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ARVO EEK (Tallinn)

ARTICULATION OF THE ESTONIAN SONORANT CONSONANTS. IV. [m]

1. Methods and material

1.1. The experimental material was obtained by the complex techniques of lateral cinefluorography, static roentgenography and the filming of lip articulations, synchronized with sound spectrography (and oscillography).[1] In order to measure the contact between the tongue and the hard palate, the traditional palatographic procedure was used; this was supplemented by the method of direct palatography.

For the measurement of roentgenograms a coordinate system was designed (see Fig. 1).[2]

1.2. For experiments in roentgenography and filming lip movements the following test material was used: *Sa|m|a poiss tulebki* 'The s a m e boy is coming there'. *Sa|mm|a püügikohad on ju teada* 'The fishing places of the s t u r g e o n are known'. *Sa|mm|a pinki istus ka tema* 'He, too, took his seat in the s a m e desk'.

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]. One sample of each unit to be analyzed was obtained from every informant. The total experimental material amounts to 187 cinefluorograms, 17 static X-ray shots and 124 cineframes of lip movements. In addition, 7 X-ray shots were made of [m] pronounced in isolation.

Taking into consideration the fact that the peculiarities of the articulation dynamics may play quite an essential part in distinguishing the Estonian phonemic degrees of quantity, the whole word containing [m] was drawn and measured frame by frame.

For palatography the experimental material consisted of single (nonsense) words containing [m] in the three degrees of quantity embedded in the vowels [a], and the same sonorant in a word-final position: /ama/, /mam:a/ 'mamma', /am::a/, /am::/ 'nurse'. Each of the

[1] A detailed description of the methods used has been presented in earlier papers: Г. Лийв, А. Ээк, О проблемах экспериментального изучения динамики речеобразования: комплексная методика синхронизированного кинофлуорографирования и спектрографирования речи. — Eesti NSV Teaduste Akadeemia Toimetised. Bioloogia 17 1968 1, pp. 78—102; A. Eek, Uusi meetodeid artikulatoorses foneetikas. — KK 1969 8, pp. 475—489.

[2] For a description of the coordinate system, see A. Eek, M. Remmel, Some Remarks Concerning Speech Production. — СФУ V 1969 2, pp. 141—145; A. Eek, Articulation of the Estonian Sonorant Consonants. I. [n] and [l]. — ETATU 19 1970 1, § 2.1.7.

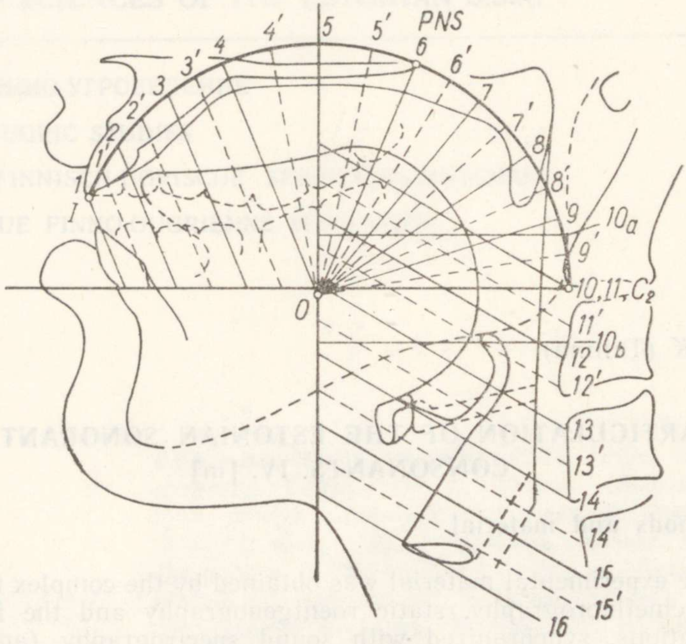

Fig. 1. X-ray tracing with landmarks and reference coordinate system.

informants used for palatography pronounced every word 3 times (48 palatograms in all with the method of traditional palatography and 12 palatograms with direct palatography).

