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ON THE ACOUSTIC COMPOSITION OF ESTONIAN VOWELS OF THREE DEGREES OF LENGTH

G. LIIV

1. MATERIALS AND METHODS

Speech is not a sequence of sounds determined by a definite position of the organs of speech, but a flow of continuously changing speech elements. The constant interaction of movements belonging to different sounds as occurs during the production of connected discourse determines changes in the geometry of a cavity system. The latter changes are reflected in the acoustical signal as variations in the spectral composition.

What is usually regarded as the occurrence of a certain phoneme in a given word consists in reality of a whole series of qualitatively different elements. Although we do not very often notice the vicissitudinous construct of vowels, the data on the physical characteristics of the phenomenon are of prime importance in the successful mechanical recognition of speech.

The present work deals with the auditory, oscillographic and spectral analysis of the qualitative changes occurring during the phonation of Estonian stressed monophthongs of three phonological degrees of length. Particular attention has been paid to the acoustical characteristics of transitional segments, and the duration of separate segments has also been determined.

The vowels of three degrees of length have been investigated in dissyllabic words. The latter were pronounced by the informants not separately, but as identical portions of a sentence: as the first words of declarative affirmative sentences in the indicative mood that do not carry the logical sentence stress. Both syllables of the words studied were open. The vowels contrasted with regard to quantity occurred in completely identical consonantal environments in all three, i. e. the short, long and over-long degrees of length.

The vocabulary used in the sentences was the following (the Roman numbers denote the degree of quantity):

tiru 'gland', dial., *Nominative Sg.* — *tiiru* (II) 'circle', *Genitive Sg.* — *tiiru* (III) 'circle', *Partitive Sg.;*

keda 'whom' — *keeda* (II) 'boil', *Present Imperative, 2nd pers. Sg.* — *keeda* (III) 'boil', *Infinitive;*

püri 'strive', *Present Indicative Negative* — *kupüüri* (II) 'omission', *Gen. Sg.* — *kupüüri* (III) 'omission', *Part. Sg.;*

pöra 'noise', *Nom. Sg.* — *pööra* (II) 'toggle', *Gen. Sg.* — *pööra* (III) 'toggle', *Part. Sg.;*

käru 'hand-cart', *Nom. Sg.* — *kääru* (II) 'bend (in a river, etc)', *Gen. Sg.* — *kääru* (III) 'bend', *Part. Sg.;*

sama 'same', *Nom. Sg.* — *saama* (II) 'getting, acquiring', *Gen. Sg.* — *saama* (III) 'get', *Inf.;*

puri 'sail', *Nom. Sg.* — *puuri* (II) 'cage', *Gen. Sg.* — *puuri* (III) 'cage', *Illative Sg.;*

kosi 'ask in marriage', *Pres. Indic. Negat.* — *koosi* (II) 'course (of a ship)', *Gen. Sg.* — *koosi* (III) 'course', *Part. Sg.*;

mõdu 'mead (drink)', *Nom. Sg.* — *mõõdu* (II) 'measure', *Gen. Sg.* — *mõõdu* (III) 'influence', dial., *Pres. Indic. Negat.*[1]

The characteristic and transitional segments of vowels in three degrees of length have been subjected to auditory analysis on the basis of the pronunciation of five informants. Oscillographic recordings of the materials obtained from three speakers were used. Transitional segments in the pronunciation of four informants have been spectrographically analyzed. All informants speak perfect Standard Estonian with a Tallinn pronunciation and without any dialectal peculiarities. Subjects I, II and III are men; Subjects IV and V are women. The ages of the speakers range from 26 to 46. Speakers I and V have read the sentences right through silently, pronouncing aloud only the words being analyzed (i. e. the first words of the sentences). Although the speakers are very experienced radio announcers, the absolute lengths of the separate segments are somewhat longer (this is particularly true in the case of female Speaker V), the relative durations, however, being substantially the same. The other speakers have read out the sentences in full.[2]

The experiments were carried out in the Experimental Phonetics Laboratory of Leningrad State University in 1959.

The author is sincerely grateful to Prof. L. Zinder, L. Bondarko and L. Varshavski for their kind permission to use the apparatus as well as for their valuable advice during the compilation of the present paper.

The actual procedure used in the present investigation was the following. Tape-recorded speech was first subjected to auditory analysis by means of a *gating circuit* in order to determine the phonetic quality and duration of different vowel segments of relatively homogeneous quality occurring in stressed syllables of words contrasted as to their quantity. The results of auditory analysis were compared with changes in the general wave shape as revealed in oscillographic recordings on the basis of a rough visual estimate of the frequency composition of the vowels (recognition of the presence or absence of higher frequencies). A model МПО-2 *oscillograph*, a film speed of 2000 mm/sec, a vibrator with a fundamental frequency of 10,000 cps and time marker — 500 cps were used. The spectra of separate segments were obtained by means of a *L. F. Spectrometer*, model 74100-A, serial No. 22603, Standard Telephone & Cables Ltd., London, supplied with a set of third-octave filters. A frequency range of 100 cps to 10,000 cps was analyzed (the figures illustrating the present paper contain frequency spectra plotted only for 100 cps to 6400 cps). The changes in the spectral composition of vowels have also been observed in sonagrams and sections obtained by means of a *48-channel dynamic spectrograph* and its *sectioner*.[3] More than 300 spectra have been analyzed in connection with the problems discussed in this article.

