.5	28.5	13.5	45.5	—
	an::a	11.0	3.5	9.5	9.5	10.0	22.5	22.0	20.5	19.5	17.5	—	12.5	7.5	28.5	13.0	46.5	—
K. K.	kan:a	11.5	8.5	16.5	16.5	16.0	24.5	24.5	23.0	20.5	16.5	—	10.0	11.0	33.5	20.0	39.0	—
	an::a	9.0	4.5	15.0	15.0	15.5	24.0	23.5	23.0	21.5	19.5	—	13.5	12.0	31.5	20.0	38.5	—
	isol.[n]	8.0	3.0	12.5	12.5	14.0	22.5	20.5	18.5	25.5	23.5	—	13.5	6.5	35.0	14.0	39.5	—
T. K.	kana	6.5	4.5	11.0	9.0	7.0	34.5	32.0	29.0	20.0	16.0	—	11.5	8.5	23.5	16.0	35.0	—
	kan:a	4.5	3.0	10.5	9.5	9.0	30.0	28.5	25.5	24.0	20.0	—	14.0	8.5	24.0	17.0	35.0	—
	an::a	3.5	3.0	8.0	8.0	6.5	28.0	25.5	22.5	25.0	23.0	—	17.0	1.5	25.0	14.0	34.0	—
	isol.[n]	5.5	3.0	13.0	14.5	16.5	19.5	17.5	15.5	37.0	34.0	—	20.0	19.0	35.0	27.0	43.0	—
R. T.	tala	14.5	13.0	18.5	17.5	15.0	33.5	33.0	33.0	16.0	17.0	13.0	—	6.5	28.5	—	—	51.5
	tal:a	14.5	14.0	16.0	15.5	13.0	35.5	34.0	30.5	19.5	21.5	19.0	—	5.5	30.5	14.0	39.5	52.0
	tal::a	14.0	12.5	14.5	14.5	11.0	37.0	36.0	32.5	20.5	22.5	20.0	—	5.5	30.0	—	—	52.5
	isol.[l]	7.0	6.5	8.5	9.0	6.0	41.0	39.0	33.5	19.0	22.5	20.0	—	1.5	30.0	5.0	49.0	51.0
Õ. P.	tala	13.0	7.5	12.0	12.0	10.5	26.0	26.0	26.0	14.0	12.0	—	7.5	14.0	30.0	16.5	46.0	37.5
	tal:a	12.0	7.0	9.5	9.5	9.5	26.0	25.5	25.5	15.5	14.0	—	9.0	13.5	30.0	16.5	46.0	38.5
	tal::a	12.5	7.5	7.5	8.5	8.0	29.0	28.0	27.0	15.5	15.0	—	12.5	12.0	29.0	15.0	45.0	38.5
K. K.	tal:a	13.5	10.0	15.0	14.0	13.0	30.0	28.5	27.5	18.5	17.0	—	14.5	14.0	38.0	21.0	41.0	44.5
	tal::a	12.5	8.5	14.5	13.5	12.0	30.5	30.0	27.5	19.0	18.5	—	16.0	14.0	36.5	21.5	40.0	45.0
	isol.[l]	11.0	7.0	13.0	11.5	10.5	29.5	27.5	23.0	22.0	22.5	—	18.0	7.5	38.0	15.0	41.5	46.5
T. K.	tala	11.5	9.0	14.0	13.5	11.5	34.0	34.0	33.0	15.5	12.0	—	10.0	12.0	28.0	20.0	36.5	37.0
	tal::a	9.0	6.0	13.0	13.0	12.5	32.0	30.0	26.0	24.0	20.5	—	12.5	10.5	27.0	19.0	37.0	41.0
	isol.[l]	7.5	5.5	12.0	12.0	12.0	26.5	24.5	20.5	32.0	32.0	—	27.0	18.0	39.0	25.0	41.5	43.0
H. P.	tala	12.0	11.0	17.5	18.5	17.5	26.0	26.0	25.5	19.5	15.5	—	7.0	15.0	31.0	21.0	40.0	44.5
	tal::a	10.5	8.5	16.0	16.0	16.0	23.0	22.5	20.0	24.0	19.0	—	10.5	11.5	33.5	18.0	42.0	45.5
	isol.[l]	8.0	8.0	17.0	17.0	17.0	24.5	24.5	24.0	20.5	18.0	—	15.0	11.5	38.0	16.0	51.0	45.5
A. E.	tal:a	13.5	10.0	15.0	15.0	13.5	32.5	32.5	32.5	11.5	11.0	—	10.0	3.0	26.0	6.5	45.0	52.0
	tal::a	12.0	9.0	14.0	14.0	13.0	34.0	33.5	32.5	13.0	14.0	—	13.0	2.0	25.0	6.5	46.5	52.5
	isol.[l]	17.0	10.5	11.5	11.5	9.0	35.5	30.5	26.0	21.5	22.0	—	16.5	4.5	34.0	10.0	54.0	52.5