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

2. Articulation dynamics in words containing bilabial nasals

2.1. ***Word-initial*** [s]. It is difficult to determine the onset of the articulation phase of [s] in a cinefluorographic film. When making comparisons between the cinefluorographic film and the synchronized spectrograms, it becomes evident that the tongue has already 1—4 frames before the onset of [s] taken the position characteristic of [s]. In view of this circumstance the frame of the cinefluorographic film corresponding to the onset of the noise spectrum on the spectrogram is regarded as the beginning of [s]. The end of [s] is defined by the frame before an abrupt downward shift of the tongue tip and the mandible for [a].

Let us examine the articulation of [s] in the words /sama/, /sam:a/, /sam::a/. Beginning with the first frame of [s] and up to the medial temporal phase of [s] or even a bit longer the postdorsum moves back towards the uvula, so that the oral pharynx becomes narrower. At the same time the hyoid bone rises; the concavity on the tongue contour between the predorsum and the mediodorsum deepens. These movements are more or less equal in all the degrees of quantity. Probably in order to retain the narrow passage needed for friction, the aperture between the mandible and the maxilla and the position of the predorsum remain unchanged during the pronunciation of [s].

In the final part of [s] the lower lip moves somewhat downwards, the postdorsum withdraws from the uvula, the root of the tongue approaches the rear wall of the pharynx, the hyoid bone starts moving downwards. These [a]-directional movements (which continue in the initial part of [a]) begin first of all in the Q3 words [3]. The same tendency can be observed also in the film of lip articulation. In the Q1 and Q2 words the lip aperture widens only with the last [s] frame; in the Q3 word the lower lip moves down already during the last 3 frames. The coarticulatory link between the word-initial [s] and the following [a] seems to be the strongest in the Q3 word. As a result of this, in the last frame of [s] of the Q3 word the lip aperture and the oral cavity are the largest, the pharyngeal cavity is the narrowest (R. T.: $L_h = 5.5$, 5.5, 6.0; $4 = 18.5$, 18.5, 20.0; $4' = 18.5$, 18.5, 20.5; $5 = 15.5$, 16.5, 17.5; $10 = 16.5$, 17.0, 15.5 mm in Q1, Q2, Q3 word respectively).

2.2. ***The vowel [a] of the stressed first syllable.*** The phase of [a] of the first syllable has been defined in the cinefluorographic film beginning from the first opening frame of the constriction of the word-initial [s] (thus the release of [s] has been included, as well) up to the last frame (inclusive) where the lips are still open.

2.2.1. D u r a t i o n s. The duration of the vowel of the stressed syllable in the words /sama/, /sam:a/, /sam::a/ is almost equal irrespective of the quantity degree of the following [m]. The average absolute durations of [a] of two informants, measured from the dynamic spectrograms by a comparative analysis of cinefluorograms and spectrograms, are 152, 155, 142 msec before [m] of Q1, Q2, Q3 respectively.

2.2.2. D i f f e r e n c e s i n a r t i c u l a t i o n. The opening speed of the [s] constriction during the initial transition of [a] is the highest in the Q3 word (e.g. the average speeds of the lip, the mandible and the tongue tip movements during the time interval from the last frame of [s] up to the moment when the corresponding articulators have reached the maximum position in their [a]-directional movement, with Informant R. T.: $L_h = 1.5$, 1.4, 2.0; $I_d = 1.7$, 2.0, 2.7; $2' = 2.0$, 2.8, 3.0 mm/20 msec in Q1, Q2, Q3 word respectively). Depending on these circumstances the quasi-culmination phase [4] of [a] in the Q3 word has been pronounced with a somewhat larger lip aperture and oral cavity than in the Q1 and Q2 word.

During the final transition of the first syllable [a] the movements of the tongue are minimal, as expected. It is known that during the articulation of bilabial consonants the vocal tract gains the position of the following vowel.[5] Since in the present case the vowel of the following syllable is also [a], it can be understood why the lingual articulation during the transition from [a] to [m] is relatively stationary.

In the final part of [a] the basic movements are the closing gesture of the lips and the continuing opening of the velopharyngeal passage.

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[3] Q1, Q2, Q3 — the first, second and third degrees of quantity respectively.

