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ARVO EEK (Tallinn)

SOME COARTICULATION EFFECTS IN ESTONIAN

Speech production is likely to consist in the rearrangement of a limited number of memorized units. So far, little can be said about the size of these units on the neurophysiological level. Until possibilities will be found for a direct examination of brain processes we can only make use of indirect information from the movements of articulators and from changes in muscle biopotentials.

In what follows coarticulation phenomena within and between words will be described on the basis of Estonian examples as pronounced by 2—3 informants. The experimental material was obtained by the complex methods of lateral cinefluorography and of the filming of lip articulations, synchronized with sound spectrography and oscillography (filming speed for both procedures 50 frames/s).[1] Cinefluorograms were drawn frame by frame. A coordinate system was designed for the measurement of roentgenograms, bearing in mind the demand that the system should follow as closely as possible the shape of the vocal tract and the movement of articulators, and that it also should allow a comparison of the measurement data obtained from various informants.[2]

If the hypothesis be accepted that on a certain control level of the central nervous system such instructions are communicated to the effectors that characterize the syllable as a whole (simultaneously both the vowel and the consonant(s))[3], i. e. if a syllable is encoded as an integral set of articulatory movements, it is natural to expect that this is reflected on the articulatory level.

1. Let us scan the movements of articulators during the pronunciation of the syllables *pa-*, *pe-*, *pi-*, *po-*, *pu-*, *pü-*, each appearing in the first syllable of the second word of a sentence, the preceding word ending in [a]. After the culmination phase[4] of the final [a] of the first word

[1] For technical particulars, see Г. Лийв, А. Ээк, О проблемах экспериментального изучения динамики речеобразования: комплексная методика синхронизированного кинофлуорографирования и спектрографирования речи. — Eesti NSV Teaduste Akadeemia Toimetised. Bioloogia XVII 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.

[3] Л. Чистович *et al.*, Речь. Артикуляция и восприятие, Москва—Ленинград 1965; V. Fromkin, Speculations on Performance Models. — Journal of Linguistics IV 1968 1, pp. 47—68.

[4] The culmination phase of a vowel is now and henceforth described by the data from the last frame of the culmination phase, the next frame displaying already a measurable transition toward the articulation place of the following sound.

the lips start for the closing movement of the initial consonant of the following word. The transitions to *pu-*, *pü-* (less noticeably to *po-*) comprise a simultaneous lip protrusion gesture.[5] A little later, yet 1—3 frames before the implosion of [p], the tongue also begins to move toward the position of the vowel that comes after [p]. As early as the end of the occlusion phase of [p] the tongue has essentially reached the position of the next vowel (although less significantly movement toward the vowel is continued up to the culmination phase of the vowel). True, part of the changes in the vocal tract may be considered as concomitants of the upward movement of the mandible for lip closure; however, those changes are not big enough to explain all the narrowing of the oral cavity and the widening of the pharyngeal cavity in the syllables *pe-*, *pi-*, *pü-* or the rise of the postdorsum toward the velum and uvula in *pu-*.

The independence of the movement of the tongue during the formation of the closure for [p] is also reflected in the widening of the anterior part of the oral cavity and the narrowing of the pharyngeal cavity in the combinations *-i + pa-*, *pe-*, *po-*, *põ-*. Unlike the combinations *-a + p*V, however, movement toward the following vowel here begins later, normally just a frame before the implosion of [p] or even with the implosion frame. Yet by the end of the occlusion phase the tongue has essentially reached the position for the following vowel.

Thus data on the production of a *p*V-combination agree with the hypothesis of a syllabic production unit. However, during [p] only such movements of the vowel can take place that do not contradict the articulation of the consonant itself (closure vs openness of lips). In spite of the assumptions of various authors[6] the mechanism that orders in time antagonistic movements remains obscure.

The tongue is by far more restricted in movement toward the vowel when the following syllable-initial stops are [k] or [t] whose articulation causes a considerable deformation of the vowel contour. Nevertheless, here again (combinations *-a + ku-*, *-a + to-*) lip protrusion conditioned by labial vowels can be observed as early as the transition from [a] to the initial stop of the following word. The simultaneous articulation of the consonant and the vowel of a syllable is further evidenced by what we observe when comparing, for example, the changes in the vocal tract configuration during the occlusion phase of [k] in the combinations *-a + ka-* and *-a + ku-*. Namely, the last frame of the occlusion phase of [k] preceding [u], compared to that preceding [a], exhibits a strong protrusion of lips, a narrower mouth orifice and anterior part of the oral cavity, and an advanced velar closure.

2. Having found evidence of the partly simultaneous articulation of the consonant and the vowel within a syllable, we could also see that the articulatory organs are aware of the following syllable already when pronouncing the final vowel of the preceding syllable. In view of the inertia of speech organs, it can be assumed that neuro-motor commands for the production of the new syllable are received by the articulators at the latest during the culmination phase of the vowel of the preceding syllable, but probably even earlier.