The illustrations include a selection of the energy density spectra of the separate segments of allophones only in the third degree of length of all vowels (40 different spectra are given in the present paper). In the first and second degrees of length

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[1] In order to keep other conditions equal it was occasionally necessary to use a negative sentence. In the list of words analyzed only those meanings of polysemantic words have been given as occur in the sentences used in the course of the present investigation. The same principle has been observed in the presentation of word-forms.

[2] The above-mentioned speakers as well as their enumeration are the same as analyzed and presented in G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length. "Eesti NSV Teaduste Akadeemia Toimetised — Ühiskonnateaduste Seeria" ["Transactions of the Academy of Sciences of the Estonian S.S.R.", Series of Social Sciences], Tallinn, 1962, No. 1, pp. 63—97.

[3] The sonagrams may be found in G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length, Figs. II (Plate II), IV (Plate III), VI (Plate IV), VII (Plate V), IX (Plate VI), XI (Plate VII), XIII (Plate VIII), XV (Plate IX), XVII (Plate X).

the changes as regards their general trend are roughly analogous to those in the third degree, although qualitative heterogeneity is relatively somewhat smaller. In the figures the so-called characteristic segment has been marked with a continuous red line. Various types of black lines are used to denote the transitional segments between preceding consonants and characteristic segments. The transitional segments between characteristic segments and following consonants are marked with various kinds of green lines. The unfilled dots on the curves denote the centre frequencies of the filters.

The phonetic quality of separate segments has been recorded on the basis of auditory analysis in both the Fenno-Ugric phonetic alphabet and in that of the International Phonetic Association (the latter is given in round brackets). In the tables the characteristic segment of a vowel is printed in medium-faced type. The absolute duration of separate segments in milliseconds is indicated by a corresponding figure placed above the symbol for each segment.

At the end of the article the absolute and relative average durations are given of the characteristic segment and transitional segments in three degrees of phonological length.

Finally it should be noted that in the present work F'_1 is used to denote the summary energy concentration area formed by close F_1 and F_2, and F'_2 stands for the summary expression of close-located F_2 and F_3 (resp. of all higher formants) if they cannot be distinguished in a spectrogram due to the relatively broad band pass of the analyzing filters. Proceeding from a certain indeterminacy of spectrogram dimensions, in the present work the rise of a formant (resp. its lowering) is conditionally regarded as meaning both the shift of the peak of the reinforced band towards higher (resp. lower) frequencies as well as, for instance, the increase (resp. decrease) in the relative intensity of the adjacent components with a higher frequency or the decrease (resp. increase) in the relative intensity of the components with a lower frequency, which also indicates a certain shift in the concentration of energy.[4]

Notes on transcription

The phonological transcription employed in this work has been commented on in a previous article.[5] Phonetic phenomena have been represented in both the phonetic alphabet generally used in transcribing Fenno-Ugric languages (FUT)[6] as well as in the alphabet of the International Phonetic Association (IPA)[7].

In the present work the alphabets referred to have been supplemented as follows. It was found expedient to employ the following additional symbols in the Fenno-Ugric transcription: [a] denotes the corresponding front vowel, [ɑ] denotes the corresponding back vowel; [ω] is the symbol for the unrounded sound [o] (the same symbol is used with the same value for typographical reasons in the IPA alphabet); [ɯ] stands for an unrounded [u] (N. B. that it does not denote the central vowel [u], for which this symbol is used in some sources). The diacritic mark [˷] denotes a certain delabialization of the corresponding vowel. The degree of nasalization, labialization and delabialization is represented as follows: the smallest degree of the occurrence of the pertinent phenomenon is indicated by a corresponding diacritic mark placed to the right at the foot of the vowel symbol, a greater degree of the same phenomenon is designated by a corresponding mark

[4] For a more detailed account of materials, methods and principles, see G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length, esp. pp. 63—69.

[5] See G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length, p. 69.

[6] See E. N. Setälä, Über transskription der finnisch-ugrischen sprachen. "Finnisch-ugrische Forschungen" I, 1901, pp. 15—52; A. Sovijärvi, R. Peltola, Suomalais-ugrilainen tarkekirjoitus. Toinen painos. Helsinki, 1958; also see references to pertinent literature in A. J. Joki, Tarkekirjoituksemme yksinkertaistaminen. "Virittäjä" 1958, pp. 291—298.

[7] The Principles of the International Phonetic Association, London, 1949; Reprinted 1958.

to the right of the top of the symbol, the greatest degree is denoted by a diacritic mark in the middle above the vowel symbol. The same principle is employed to represent different degrees of nasalization in the IPA alphabet. In both the FUT and the IPA alphabet the use of the same diacritic mark twice indicates an especially conspicuous occurrence of the phenomenon concerned, e. g., [i̯̽] stands for an even fronter vowel than [i̯̽].[8]

2. RESULTS

Some Illustrations

A number of graphic examples are given in Figs. I—VI of changes occurring during phonation in the quality of Estonian vowels of different degrees of length.