* Data on the quasi-culmination phases of Informants R. T. and Õ. P. have been drawn from cinefluorograms (the corresponding frames of Informant R. T. are indicated in Fig. 5 by encircled numbers on the upper edge of spectrograms; small crosses in Fig. 11 indicate the same phases in [n] of Õ. P. and [l] of R. T.). Data of other informants have been drawn from static roentgenograms as well as measures Lar_f and Lar_u of Informant R. T. (since the 5″ image intensifier left his larynx beyond the cineframe). Depending on the informant's vocal tract peculiarities either coordinate *12* or *13* is used.

2.3. On some aspects of the articulation dynamics of [n] and [l]

2.3.1. *The movements of articulators in the occlusion phase of the sonorants*

Above, when the quasi-culmination phase was defined (Section 2.1.6.), attention was called to a certain independence of different parts of the tongue. This has also been pointed out by S. Öhman who says that "... the production of vowel + stop consonant + vowel utterances of certain languages seemed to involve two simultaneous gestures, viz., a diphthongal gesture of the tongue-body articulator and a superimposed constrictory gesture of the apical or the dorsal articulators" (Öhman, 1967b; cf. also Perkell, 1968, 4.3). At all events, on the basis of data measured from the cinefluorograms we may assume that different commands are sent to the apical and the dorsal articulator. The apical closing gesture (which for its greatest part is performed very quickly during a time interval of 2—3 frames) is accompanied by a rise of the predorsum toward the hard palate and a withdrawal of the tongue root from the rear wall of the pharynx. At the same time it is impossible to classify the convexity vs concavity of the dorsum (at least in the velar region) as a mere attendant phenomenon of the movement of some other part of the tongue. This allows us to presume an independent behavior of the dorsal articulator not only in the case of velar sounds [k, g, ŋ], but for [n] and [l] as well. However, though it is obvious that different parts of the tongue are innervated by different neural commands, the complicated muscular system of the tongue makes a partial interlacing of muscular activities highly probable. Taking into further consideration a different inertia of various parts of the tongue one can understand why culmination is not reached simultaneously by all parts when the sonorants are articulated.

2.3.2. Frame-by-frame measurement of cinefluorograms reveals that, as a rule, the pre- and mediodorsum come to a quasi-stationary state somewhat earlier than the root of the tongue and the postdorsum which move more sluggishly. This tendency is even more notable when the speaking tempo is slower (see Fig. 11B). The presumable relaxation of the linguopalatal contact is accompanied by a slow downward movement of the pre- and mediodorsum (which is abruptly accelerated after the release of the apical closure). On the other hand, the relaxation of the pressure in the linguopalatal contact is accompanied by a simultaneous (when the speech tempo is higher, see Fig. 11A) or a considerably delayed (at a lower speech rate, see Fig. 11B) movement of the tongue root at constant speed (showing no essential change even after the release) in the direction of the rear wall of the pharynx. The postdorsum, compared to other parts of the tongue, is relatively steady during the occlusion phase, i. e. after reaching its culmination and up to the release. Smaller movements of articulators during the occlusion are probably caused by some possible fluctuation of the vocal tract which we shall not take into account here.