[4] The quasi-culmination phase of a vowel is described by the data from the last frame of its culmination phase, the next frame displaying already a measurable transition toward the articulation place of the following bilabial nasal (see Fig. 2).

[5] A. E e k, Some Coarticulation Effects in Estonian. — СФУ VI 1970 2, pp. 81—85.

The average speed of the lip-closing gesture during the time interval from the quasi-culmination phase of [a] up to the following bilabial nasal is the highest in the Q3 word, e.g. R. T.: $L_h = 3.7$, 3.1, 3.9 and Õ. P.: $L_h = 2.3$, 2.7, 3.7 mm/20 msec before [m] of Q1, Q2, Q3 respectively.[6] The lip-closing gesture is accompanied by the quickest upward movement of the mandible in the Q3 word (the average decreasing speed of the aperture between the maxilla and the mandible during the final transition of [a], e. g. R. T.: $I_d = 0.8$, 0.6, 1.0; Õ. P.: $I_d = 0.0$, 0.6, 0.8 mm/20 msec before [m] of Q1, Q2, Q3 respectively). When during the initial transition of [a] the speeds of both L_h and I_d are more or less equal (sometimes I_d having even a higher speed), then during the final transition of [a] the upward movement of the mandible that accompanies the lip-closing gesture begins later and the movement is considerably slower than the closing movement of the lips. Since the vowel of the following syllable is also [a], the relatively small movability of the mandible can probably be explained by the attempt to retain the vocal tract configuration characteristic of [a].

2.3. ***The occlusion phase of* [*m*].** The occlusion phase of [m] in the cinefluorographic film has been determined by an interval beginning from the first frame of the bilabial closure up to the last frame of the closure, inclusive.

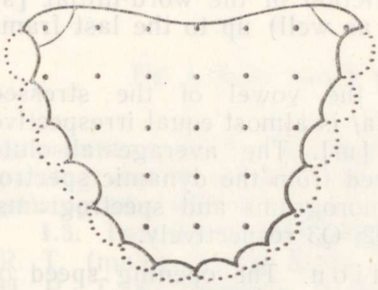

Fig. 3. Palatogram of Estonian [m] in the first degree of quantity. Informant R. T.

2.3.1. Durations. The absolute durations of [m] in Q1, Q2 and Q3 as averaged over 2 informants are 78, 193, 260 msec, respectively (Q1:Q2:Q3 = 1:2.5: 3.3; Q2:Q3 = 1:1.3).

2.3.2. Linguopalatal contact. The contact of the tongue was registered on the postpalate on about one half of the palatograms (in 28 cases out of 60 possible) (see Fig. 3); in the rest of the cases the contact between the tongue and the palate cannot be recorded at all. In different degrees of quantity there are no differences either in the size or the place of the contact. In the preliminary experiments with [a] pronounced in isolation, made before the palatographic procedures for the sonorants, there was not a single case where the tongue had left a trace on the artificial palate. It can be concluded here that the tongue position of [a] in the neighbourhood of [m] is more advanced (cf. below 2.3.3).[7]

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[6] The highest speed of movements in the Q3 word depends on the fact that the articulators, in order to reach the articulation place of the consonant, have to cover a longer distance than in the Q1 and Q2 words, the time interval remaining unchanged. The highest speed of the lip-closing gesture in the Q3 word can probably be controlled peripherally by means of a closed loop feedback circuit (cf. H. M. Sussman, What the tongue tells the brain. Preprint 1970; to be published in the Psychological Bulletin). But it can hardly be explained by means of the peripheral control mechanism why the [a] preceding the Q3 [m] is articulated with the largest lip aperture and why the speed of the initial transition of [a] is the highest. The influence of the tense articulation of the intervocalic Q3 sonorant over the whole first syllable as it has just been described suggests a possibility that on a certain control level the motor commands corresponding to the syllables are stored. Since consecutive ordering of consonants and vowels implies units smaller than the syllable, it is possible that these intra-syllable segments are controlled according to the feedback mechanism mentioned above.