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[5] Cf. R. Daniloff, K. Moll, Coarticulation of Lip Rounding. — Journal of Speech and Hearing Research XI 1968 4, pp. 707—721.

[6] Л. Чистович *et al.*, *op. cit.*, pp. 123—126; S. Öhman, Peripheral Motor Commands in Labial Articulation. — Royal Institute of Technology (Stockholm). Speech Transmission Laboratory, Quarterly Progress and Status Report 1967 4, pp. 43—44.

This can be shown by a comparison of the culmination phases of the word-final [a] preceding the combinations *p*V, *t*V, *k*V described above. The disyllabic word ending in that [a] have a structure C_1VC_2V where C_2 is [l, n, r] in three phonological degrees of quantity, whereas V = [a]. It is believed that the shape of the vocal tract in the culmination phase of the word-final [a] depends on both the preceding and the following consonant. In order to first determine the effect of the preceding consonant, let us examine such word pairs where the following CV-group is identical (e. g., *kana* + *ka-* — *sara* + *ka-*), thus excluding possible differences due to regressive coarticulation as described in Section 1. What remains different in the given example is the intervocalic consonants of *kana* and *sara*. The articulation of [r] is characterized by a certain degree of velarization and by a greater distance between the lips whereas [n] is in contrast produced with a strong develarization and a narrower lip aperture.[7] The same difference is preserved in the culmination phase of the final [a].

The inertial effect of the articulation of the preceding intervocalic sonorant on the unstressed final [a] grows with the degree of quantity of the sonorant, i. e. with the growing articulatory tension of the sonorant (incidentally, this regularity is also seen in consistent shortening of [a]). By way of an example, let us compare the word pairs *tala* + *ku-* and *talla* + *ka-*, with an opposition of an intervocalic [l] in the first degree of quantity and one in the third degree. The culmination phase of the [a] preceded by the sonorant in the first degree of quantity is pronounced with a wider oral cavity, a narrower pharyngeal cavity and a lower degree of the velarization characteristic of the Estonian [l]; in other words, [a] in this case has come closer to its so-called target position than when preceded by a sonorant in the third degree of quantity.

At the same time, a weak labialization of the word-final [a] in the word pair *tala* + *ku-* indicates the influence of the following syllable. The influence of the following syllable on the culmination phase of the [a] of the preceding syllable is likewise demonstrated by the examples *anna* + *ta*, *sarra* + *to-*, *talla* + *ka-* (in all these, the vowel is preceded by an alveolar sonorant in the third degree of quantity). If the following syllable begins with a [t], the predorsum never sinks so much as before a [k]. In addition to that, [a] before [k] is more velarized than otherwise [8].

Thus in the final analysis the shape of the vocal tract in the culmination phase of a vowel is determined by the complicated relations of the inertia of the articulators acting upon the transition from the preceding consonant to the vowel on the one hand and the preparation of the articulation of the next syllable on the other. Our chief interest in this section being the influence of a syllable on the preceding vowel, we have seen that the so-called target position characteristic of a vowel is attained, or, which is the same, the movement toward the target position is completed, in the culmination phase of the vowel with different success depending on the following syllable. Hence we can state that obviously the articulators are informed of the following syllable already at the beginning of the preceding vowel (i. e. before the culmination phase). But the proper articulation of the following syllable (to some extent simultaneous for the consonant and the vowel) as manifested

[7] A. Eek, Articulation of the Estonian Sonorant Consonants. I. [n] and [l]. — Eesti NSV Teaduste Akadeemia Toimetised. Ühiskonnateadused 19 1970 1, pp. 103—121.

[8] Cf. data in literature: Е. Лисенко, Артикуляторна динаміка і модифікація німецьких голосних фонем [a:] і [a]. — Вісник Київського університету. Серія іноземної філології 1969 3, pp. 89—99.

in measurable movements begins after the culmination phase of the vowel [9].

3. According to the hypothesis of L. Čistovič *et al.*, a Russian syllable on the articulatory level always ends in a vowel; consonant clusters occurring within words or arising on word boundaries are considered as wholly belonging to the beginning of the next syllable.[10] This hypothesis refuses to work when applied to interpret certain articulatory facts connected with the pronunciation of Estonian intervocalic sonorants occurring in three degrees of quantity. It is likely that an intervocalic sonorant in the second or third degree of quantity comprises a so-called geminate, each component of which belongs to a different syllable.