Fig. I gives an oscillogram of Estonian over-long /o::/ as pronounced in the word /ˈko::śi/. The pronunciation of Subject I is represented in all the oscillograms contained in this article. An examination of the general wave shape reveals an instability of the picture of the periods. It appears to be possible in this connection to distinguish at least four fundamentally different parts of the curve: 1. [o̯] ([o̯]) — ca 35 msecs; 2. [o] ([o]) — 75 msecs; 3. [o̯] ([o–])* — 100 msecs; 4. [o̯˽] ([o̯‹–]) — 45 msecs.

Fig. II presents an oscillogram of Estonian long /o:/ in the word /ˈko:śi/. On the basis of visual estimation it is possible to distinguish four different parts of the curve: 1. [o̯] ([o̯]) — ca 35 msecs; 2. [o̯] ([o+]) — 75 msecs; 3. [o] ([o]) — 60 msecs; 4. [o˽] ([o‹]) — 50 msecs.

Fig. III gives an oscillogram of Estonian short /o/ pronounced in the word /ˈkośi/. There seem to be grounds for distinguishing three fundamentally different parts of the curve: 1. [o̯] ([o̯]) — ca 30 msecs; 2. [o̯] ([o+]) — 25 msecs; 3. [o̯̽] ([o̯̽]) — 45 msecs.[9]

Fig. IV represents an oscillogram of Estonian over-long /ü::/ in the word /kuˈpü::ri/. Visual estimation of the oscillographic curve shows that five separate segments may be distinguished here: 1. [ü̯°] ([y»+]) — ca 35 msecs; 2. [ü̯˳] ([y›]) — 50 msecs; 3. [ü̯] ([y–]) — 50 msecs; 4. [ü̯̽] ([y̆–]) — 70 msecs; 5. [ü̯̽˽] ([y̆‹–]) — 40 msecs.

Fig. V gives an oscillogram of Estonian long /ü:/ in the word /kuˈpü:ri/. In this case it seems to be possible to distinguish four fundamentally different portions of the curve: 1. [ü̯˳] ([y»+]) — ca 40 msecs; 2. [ü] ([y]) — 55 msecs; 3. [ü̯] ([y–]) — 40 msecs; 4. [ü̯̽˽] ([y̆‹–]) — 30 msecs.

Fig. VI gives an oscillogram of Estonian short /ü/ in the word /ˈpüri/. Three fundamentally different curve portions may be seen here: 1. [ü̯˳] ([y»+]) — ca 35 msecs; 2. [ü] ([y]) — 35 msecs; 3. [ü̯˽] ([y̆‹]) — 40 msecs.

The visual estimation of the general shape of the separate curve portions and their length, on the one hand, and the determination on the basis of auditory estimation of the quality and duration of segments isolated by a gating circuit, on the other hand, indicate in general that there is a correspondence between the objective and subjective observations referred to.

Results of Auditory Analysis

In order to provide a summary survey of the quality and duration of the separate segments of vowels in three phonological degrees of length, the data obtained are presented in the form of the tables 1—9.

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[8] The author would like to use this occasion to express his gratitude to V. Hallap of the Institute of Language and Literature, the Academy of Sciences of the Estonian S.S.R., for valuable discussions of problems pertaining to transcription.

* The so-called characteristic segment of a vowel is given in medium-faced type.

[9] Sonagrams of the same words as pronounced by the same subject can be found in G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length, Fig. XV (Plate IX).

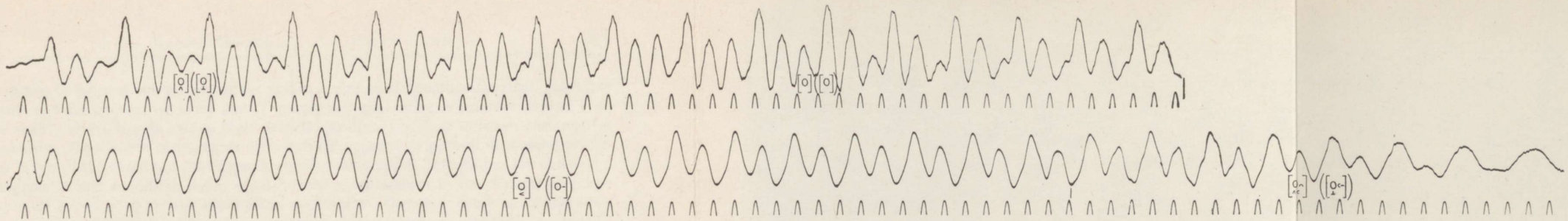

Fig. I. Oscillogram of Estonian over-long /o::/ in the word /ˈko::śi/.