[7] Cf. P. Ariste, Hiiu murrete häälikud. — Acta et Commentationes Universitatis Tartuensis B 47 1, Tartu 1939, p. 233; *idem*, Eesti keele foneetika, Tallinn 1953, p. 38; *idem*, Eesti keele foneetika. Õpik Ajaloo-Keeleteaduskonna keeleosakondade üliõpilastele, Tartu 1968, p. 67.

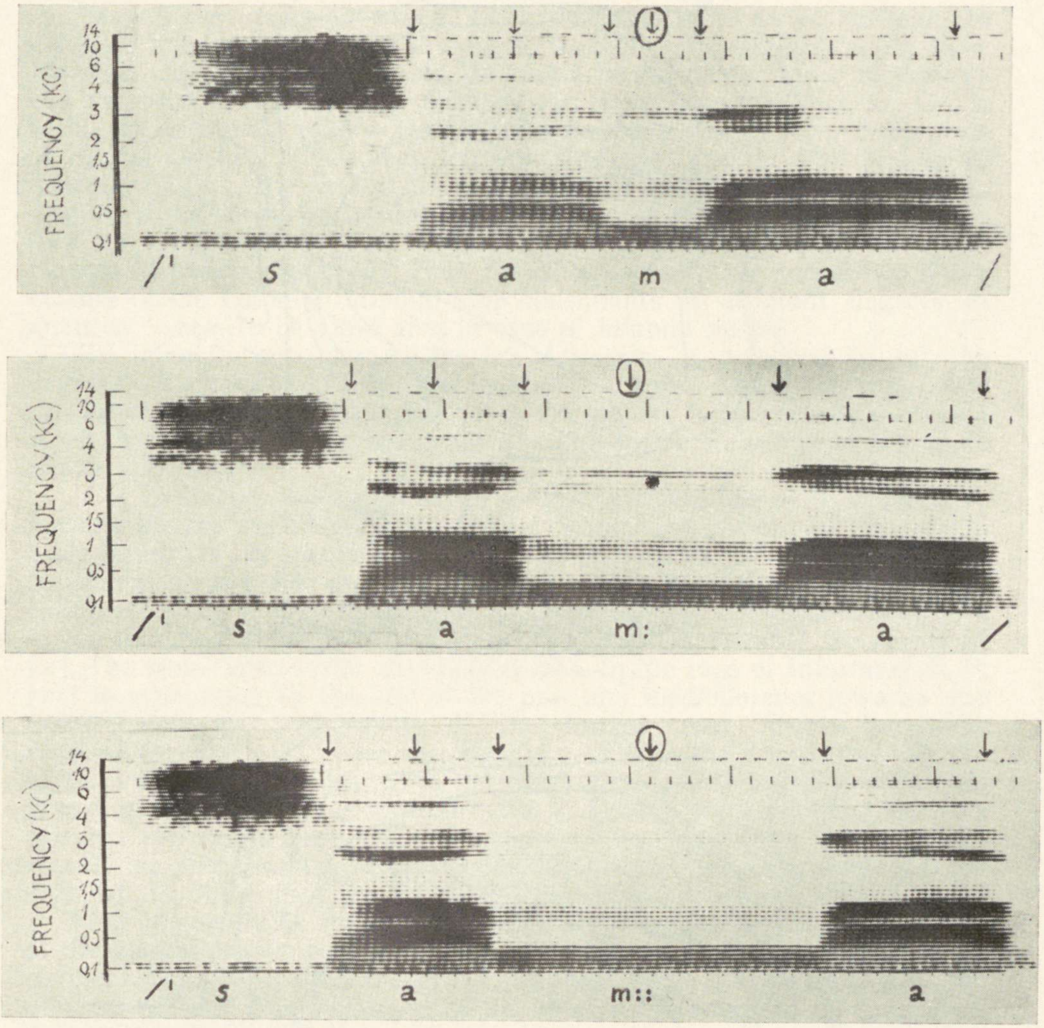

Fig. 2. Dynamic spectrograms, synchronized with cinefluorograms, of the Estonian words *sama* (*a*); *samma*, Genitive (*b*); *samma*, Illative (*c*). Informant R. T.
Vertical lines in the upper part of the spectrograms indicate time intervals, the distance between two shorter lines represents an interval 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. The first vertical arrow in the uppermost edge of the spectrogram indicates the first frame of [a]; the second arrow designates the quasi-culmination phase of the stressed vowel; the third arrow marks the first closure frame of [m]; the fourth arrow (encircled) — the culmination phase of [m]; the fifth is for the first frame of the unstressed vowel [a]; the sixth indicates the last frame of [a].