The movement tendencies just described are similar for sonorants in Q2 and Q3. The pre- and mediodorsum reach their maximum [n]-ness or [l]-ness before the temporal midphase of the consonant occlusion and retain it up to the midphase where a slow transition to the following vowel begins. In other words the C—V transition is initiated for quite a period before the consonant release. The root of the tongue reaches its culmination somewhat later, i. e. approximately during the midphase of the consonant. When a sonorant in Q1 is pronounced, the pressure in the linguopalatal contact relaxes only just before the release while the root of the tongue may still continue its movement away from the rear wall of the pharynx up to the very explosion. Thus the essential difference between Q2 and Q3 is not in the movement tendencies of articulators during the occlusion phase but in degree of approach of the vocal tract to the target value for the corresponding sound, the degree being greater in Q3 than in Q2 (see data presented above on quasi-culmination phases).

2.3.3. The movement tendencies of articulators in Q2 and Q3 as described in the preceding section may be relevant for the determination of syllable boundaries. On perceptual grounds, the syllable boundary is located in the middle of sonorants in Q2 or Q3 (i. e. at the point when certain articulators have reached their culmination and start off towards a position for the following [a]) which suggests a treatment of sonorants in Q2 and Q3 as so-called geminate consonants. However, at present it is not known why exactly one consonant is perceived as single while another as a geminate. Besides the already mentioned differences in the V—C and C—V transition account should also be taken of durational differences. Thus a geminate is perceived as a double sound (i. e. as a long vs a short sound from the articulatory point of view, cf. Ariste, 1953, 95) with a syllable boundary located in the middle. The spelling of geminates has apparently been one of the reasons why repeated attempts have been made to find a separate stress peak for each of the components of the geminate. The fruitlessness of such endeavours has been demonstrated by L. Hegedüs (at least as far as Hungarian is concerned; Hegedüs, 1953).

2.3.4. In view of the above data concerning the articulation of [n] and [l], the three phonological degrees of quantity of these sonorants can be re-interpreted as /n/ and /l/ (Q1), geminates with a lax syllable-final component, [nn] and [ll] (Q2), and geminates with a tense syllable-final component, /n̂n/ and /l̂l/ (Q3). In Q3 the linguopalatal contact is produced with greater muscular effort than in Q2.[4] The pre- and mediodorsum on their way toward the palate reach their maximum height at the beginning of the occlusion phase, and only later, after some steady-state period, apparently with the relaxation of the pressure in the contact, do the pre- and mediodorsum start moving downward. Consequently the peak of tension is probably at the beginning of the occlusion phase. Incidentally, it has been stated by V. Hallap that also perceptually the first half of the intervocalic consonant matter of Q3 would leave an impression that it has a far higher intensity relative to the immediately preceding transitional segment, or a "sharper" onset, than that of Q2, the initial portion of the consonant comprising something like an additional intensity peak next to the preceding vowel (Hallap, 1962, 246; cf. Tauli, 1968).

2.3.5. It is quite logical to expect that the formation of a tenser closure is accompanied by a longer duration. The existence of such an interrelationship is also pointed out by P. Ariste in his analysis of relations between lenis and fortis stops: the production of a stronger closure takes more time (Ariste, 1938, 67; 1953, 94; 1968, 153—154). But in some other places the relation of cause and consequence is obscure (Ariste, 1953, 22 *et passim*; 1968, 41—42 *et passim*).

While two relevant duration-controlling signals can be presumed in an articulatory control program to distinguish between the short and the long sound, or the single and the geminate consonant, an additional tenseness-controlling signal may be presumed within the class of long sounds as if superimposed on the duration signal of Q3 to distinguish it from Q2. Hence the primary distinction between Q2 and Q3 seems to be tenseness signal. At the same time owing to greater articulatory effort for a sonorant in Q3 the vocal tract will come the closest to its target value, with a possible purely physiological consequence of a longer duration than that in Q2.