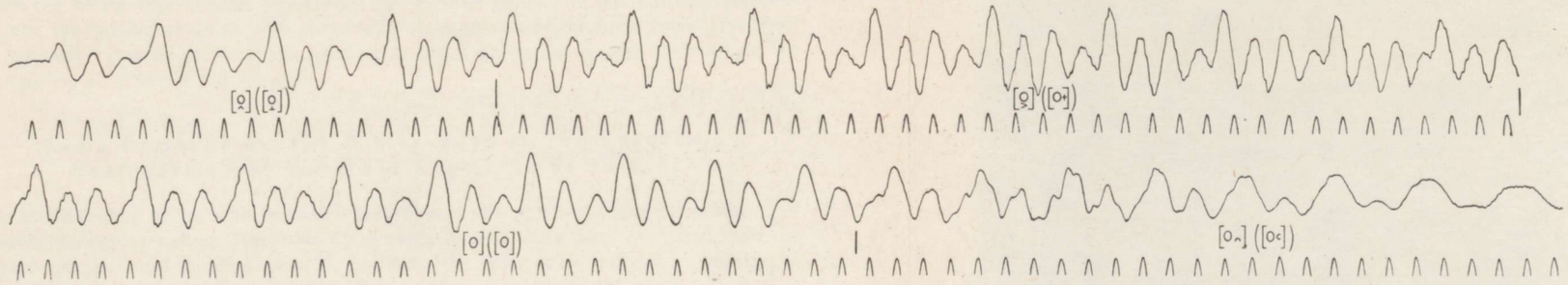

Fig. II. Oscillogram of Estonian long /o:/ in the word /ˈko:śi/.

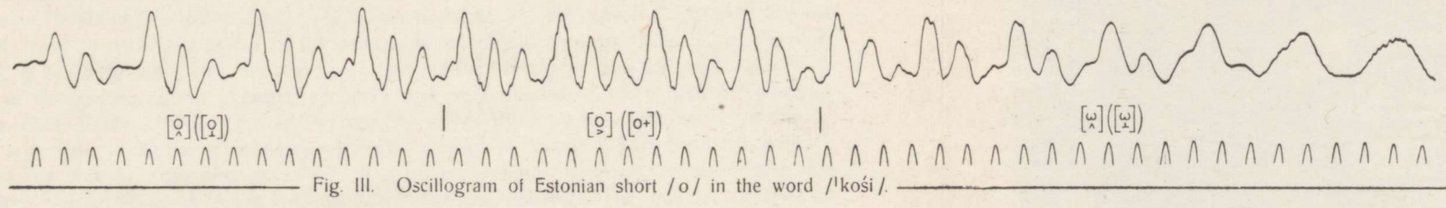

Fig. III. Oscillogram of Estonian short /o/ in the word /ˈkośi/.

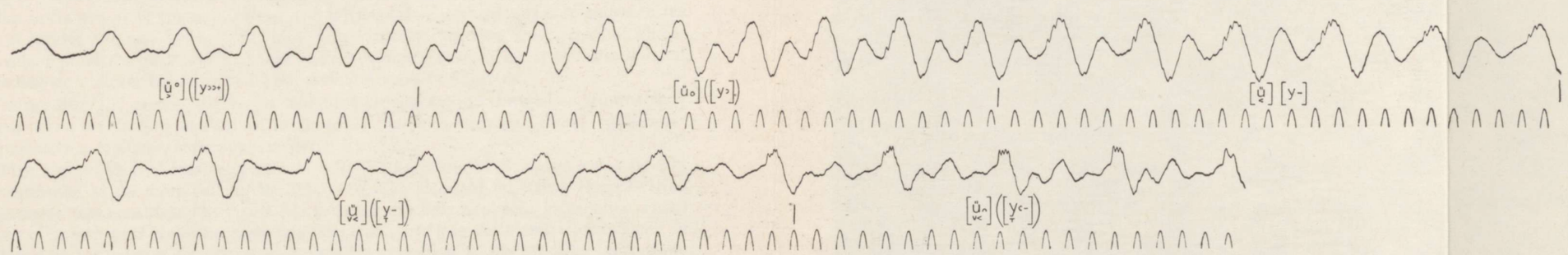

Fig. IV. Oscillogram of Estonian over-long /ü::/ in the word /kuˈpü::ri/.

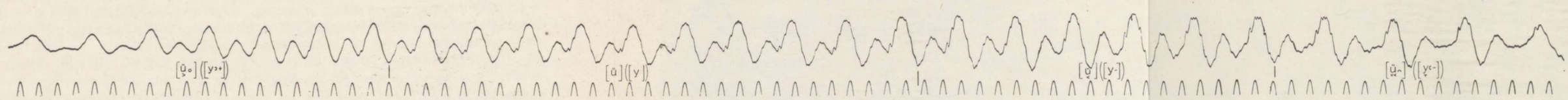

Fig. V. Oscillogram of Estonian long /ü:/ in the word /kuˈpü:ri/.

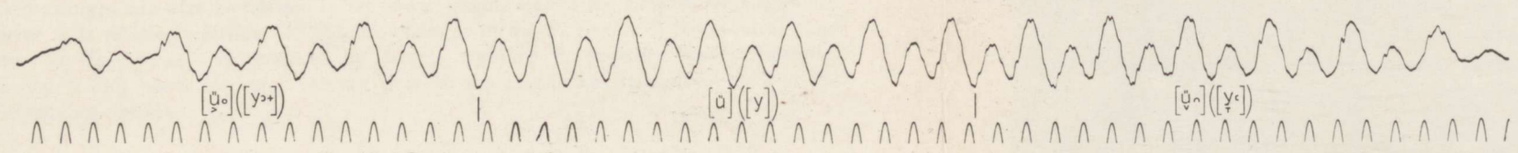

Fig. VI. Oscillogram of Estonian short /ü/ in the word /ˈpüri/.