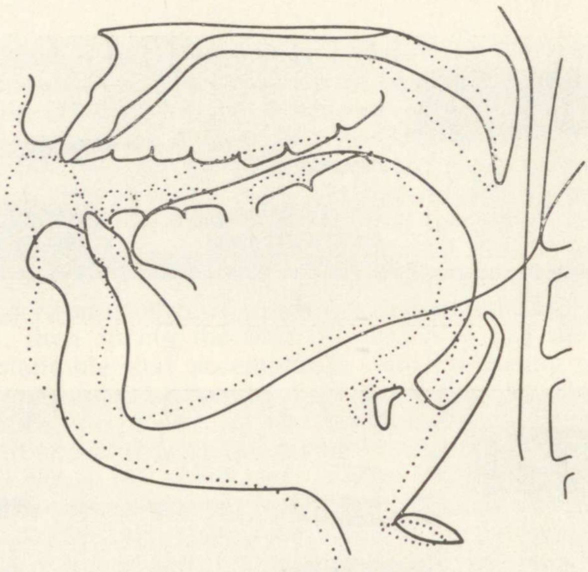

Fig. 4. Cinefluorograms of the first syllable [a] and the intervocalic [m] of the word *samma* (Illative), with both sounds represented in their quasi-culmination phases. Informant Õ. P.
[a] ———; [m] ......

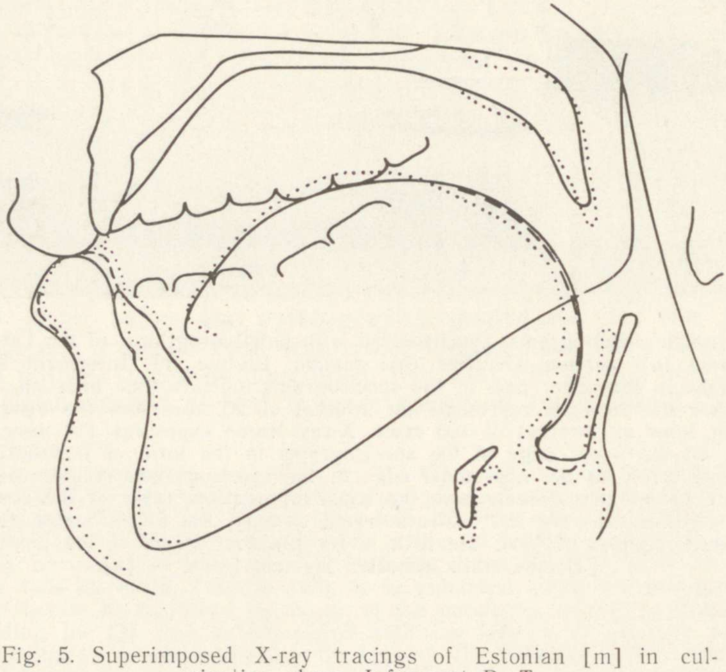

Fig. 5. Superimposed X-ray tracings of Estonian [m] in culmination phase. Informant R. T.
Q1 (in the word *sama*) ———; Q2 (*samma*, Genitive) - - - - -;
Q3 (*samma*, Illative) .....
The median line of the dorsum has been drawn; projections of the side edges of the tongue have been omitted for the sake of clarity. The exposures of the frames traced for this Figure are indicated by an encircled arrow on the spectrograms *a*, *b*, *c* in Fig. 2.

2.3.3. The movements of articulators. It is difficult to estimate the tensity of the lip closure from the cinefluorographic film. However, in the case of Q2 and Q3 [m] a larger contact area of the lips can be recorded than for Q1 [m]; in the latter case the lips are in a rather loose contact. If we compare the results obtained from cineframes of lip movements, it becomes evident that the greater the degree of quantity of [m], the shorter the distance between the Indian ink spots drawn on the vermilion border of the upper and lower lip (e.g. 16.5, 15.0, 14.0 mm for Q1, Q2, Q3 [m] respectively), i. e. the more tensely the labial closure has been produced.[8] Thus the differences in the tenseness of the closure of the Estonian bilabial stop consonants in different degrees of quantity [9] seem to be valid also in case of bilabial nasals.