We shall now present average durations of the occlusion phases of [n] and [l] in the three degrees of quantity as measured from spectrograms and oscillograms made of the speech of 6—7 informants recorded during the X-ray procedures:[5] [n]=77, 178, 256 msec (Q1 : Q2 : Q3=1 : 2.3 : 3.3; Q2 : Q3=1 : 1.4); [l]=66, 194, 312 msec (Q1 : Q2 : Q3=

[4] By way of a comment may it be said that the phonetic basis of the distinctive opposition of tense-lax ought to be seen only in greater muscular effort. At this J. S. Perkell is of course quite right in that greater muscular effort may have more specific physiological manifestations of tenseness different for vowels and for consonants. But it can hardly be correct to restrict greater muscular effort in the whole class of consonants to one single articulatory realization: "... for consonants it seems to be related to resisting increases in intraoral pressure". And further, "The feature tense-lax will not play a role, however, when there is no increase in pressure, as in the sonorant consonants" (Perkell, 1968, 4.3). It seems, however, that at least in Estonian the feature of tense-lax does play a role in distinguishing the sonorant consonants as well. This provides indirect evidence of the universal nature of the feature of tenseness-laxness (see also Eek et al., 1969).

[5] A more detailed durational analysis of the sonorants will be published elsewhere.

=1 : 2.9 : 4.7; Q2 : Q3=1 : 1.6).[6] The sonorants of Q3 are 3.3—4.7 times longer than those in Q1 and 1.4—1.6 times longer than in Q2. There are cases where the durational difference between Q3 and Q2 is negligible (e. g. [n] of K. K.: Q2=200 msec, Q3=220 msec); such cases are particularly indicative of the primacy of tenseness.

2.4. Vowel transitions

2.4.1. When it is assumed that the distinguishing of the three degrees of quantity of sonorant consonants is accomplished by an articulatory control program with duration in the role of the leading parameter, then it would be natural to expect that articulators would move toward their target positions at even speed, being able to do so for a period proportional with duration. Yet the average speeds of, e. g., the pre- and mediodorsum and the tongue root (at the points where the tongue contour intersects with coordinates *2′, 4′, 10*) during their movement from the quasi-culmination phase of the vowel to the first closure frame of the consonant inclusive, vary with degrees of quantity. The average speed is highest in Q3 and lowest in Q1 (R. T., average speed in millimeters per 20 msec for [l] in Q1, Q2, Q3 respectively: *2′*=4.1, 4.2, 4.6; *4′*=0.8, 0.8, 1.1; *10*=0.4, 0.8, 1.3). And a point of further interest is that the articulators do not move at an even speed but with acceleration.[7] While the movement of articulators from a vowel toward a sonorant in Q1 is the slowest and most even (acceleration almost zero or occasionally even negative), the movement toward a sonorant in Q3 is the quickest with acceleration predominantly positive (which occurs with particular consistency in the movement of the tongue root). Higher speed of articulators for Q3 is an indirect reflexion of greater muscular effort.

The subsequent section is a study of how closely the vowels [a] preceding and following a sonorant are (if at all) related to the quantity structure of sonorants. The symbol [a_1] will be used for the quasi-culmination phase of the stressed vowel preceding the sonorant and the symbol [a_2] for that of the unstressed vowel following the sonorant.