Here are a few data to support such an assumption. The words *tala*, *talla*, *talla* will serve as an example where each successive word contains an [l] of a successively higher degree of quantity. This growth of quantity of [l] is accompanied by a larger area of the linguopalatal contact, a narrower oral cavity, a wider pharyngeal cavity and *vestibulum laryngis*, a higher speed of articulators. The culmination phase of the sonorants in the second and the third degree of quantity is located temporally before or in the middle of their overall duration whereas toward the end of the sonorant a transition to the following vowel is observed. The culmination phase in the first degree of quantity is located temporally at the very end of the occlusion phase of [l]. Thus the first component of an intervocalic sonorant in the third degree of quantity is probably articulated with greater muscular effort. The vowel of the first (stressed) syllable of these words is pronounced with growing width of the anterior part of the oral cavity according to an increase in the degree of quantity of the following sonorant. In so far as it is [l], quite the opposite might be expected. Consistent differences are observed in the pronunciation of the initial stop [t] of the same words (namely the initial stop [t] of the third degree of quantity is articulated with a 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). We can only infer that a sonorant in the third degree of quantity is produced by a tenser articulation of not only its initial part but of the whole syllable preceding it, i. e. the feature of tenseness culminating on the sonorant seems to exert an organizing effect on the syllable as a whole.

Recalling now what we saw in Section 1, *viz.* that a consonant and a vowel following it are produced more or less simultaneously to form a syllable, it seems most appropriate to consider the overlong sonorant (in the third degree of quantity) as divided between the two syllables so that the tense beginning of it belongs to the first syllable and the end to the second. A similar division is to be recognized in the long consonant (in the second degree of quantity), with the difference that its first, syllable-final component is lax.

In case the articulatory tension of the syllable-final first component of a geminate sonorant is greater (in the third degree), the duration of the vowel of the following syllable shows regular decrease, presumably

[9] Compare these findings about regressive and progressive coarticulation with compatible data in: P. F. MacNeilage, J. L. DeClerk, On the Motor Control of Corticulation in CVC Monosyllables. — The Journal of the Acoustical Society of America 45 1969 5, pp. 1217—1233.

The influence of this kind of coarticulation on the locus frequency of consonants has been described by S. Öhman on the basis of spectral analysis: S. Öhman, Coarticulation in VCV Utterances: Spectrographic Measurements. — The Journal of the Acoustical Society of America 39 1966 1, pp. 151—168.

[10] Л. Чистович *et al.*, *op. cit.*, pp. 126—140.

due to concomitant greater inertia. No essential differences have been observed in the duration of the vowel of the first syllable. These circumstances point quite definitely to the existence of a phonetic structure involving the word as a whole; however, at the encoding level of articulation speech (a word) is presumably produced by syllables. (Speech production models operated by phonemic input units are inadequate to interpret some of the above phonetic facts.) A syllabic model does not exclude variation of articulatory syllable structures in various languages.

One of the possible ways for the establishment of syllable boundaries in case of intervocalic geminate consonants or consonant clusters could perhaps be in a study of such words where the geminates or clusters are surrounded by different vowels. It should be possible to ascertain the belonging of any one or all of the components of a geminate or a cluster to the preceding or the following syllable on the basis of which vowel is articulated simultaneously with that component, or, from another point of view [11], which vowel has clearer traces of movements for that consonant superimposed on its own articulation. This criterion has allowed us to draw the syllable borderline between the consonants in the word *pulgad* included in the corpus (besides, one informant pronounced it with no temporal overlap of the alveolar and the velar contact, whereas the other's implosion of [k] took place on the last frame of [l]).

АРВО ЭЭК (Таллин)

НЕКОТОРЫЕ КОАРТИКУЛЯТОРНЫЕ ЭФФЕКТЫ В ЭСТОНСКОМ ЯЗЫКЕ

На базе экспериментального материала, полученного при изучении артикуляции эстонского языка с помощью синхронизированного со спектрографией (осциллографией) латерального кинофлуорографирования и киносъемки движения губ, рассматриваются коартикуляторные явления внутри слова и на границе слов. При помощи покадрового измерения конфигурации речевого тракта и движения артикуляторов определяются участки влияния отдельных звуков.

Полученные данные не противоречат предположению о том, что слог кодируется как единый артикуляторный комплекс движений. Не исключено, что в разных языках артикуляторные слоговые конструкции различны. Форму речевого тракта в кульминационной фазе гласного определяют в конечном счете сложные отношения, с одной стороны, инерции артикуляторов при переходе от предыдущего согласного к гласному, с другой, подготовка артикуляции к следующему слогу. При этом артикуляторы информированы о следующем слоге, очевидно, уже в начале предыдущего гласного (до кульминационной фазы). Артикуляция же регистрируемыми движениями следующего слога (в определенной степени одновременная для согласного и гласного) начинается после кульминационной фазы гласного.

[11] Cf. S. Öhman, Numerical Model of Coarticulation. — The Journal of the Acoustical Society of America 41 1967 2, pp. 310—320.