The intensity maximum of the labial closure is achieved in all the degrees of quantity before the medial temporal phase of [m]. The relaxation of the closure begins after the medial temporal phase of [m] when the continuous increase in the distance between the Indian ink spots can be recorded.

It is commonly known that the tongue articulation of bilabial consonants follows the articulation of the neighbouring vowels. In the present case, where [m] is surrounded by the vowels [a], only the [a]-directional movement should be expected. Actually the above-described intensity culmination of the labial closure is accompanied by the tongue articulation in the direction opposite to the expected movement towards the target of [a]. The movements differ with informants. In the case of Informant Õ. P. [m] is articulated by the rise of the pre- and mediodorsum towards the palate and the withdrawal of the tongue root from the rear wall of the pharynx. These movements result in the narrowing of the oral cavity and the widening of the pharyngeal cavity and the *valleculae* (see Fig. 4). In the case of Informant R. T. only the mediodorsum rises towards the palate (the predorsum may at the same time move downward), the root of the tongue withdraws from the rear wall of the pharynx. In both cases the tongue contour approximates a circle.

With Informant Õ. P. the movements of the mediodorsum and the root of the tongue are more or less equal; with Informant R. T. the pharyngeal cavity widens more than the oral cavity narrows. The narrowing of the oral cavity could be conditioned by the upward movement of the mandible; it remains obscure, however, why the pharyngeal cavity grows larger. The mentioned deviations from the [a]-directional movement are too considerable (3—4 mm) and consistent to be regarded as drawing mistakes. These perturbations in the motion of the tongue may, probably, depend upon the oral pressure variations also during the articulation of [m], as it has been experimentally proved in the case of the voiced bilabial stop consonant.[10] However, this motivation can hardly be credible because these movements start in the final transition of the vowel preceding [m] already and continue up to the medial temporal phase of [m]. It should be mentioned here that the movements contrary to [a]-directional ones occur only in the occlusion phase of Q3 [m]; in the Q1 and Q2 words the corresponding motions are completed during the final transition of

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[8] Cf. L. Kettunen, Lautgeschichtliche untersuchung über den kodaferschen dialekt (= MSFOu XXXIII), Helsinki 1913, p. 6.

[9] P. Ariste, Eesti *b, d, g* ja *k, p, t* suhteist. — Litterarum Societas Esthonica 1838—1938. Liber saecularis, Tartu 1938, pp. 65—68; *idem*, Hiiu murrete häälikud, p. 232.

[10] R. A. Houde, Perturbations in the Articulatory Motion of the Tongue Body. — Reports of the Sixth International Congress on Acoustics II, B & C. Speech, Tokyo 1968, August 21—28, pp. B-13 — B-16; *idem*, Tongue-Body Motion during Selected Speech Sounds. — Preprints. Speech Symposium, Kyoto 1968, pp. S-1-1 — S-1-17.

the preceding [a] already, so that the tongue movement in the closure phase of [m] is minimal.

It seems that in the articulation of [m] (particularly in Q3) the tongue muscles are also strained and the tongue assumes the position for the neutral vowel (in any case the tongue has a more advanced and higher position than for [a]; cf. 2.3.2).[11]

The culmination phase of the Q3 [m] (in the present case the medial temporal phase) is characterized by a considerably larger pharyngeal cavity and a somewhat higher position of the mediodorsum than that of the Q1 and Q2 [m]. There are no regular differences in the position of the predorsum with the degrees of quantity. The differences between the culmination phases of Q1 and Q2 [m] are negligible (R. T.: *5* = 19.5, 20.0, 18.5; *7₀* = 28.5, 28.0, 28.0; *8₀* = 30.0, 29.5, 28.0; *10a* = 16.5, 16.5, 17.5; *10* = 16.5, 15.5, 18.0 mm for [m] of Q1, Q2, Q3 respectively; Õ. P.: *5* = = 16.5, 15.0, 14.5; *7₀* = 22.5, 22.5, 21.5; *8₀* = 24.0, 24.0, 22.5; *10a* = 15.5, 15.5, 18.0; *10* = 11.5, 11.5, 14.5 mm for [m] of Q1, Q2, Q3 respectively; see Fig. 5). With the growth of the degree of quantity a slight tendency towards increase in nasality can be observed (R. T.: U_w = 7.5, 7.5, 8.0; A. S.: U_w = 4.5, 6.5, 7.5 mm for [m] of Q1, Q2, Q3 respectively).