2.4.2. The u n s t r e s s e d v o w e l s of the second syllables of the words /kana/, /kan:a/, /an::a/ are characterized by the widening of the rear part of the oral cavity and the oral pharynx with the degree of quantity of the sonorant (Õ. P.: δ_0=25.5 mm for [a_2] in /kana/, 24.5 in /kan:a/, 23.5 in /an::a/; this is even more noticeable in the tracings of Informant R. T.). A tendency like this in the pronunciation of [a_2] is very difficult to interpret in view of complicated coarticulatory relations. Obviously there is an intimate interlacing of the effects of progressive and regressive coarticulation. Progressive coarticulation is understood as the influence of a sound on a following sound (i. e. the production of the following sound is hampered by a certain mechanoinertia of articulators). Regressive coarticulation is understood as the influence of a speech segment on a preceding segment (i. e. the neuromuscular command for the production of a following segment is emitted and its realization initiated during a preceding speech segment). Let us re-examine the example at the beginning of this section. The decreasing rise for [a_2] of the postdorsum toward the velum and uvula with an increase in the degree of quantity may seem convincing evidence of the effect of the preceding [n] on the vowel. Nevertheless, the possibility of regressive coarticulation — the influence exercised by the initial consonant of the next word — also requires attention. The speech production mechanism does not recognize word boundaries (cf., e. g., a recent study on labialization: Daniloff et al., 1968). The fact that the location of the postdorsum for [a_2] in /kana/ is closer to the velum and uvula than in /an::a/ may as well be a result of the influence of the initial consonant of the next word, which is [k] in the first case and [t]

[6] This is quite similar to average durations computed from P. Ariste's data concerning [n] of three degrees of quantity pronounced in disyllabic words by informants from Reigi and Kassari: 8.25, 20.0, 27.25 csec; Q1 : Q2 : Q3=1 : 2.4 : 3.3; Q2 : Q3=1 : 1.4; cf. Ariste, 1941, 26—29.

[7] In principle it is quite possible by means of a computer to synthesize changing configurations of the vocal tract on the basis of data concerning articulation dynamics obtained from a cinefilm. Among other things the control programs should be compiled with consideration of the acceleration factor of the movement of articulators.

in the second (the contexts were /kana+ka:kut:ap/ and /an::a+ta/). This is most of all suggested by a very high location of the pre- and mediodorsum and by a wide pharyngeal cavity for [a_2] in /an::a/ (see Fig. 11A *a*, *b*, *c*, *d*, *f*).

Let us now compare the vocal tract configurations for [a_2] in the words /tala/, /tal:a/, /tal::a/. The immediate environment for [a_2] is qualitatively identical in words /tala+kuk:up/ and /tal::a+kas/. The postdorsum is always closer to the velum and uvula for [a_2] following a sonorant in Q3 than for [a_2] after a sonorant in Q1. Towards the end of the occlusion phase of the sonorant a typical descent of the postdorsum begins in the direction of the articulation place of [a_2]. Since the unstressed vowel in a Q3 word is always of short duration (see also Fig. 5), a longer descent of the postdorsum would practically be impossible; and in view of a rather great inertia of this part of the tongue, the movement toward the production place of the initial consonant of the next word is started the earliest (see Fig. 11B *e*). Regressive coarticulation in [a_2] of the two words, is also indicated by the different curve of the postdorsum movement during the unstressed vowel [a] in the sequence /tal:a+pak::sus/. Namely as the next word begins with [p], after a short sustain phase of [a_2] the postdorsum begins to descend. Nevertheless there remains a possibility that a sonorant in Q2 and especially in Q3 has an effect of stronger reduction on the following unstressed vowel.

Thus during articulating [a_2] both after [l] and [n] in Q3 the vocal tract attains the least of the target value of the [a]-sound. A second effect of the articulatory tension of a preceding sonorant makes itself felt in the duration of the following vowel. The duration of the unstressed vowel decreases with an increase in the degree of quantity. Averaged over 6—7 informants, the durations of the unstressed vowel [a] of the second syllable are as follows: 253, 177 and 106 msec after [n] in Q1, Q2 and Q3; 256, 188 and 105 msec after [l] in respective degrees of quantity. Note that there is hardly any variation in the duration of the stressed vowel of the first syllable, the corresponding data being 165, 145, 150 msec before [n] and 142, 140, 140 msec before [l].