All the oscillograms represent Subject I. Time marker — 500 cps.

It should be pointed out, on the whole, that the number of conditionally distinguishable segments and the general tendency and range of their qualitative differences depend both on the quality of the vowels and on their phonetic position, i. e. their different consonantal environments. The number of segments distinguished appears, in general, to depend on the degree to which the quality of the terminal elements of a vowel differs from the characteristic segment. Other conditions being equal, consistent differences in the changes of vowel quality must be recorded in their dependence on duration. Generally speaking, a lengthening of the degree of vowel length seems to be attended by a relatively greater heterogeneity of quality. Vowel quality appears to be the least stable in the third degree of length; it is here, on the whole, that one can distinguish the greatest number of qualitatively different segments; the qualitative differences of the separate segments of the same vowel also seem to be somewhat greater and one can likewise record a somewhat greater variation in the pronunciation of different individuals.

Some Remarks on the Differences in the Spectral Composition of Separate Segments of Vowels

In the following pages some examples are given of changes in the spectral composition of vowels during phonation. Transitional segments have usually been compared with the spectral composition of the characteristic segment (the latter is represented in the figures by a continuous red line); other comparisons are referred to additionally.

These specimens are in fairly good agreement with data obtained from other speakers. However, it should be pointed out that some elements in the spectral composition of vowels vary to a certain extent in the pronunciation of different speakers, a phenomenon which is in conformity with the results of the auditory analysis (see Tables 1—9). Thus, e.g., in the pronunciation of some speakers one may observe a more distinct lowering (resp. rise) of the first formant in the spectral composition of the plain acute vowels or their segments, while the expected rise (resp. lowering) of certain higher formants is more vague (or may be altogether missing); with other speakers, however, more considerable changes can be observed in the last-mentioned spectral elements. The spectral analysis of the flat acute vowels or the segments with a different degree of labialization shows in the case of certain speakers, on the one hand, a considerable lowering (resp. rise) of higher formants, and on the other hand, a more distinct lowering (resp. rise) of the first formant depending on a closer labialization (resp. certain delabialization), etc.

In the first and second degrees of length of the vowels the changes as regards their general trend are roughly analogous to those in the third degree, although qualitative heterogeneity is relatively somewhat smaller.

Fig. 1 gives energy density spectra of different segments of Estonian over-long /i::/ as pronounced in the word /ˈti::ru/ by Subject V. The principal difference characterizing the elements that constitute this vowel lies in an increasingly advanced articulation as the organs of speech pass from the preceding consonant towards the culminational phase of the vowel and a relative retractedness during the transition to the following consonant. An acoustical consequence of the articulatory changes first mentioned appears to be primarily a shift towards relatively higher frequencies of the energy concentration region located in the upper part of the spectrum (F'_2). The frequencies of the peaks here are located at about 3600 cps, 4000 cps and 5000 cps respectively in the spectral composition of the lst segment [i̯] ([i̯]), the 2nd segment [i̯] ([i̯+]) and the 3rd segment [i̯] ([i̯++]). The auditory impression of the relatively more retracted and the more open articulation produced by the 4th segment [i̯] ([i̯−]) is probably due to a very marked drop in intensity in the 3200—5000 cps frequency band, the peak here shifting to the proximity of 2500 cps. Certain changes can also be noticed in the lower frequencies of the spectra. On the whole, however, it is relatively difficult to observe changes in the F_1 region of the spectral composition of close vowels as produced by female Speaker V, because the fundamental frequency of this speaker's voice is very near to the resonance frequency of F_1 in the corresponding vowels.

In Fig. 2 are presented energy density spectra of different segments of Estonian over-long /e::/ in the word /ˈke::ta/ as pronounced by Subject I (a male voice with an average