The data presented on the articulation of intervocalic bilabial nasals make it possible to suppose that the Q3 [m] has been articulated most tensely (the highest speed of the lip-closing gesture, the greatest intensity of the labial closure; the greatest deviation of the tongue position from the target of the neighbouring [a], the longest duration).

In the final part of the occlusion phase of [m], in connexion with the relaxation of the labial closure (when the distance between the Indian ink spots begins to increase), the tongue starts moving towards the following [a].

2.3.4. [m] p r o n o u n c e d i n i s o l a t i o n. The comparison of isolated and intervocalic bilabial nasals brings out several differences that may result from the absence of a specific vowel context about the former. Thus the degree of nasality of [m] pronounced in isolation is higher than that of the intervocalic [m] (H. P.: U_w = 5.0, 7.0 mm for [m] of Q3 and in isolation respectively). The isolated (sustained) [m] is articulated with the narrowest aperture between the mandible and the maxilla (Informant H. P. excluded), and the widest and longest pharyngeal cavity (K. K.: I_d = 6.5, 4.0; *10a* = 12.5, 15.0; *10* = 12.5, 13.0; Lar_u = 34.0, 44.0; H_u = 29.0, 39.0 mm for [m] of Q3 and in isolation respectively). In the pre- and mediodorsal region no significant differences valid for all the informants can be found.

If we regard the described articulation peculiarities of the sustained bilabial nasal as a habitual lingual articulation typical of [m], i. e. as a so-called target position, we can motivate the deviations from the [a]-directional movements recorded in the occlusion phase of the intervocalic [m] and in the final transition of the preceding [a] by the motion towards the target position of [m]. In this case the lingual articulation comes closest to the target of [m] in the occlusion phase of a Q3 word.

2.4. ***The vowel [a] of the unstressed second syllable.*** The second syllable [a] has been determined from the cinefluorographic film as an

[11] In Russian the tongue articulation of bilabial consonants is characterized by the rise of the postdorsum towards the palate (see Л. Г. С к а л о з у б, Палатограммы и рентгенограммы согласных фонем русского литературного языка, Киев 1963); in the case of the Estonian [m] the opposite tendency seems to take place: the dorsum rises towards the mediopalate, the postdorsum and the root of the tongue move away from the velum and the rear wall of the pharynx.

interval from the first opening frame of the labial closure (thus the release of [m] has also been included) up to the last frame (inclusive) where the lips are still open (see Fig. 2).

2.4.1. Durations. An increase in the degree of quantity of the intervocalic [m] brings about a shortening in the duration of the following vowel. The average durations of the second syllable [a] of two informants are 255, 192, 155 msec after [m] of Q1, Q2, Q3 respectively.

In many languages the word-final vowel is the longest (not depending on syllable stress) in CVCV utterances.[12] This final lengthening is not even limited to the phrase-final position. Apparently a phenomenon of general speech physiology, it reveals itself as well in the present material, particularly in Q1 words (e. g. the word-final vowel following short non-palatalized intervocalic sonorants [l, m, n, r] is on the average 92 msec longer than the first syllable vowel). Probably it is the greater articulatory effort of longer intervocalic sonorants that levels out the differences between the durations of the first and second syllable vowels. For instance, the vowel following intervocalic [l, m, n, r] of Q2 is, on the average, only 31 msec longer than the first syllable vowel, whereas in a Q3 word the second syllable vowel is 30 msec shorter. In the Q1 words the longer duration of the second syllable vowel can be recorded in every single case, whereas in the Q2 and Q3 words the variability of individual cases is rather considerable.