2.4.3. The s t r e s s e d v o w e l s in the first syllable of the words /tala/, /tal:a/, /tal::a/ are articulated in such a way that the anterior part of the oral cavity grows wider with a rise in the degree of quantity of the following sonorant (R. T.: $L_h=13.5$, 15.0, 16.5 mm; $l_d=11.5$, 13.5, 14.5 mm; $2'=18.0$, 19.0, 19.5 mm; $4=22.5$, 22.5, 23.5 mm; $4'=21.5$, 21.0, 21.5 mm). In view of the following [l] quite the opposite effect might be expected. But a closer examination of the whole words reveals an intimate interrelation between the differences in [a_1] and the differences in the preceding word-initial stop consonant [t] as measured for each word on the tracing of the third frame before the release. Namely it appears that the initial stop [t] of the word in Q3 is pronounced with a particularly strong removal of the pre- and mediodorsum from the palate and an equally strong motion of the tongue root toward the rear wall of the pharynx. Now if we tried to interpret the differences in [a_1] as an effect of progressive coarticulation from [t], it would remain unexplained why the initial consonant [t] of a word of Q3 is pronounced with the greatest muscular effort. We can only surmise that the production of a sonorant of Q3 is accomplished through tenser articulation not only of the syllable-final component of the sonorant and of the vowel transition immediately preceding it, but of the whole of the syllable. Perceptually, too, words containing an intervocalic sonorant in Q3 give an impression that the initial consonant has been produced with greater muscular effort.

Thus the feature of tenseness would appear to have an organizing effect on the entire syllable or rather the entire word if the reduction-strengthening effect of the tense sonorant on the unstressed vowel is considered. The aforesaid does not presuppose the treatment of tenseness as a suprasegmental since it is possible to ascertain a definite segment for the location (culmination) of tension, the centralizing influence of tenseness throughout the word being then interpreted in terms of coarticulation.

3. Summary

Analyses of articulation, especially those involving roentgenographic techniques, are limited by their rather scanty experimental material and small number of informants. On the other hand the drawing of basic conclusions is hampered by a high variability within the material. Therefore all that has been said above and the conclusions drawn here are valid only as far as the employed informants are concerned. For the language community as a whole these conclusions are only tentative; a far bigger amount of experimental material is needed to prove them.

[n] is mainly an alveolar nasal as to place of articulation. A higher degree of quantity is characterized by an increase in the area of the linguopalatal contact, narrowing of the anterior part of the oral cavity with more upward movement of the mandible and the pre- and mediodorsum, widening of the pharyngeal cavity with a removal of the tongue root and the epiglottis from the rear wall of the pharynx, growth of the concavity of the postdorsum.

[l] is an alveolar-prepalatal lateral as to place of articulation. A higher degree of quantity is characterized by increase in the area of the linguopalatal contact, narrowing of the oral cavity, widening of the pharyngeal cavity and *vestibulum laryngis*.

[l] differs from [n] in the following features: the velopharyngeal passage is closed and the air flows out through a passage between the depressed tongue sides and the cheeks; the aperture between the lips and jaws is wider; the medio- and postdorsum rise higher toward the palate and the velum and ·uvula; the postdorsum is convex; the oral pharynx is narrower.

The movement tendencies of articulators are different in quantity 1 as against quantities 2 and 3. A higher degree of quantity brings about a higher speed of articulators in the transitional phase of the vowel preceding a sonorant; the movement is not even in speed but accelerated, particularly in Q3.

The three degrees of quantity of the sonorants under study can be re-interpreted as (Q1) [n] and [l], (Q2) geminate with a lax syllable-final component, (Q3) geminate with a tense syllable-final component. In these terms the longer duration of a sonorant in Q3 is a result of greater muscular effort used for the production of the closure.

In view of the articulation dynamics of the entire stressed syllable the feature of tenseness seems to possess an organizing effect on the entire syllable or even the whole word when the reduction-strengthening effect of the tense sonorant on the unstressed vowel is considered.

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EESTI KEELE SONOORSETE KONSONANTIDE ARTIKULEERIMINE. I. [n] JA [l]

Resümee

[n] on artikulatsioonikohalt põhiliselt alveolaarne nasaal. Kvantiteediastme kasvamisel keele-suulae kontaktpindala suureneb, suuõõne esiosa aheneb alalõua ja pre- ning mediodorsumi ülespoole liikumisega. Neeluõõs laieneb keelejuure ja kõripealise eemaldumisega neelu tagaseinast, postdorsumi nõgusus suureneb.