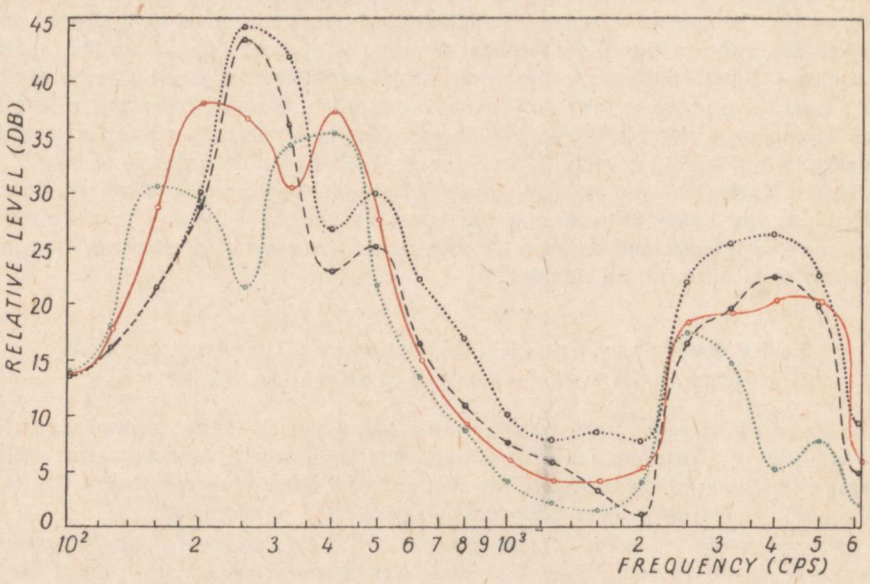

Fig. 1. Energy density spectra of different segments of Estonian over-long /i::/ in the word /ˈti::ru/, Subject V. ····· 1st segment [i̯] ([i̯]) of 90 msecs duration, - - - - 2nd segment [i̯] ([i̯+]) of 110 msecs duration; —— 3rd segment [i̯] ([i̯+]) of 110 msecs duration; ····· 4th segment [i̯] ([i̯-]) of 60 msecs duration

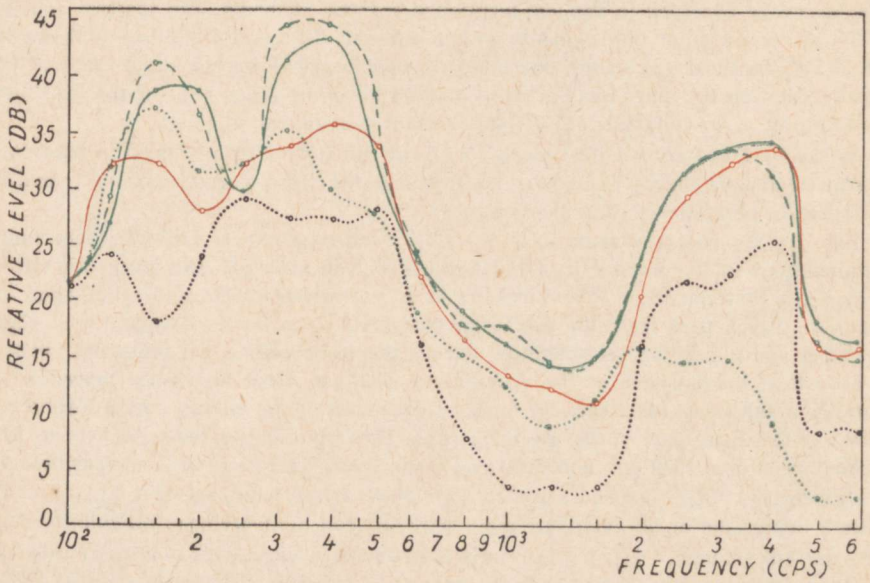

Fig. 2. Energy density spectra of different segments of Estonian over-long /e::/ in the word /ˈke::ta/, Subject I, ····· 1st segment [i̯] ([i̯]) of 50 msecs duration; —— 2nd segment [ė] ([e̯]) of 70 msecs duration, —— 3rd segment [e̯] ([e+]) of 60 msecs duration; - - - 4th segment [i̯] ([i̯]) of 90 msecs duration; ····· 5th segment [i̯] ([i-]) of 40 msecs duration.

TABLE 1

Subject	Estonian over-long /i::/ in the word /ˈti::ru/
I	30 i(i) — 50 i(i+) — 60 i(i+)* — 70 i(i) — 40 i(i-)
II	40 i(i) — 130 i(i) — 80 i(i) — 40 i(i-)
III	30 i(i) — 50 i(i+) — 50 i(i+) — 60 i(i-)
V	90 i(i) — 110 i(i+) — 110 i(i+) — 60 i(i-)

Subject	Estonian long /i:/ in the word /ˈti:ru/
II	40 i(i+) — 70 i(i) — 30 i(i-)
III	30 i(i) — 40 i(i) — 40 i(i-)
IV	40 i(i+) — 70 i(i) — 40 i(i-) — 30 i(i-)
V	40 i(i+) — 80 i(i) — 80 i(i) — 30 i(i)

Subject	Estonian short /i/ in the word /ˈtiru/
I	30 i(i) — 50 i(i) — 30 i(i-)
II	30 i(i) — 40 i(i) — 40 i(i-)
III	30 i(i) — 40 i(i)
IV	30 i(i+) — 30 i(i) — 50 i(i-)
V	30 i(i+) — 40 i(i) — 30 i(i-)

TABLE 2

Subject	Estonian over-long /e::/ in the word /ˈke::ta/
I	50 e(e) — 70 e(e) — 60 e(e+) — 90 e(e) — 40 e(e-)
II	40 e(e-) — 40 e(e) — 90 e(e) — 30 e(e) — 30 e(e-)
III	30 e(e-) — 30 e(e) — 90 e(e+) — 70 e(e) — 30 e(e-)
IV	40 e(e-) — 40 e(e) — 50 e(e) — 40 e(e) — 30 e(ë+)
V	50 e(e-) — 90 e(e) — 120 e(e) — 120 e(e) — 40 e(e) — 40 e(e)

Subject	Estonian long /e:/ in the word /ˈke:ta/
I	50 e(e) — 70 e(e) — 90 e(e-)
II	40 e(e-) — 60 e(e) — 40 e(e) — 50 e(e-)
III	30 e(e-) — 30 e(e) — 60 e(e+) — 40 e(e)
IV	40 e(e-) — 50 e(e) — 40 e(e) — 40 e(e-)
V	30 e(e-) — 60 e(e) — 60 e(e) — 60 e(e) — 30 e(e)