2.4.2. Differences in articulation. An increase in the degree of quantity of the intervocalic [m] affects the duration of the following vowel (see 2.4.1) but it has no significant influence on its quality. The vocal tract configurations of the second syllable [a] in words of different degrees of quantity differ very little from one another. Only one slight tendency can be recorded: to pronounce [a] following [m] of Q3 with a somewhat wider pharyngeal cavity. Probably due to a relatively great freedom of the tongue articulation and a slighter deformation of the tongue body in the occlusion phase of [m], as compared with [l, n, r], the articulators have been able to move more or less equally towards the target position of [a].

3. Summary

[m] is a bilabial nasal. During the articulation of [m] the tongue approaches its position for a neutral vowel. The Q1 [m] and Q2 [m] differ mainly in their duration, whereas the Q3 [m] is characterized by the most tense articulation (the highest speed of the formation of the labial closure, the greatest tenseness and duration of the closure, the strongest deviation of the tongue position from the target of the neighbouring [a]). The intensity maximum of the labial closure is achieved before the medial temporal phase of [m]; in the final part of the occlusion phase of [m] the intensity of the labial closure decreases.

In view of these circumstances the quantity degrees of the bilabial nasal may be treated in the following manner: the sound in the 1st degree of quantity is a simple /m/; in the 2nd degree of quantity it is a geminate /mm/ beginning with a lax syllable-final component; and in the 3rd degree of quantity a geminate /mm/ beginning with a tense syllable-final component.

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[12] B. E. F. Lindblom, Temporal Organization of Syllable Production. — Royal Institute of Technology (Stockholm). Speech Transmission Laboratory, Quarterly Progress and Status Report 1968 2—3, pp. 1—5; D. K. Oller, The Effect of Position-in-Utterance and Word-Length on Speech Segment Duration, Preprint 1970.

АРВО ЭЭК (Таллин)

АРТИКУЛЯЦИЯ ЭСТОНСКИХ СОНОРНЫХ СОГЛАСНЫХ. IV. [m]

[m] — билабиальный носовой согласный. Чем выше степень долготы [m], тем больше площадь губного контакта и с тем большей интенсивностью образуется губная смычка. Максимальная интенсивность лабиальной смычки во всех степенях долготы достигается еще до временно́й срединной фазы [m], ослабление смычки начинается после временно́й срединной фазы [m].

При произношении билабиальных согласных язык следует артикуляции соседних гласных. В данном случае, когда [m] окружен гласными [a], естественно было бы ожидать движения лишь в сторону [a]. Однако фактически вместо ожидаемого движения в сторону [a] кульминации смычки сопутствует движение в противоположном направлении (подъем средней части спинки языка к твердому нёбу, отдаление корня языка от задней стенки глотки). Эти движения начинаются еще в конечном переходе гласного, предшествующего [m], и продолжаются вплоть до временно́й срединной фазы [m]. Описанные движения в направлении, противоположном [a], зарегистрированы только в фазе смыкания [m] третьей степени долготы, тогда как в словах первой и второй степени долготы соответствующие движения осуществляются в продолжение конечного перехода предшествующего [a], так что в фазе смыкания [m] движение языка минимально. Представляется, что при произношении (особенно в слове третьей степени долготы) мышцы языка также находятся в напряженном состоянии и язык принимает уклад индифферентного гласного (во всяком случае, уклад языка — более передний и высокий, чем при артикуляции [a]).

Данные, полученные относительно артикуляции интервокальных билабиальных носовых, позволяют предположить, что с наибольшим напряжением артикулируется [m] в третьей степени долготы (тесная коартикуляторная связь между согласным в начале слова и последующим гласным, максимальная скорость образования лабиальной смычки, максимальная интенсивность смычки, максимальное отклонение от места образования соседнего гласного [a], максимальная длительность).

Учитывая эти факты, степени долготы билабиальных носовых можно интерпретировать следующим образом: первая степень — /m/, вторая степень — гемината /mm̥/ с заканчивающим слог ненапряженным компонентом, третья степень — гемината /mm/ с заканчивающим слог напряженным компонентом.