[l] on artikulatsioonikohalt alveolaarne-prepalataalne lateraal. Kvantiteediastme kasvamisel keele-suulae kontaktpindala suureneb, suuõõs aheneb, neeluõõs ja kõriesik laienevad.

[l] erineb [n]-st järgmiste tunnuste poolest: käik ninaõõnde on suletud, kusjuures õhuvool pääseb välja allasurutud keeleserva(de) ja põskede vahelist käiku pidi; huulte ja lõualuude vaheline ava on suurem; keele ja suulae kontakt tagapoolsem; medio- ja postdorsum tõusevad kõrgemale kõva ja pehme suulae ning kurgunibu suunas; postdorsum on kumeras; neeluõõne suumine osa ahtam.

Artikulaatorite liikumistendentsid on I vs. II, III kvantiteediastmes erinevad. Kvantiteediastme kasvamisel on artikulaatorite liikumiskiirus sonoorsele konsonandile eelneva vokaali siirdefaasis suurenenud, kusjuures eriti III kvantiteediastmes pole liikumine mitte ühtlase kiirusega, vaid kiirendusega.

Võime käsitleda vastavate sonoorsete konsonantide kolme kvantiteediastet järgmiselt: /n, l/; geminaat /nn, ll/ silpi lõpetava *lax*-komponendiga; geminaat /ǹn, l̀l/ silpi lõpetava *tense*-komponendiga. Siinjuures III kvantiteediastmes pingsama sulu moodustamisega kaasneb suurem kestuski. Arvestades kogu pearõhulise silbi artikulatsioonidünaamikat, näib pingsustunnus olevat organiseeriva mõjujõuga kogu silbile või kogu sõnale, kui arvestada ka *tense*-konsonandi reduktsiooni tugevdavat toimet teise silbi rõhutule vokaalile.

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АРТИКУЛЯЦИЯ ЭСТОНСКИХ СОНОРНЫХ СОГЛАСНЫХ. I. [n] И [l]

Резюме

[n] по месту артикуляции скорее всего — альвеолярный носовой согласный. С увеличением степени долготы возрастает площадь соприкосновения языка с нёбом, полость рта сужается при продвижении вверх нижней челюсти, а также передней и средней частей спинки языка. Полость глотки расширяется при отдалении корня языка и надгортанника от задней стенки глотки, вогнутость задней части спинки языка увеличивается.

[l] по месту артикуляции — альвеолярный-препалатальный боковой согласный. С увеличением степени долготы увеличивается площадь соприкосновения языка с нёбом, полость рта сужается, полость глотки и преддверие гортани расширяются.

[l] отличается от [n] по следующим признакам: проход в носовую полость закрыт; отверстие между губами и челюстями шире; место соприкосновения языка и нёба более отодвинуто назад; средняя и задняя части спинки языка поднимаются выше в направлении твердого и мягкого нёба и нёбной занавески; задняя часть спинки языка выпуклая; ротоглотка уже.

Тенденции движения артикуляторов в первой степени долготы отличаются от таковых во второй и третьей. С увеличением степени долготы увеличивается скорость движения артикуляторов при переходной фазе гласного, предшествующего сонанту, причем при третьей степени долготы движение происходит не с равномерной скоростью, а с ускорением.

Три степени долготы этих сонорных согласных можно рассматривать соответственно как /n/ и /l/, гeминату с ненапряженным компонентом, заканчивающим слог, и геминату с напряженным компонентом, заканчивающим слог. При этом в третьей степени долготы образование самой напряженной смычки сопровождается и большей длительностью. Если учесть всю артикуляционную динамику слога с главным ударением, представляется, что признак напряженности имеет организующее влияние на весь слог или на все слово, если принять во внимание и сильное действие редукции напряженного сонанта на безударный гласный второго слога.

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