Subject	Estonian short /e/ in the word /ˈketa/
I	30 e(e) — 40 e(e) — 50 e(ɛ-)
II	30 e(e-) — 40 e(e) — 30 e(ë+)
III	30 e(e) — 30 e(e) — 20 e(e-)
IV	30 e(e) — 40 e(e)
V	30 e(e-) — 30 e(e) — 30 e(e) — 30 e(e)

TABLE 3

Subject	Estonian over-long /ü::/ in the word /kuˈpü::ri/
I	35 ü*(y»+) — 50 ü∘(y›) — 50 ü(y-) — 70 ü(y-) — 40 ü∩(yᶜ-)
II	40 ü∘(y›+) — 60 ü(y) — 30 ü∩(yᶜ)
III	40 ü*(y») — 50 ü∘(y›+) — 70 ü(y) — 50 ü∩(yᶜ-)
IV	50 ü∘(y›) — 60 ü(y) — 40 ü∩(yᶜ-) — 30 i∘(i›-) — 30 i(iˇ-)
V	60 ü∘(y›) — 100 ü(y+) — 100 ü(y) — 70 ü∩(yᶜ)

Subject	Estonian long /ü:/ in the word /kuˈpü:ri/
I	40 ü∘(y›+) — 55 ü(y) — 40 ü(y-) — 30 ü∩(yᶜ-)
II	30 ü∘(y›) — 40 ü(y) — 30 ü∩(yᶜ)
IV	40 ü∘(y›) — 70 ü(y) — 40 i∘(i›-)
V	40 ü∘(y›) — 80 ü(y) — 70 ü(y) — 60 ü∩(yᶜ-)

Subject	Estonian short /ü/ in the word /ˈpüri/
I	35 ü∘(y›+) — 35 ü(y) — 40 ü∩(yᶜ)
III	30 ü∘(y›) — 40 ü(y) — 30 ü∩(yᶜ)
IV	30 ü∘(y›) — 30 ü(y) — 30 e∘(e›-)
V	50 ü∘(y›) — 70 ü(y) — 30 i∘(i›-)

TABLE 4

Subject	Estonian over-long /ö::/ in the word /ˈpö::ra/
I	30 ö(ɣ) — 80 ø∘(ɸ›) — 80 ø(ɸ-) — 70 ɐ∘(ë›)
II	30 ö(ɣ) — 70 ö(ɸ) — 70 ø∩(ɸᶜ) — 50 øˆ(ɸᶜᶜ-) — 30 ø̂(ɛ›-)
III	30 ö(ɣ) — 70 ö∘(ɸ›) — 40 ø̃(ɸ̃) — 40 ø(ɸ-) — 40 ø∩(ɸᶜ-)
IV	50 ü(y) — 70 ö(ɸ) — 50 ɐ(e-)
V	60 ü∘(y›) — 120 ö(ɸ) — 100 ø(ɸ) — 50 o∩(ɸᶜ) — 30 i∘(i›-)

Subject	Estonian long /ö:/ in the word /ˈpö:ra/
I	30 ö(ɣ) — 40 ø̃(ɸ+) — 40 ø(ɸ) — 40 o∩(oᶜ+) — 50 ɐ(ë)
II	60 ü(y) — 70 ö(ɸ) — 70 ø∩(ɸᶜ-)
III	40 ü(y) — 80 ö(ɸ) — 40 ø∩(ɸᶜ-)
IV	40 ü(y) — 80 ö(ɸ) — 40 ø(ɸ+) — 30 ɛ(ɛ)
V	40 ü(y) — 70 ö(ɸ) — 40 ɐ(ë+) — 30 ɛ(ɛ)

Subject	Estonian short /ö/ in the word /ˈpöra/
I	30 ö(ɣ) — 50 ö(ɸ) — 30 ø∩(ɸᶜ-)
II	30 o∘(ɸ›) — 60 ö(ɸ) — 40 ø∩(ɸᶜ-)
III	40 ø̃∘(ɸ̃›) — 50 ö(ɸ) — 40 ø∩(ɸᶜ-)
IV	30 ü∩(yᶜ) — 50 ö(ɸ) — 50 ɛ∘(ɛ›)
V	30 ö(ɣ) — 40 ö(ɸ) — 40 ø∩(ɸᶜ)

* Note. In all the tables the characteristic segment of the corresponding vowel is given in medium-faced type.

TABLE 5

Subject	Estonian over-long /ä::/ in the word /ˈkä::ru/						
I	ɛ̯~ⁱa(ɛ+~ⁱa) 50	— æ(æ̯) 50	— ä̯(æ̯) 60	— æ(æ̯) 30	— ɛ(ɛ) 50	— e(e) 50	
II	e̯(e̯) 30	— ɛ(ɛ) 30	— ä̯(æ̯) 70	— æ(æ) 40	— æ̯(æ̯-) 30		
III		e(e) 40	— ä̯(æ̯) 50	— ä(æ) 70	— ɛ₀(ɛɔ) 50		
IV		ɛ̯(ɛ-) 40	— ä̯(æ̯) 70	— æ(æ̯) 60	— e̯(e-) 40		
V		ɛ̯(ɛ̯) 40	— ä̯(æ̯-) 60	— ä̯(æ+) 90	— æ(æ̯) 50	ɛ(ɛ) 60 — e(e) 40	— e̯(e-) 45

Subject	Estonian long /ä:/ in the word /ˈkä:ru/				
I	ɛ̯~ⁱa(ɛ+~ⁱa) 40	— æ(æ̯) 40	— ä(æ) 70	— æ(æ̯) 50	
II		e(e) 30	— ä(æ) 60	— æ(æ̯) 50	
III		e̯(e̯) 30	— ä(æ) 50	— æ(æ̯) 50	— ɛ₀(ɛɔ) 40
IV		ɛ̯(ɛ-) 40	— ä(æ) 40	— æ(æ̯) 50	— ɛ̯(ɛ̯-) 50
V		ɛ̯(ɛ-) 40	— ä(æ) 110	— æ(æ̯) 40	— ɛ̯(ɛ-) 40

Subject	Estonian short /ä/ in the word /ˈkäru/			
I		ɛ̯(ɛ+) 30	— ä(æ) 50	— æ(æ̯) 30
II		e̯(e̯) 30	— ä(æ) 40	— æ(æ̯) 30
III		e̯(e̯) 30	— ä(æ) 30	— æ(æ̯) 30 — ɛ₀(ɛɔ) 30
IV		ɛ̯(ɛ-) 30	— ä(æ) 30	— ɛ̯(ɛ̯) 30
V		e̯(e-) 30	— ä(æ) 50	— æ(æ̯) 30 — e̯₀(e̯ɔ) 30

TABLE 6

Subject	Estonian over-long /a::/ in the word /ˈsa::ma/				
I	ɛ̯(ɛ̯) 30	— a(a) 50	— a~(a~) 60	— a~(a~) 70	— ɜ̃(ɜ̃) 50
II		ɛ̯(ɛ-) 40	— a(a) 100	— a~(a~) 60	— ɜ̃(ɜ̃) 40
III	ɛ(ɛ) 30	— a̯(a+) 50	— a~(a~) 50	— ã₀(ã ɔ) 50	
IV	a̯(a+) 30	— a(a) 40	— a~(a~) 50	— a~(a~) 40	— ɜ̃(ɜ̃) 30
V	a̯(a+) 30	— a(a) 70	— a~(a~) 80	— a~(a~) 40	— ɜ̃(ɜ̃) 60

Subject	Estonian long /a:/ in the word /ˈsa:ma/			
I		ɛ̯(ɛ-) 30	— a(a) 40	— a̯~(a≃) 50 — ã°(ã») 50
II		ɛ̯(ɛ-) 30	— a(a) 40	— a~(a~) 50 — a̯~(a≃) 40
III		a̯(a+) 30	— a(a) 50	— a~(a~) 40 — ɜ̃(ɜ̃+) 30
IV		a̯(a+) 30	— a(a) 60	— a~(a~) 40 — ɜ̃(ɜ̃) 50
V		a̯(a+) 40	— a(a) 70	— a̯~(a≃) 30 — ã°(ã») 40

Subject	Estonian short /a/ in the word /ˈsama/			
I		a̯(a+) 30	— a(a) 30	— a≃(a≃) 30
II		ɛ̯(ɛ-) 30	— a(a) 30	— ɔ~(ɔ~) 30
III		ɛ̯(ɛ̯) 30	— a(a) 30	— a≃(a»~) 30
IV		a̯(a+) 30	— a(a) 30	— ɔ~(ɔ~) 30
V		a̯(a+) 40	— a(a) 40	— a≃(a≃~) 40

TABLE 7

Subject	Estonian over-long /u::/ in the word /ˈpu::ri/				
I	u₀(uɔ) 50	— u̯(u̯) 50	— u̯(u-) 120	— u∩(uc-) 60	— ɯ̯(ɯ̯) 30
II	u₀(uɔ) 40	— u(u) 40	— u(u-) 40	— u̯(u̯) 40	— u̯∩(u̯c) 40
III	u₀(uɔ) 30	— u̯(u̯) 40	— u(u-) 60	— u̯∩(u̯c) 50	
IV	u₀(uɔ) 40	— u̯(u̯) 60	— u(u-) 60	— ɯ(ɯ) 40	
V	u₀(uɔ) 60	— u(u) 50	— u̯(u̯-) 100	— u(u) 70	— ɯ(ɯ) 30

Subject	Estonian long /u:/ in the word /ˈpu:ri/			
I		u̯(u̯+) 30	— u(u) 50	— u̯(u̯) 50 — u̯∩(u̯c+) 30
II		u₀(uɔ) 30	— u(u) 40	— u̯∩(u̯c) 40
III		u₀(uɔ) 40	— u(u) 60	— u̯∩(u̯c) 40
IV		u₀(uɔ) 40	— u(u) 40	— u̯∩(u̯c) 40
V		u₀(uɔ) 50	— u(u) 110	— ɯ̯(ɯ̯) 30

Subject	Estonian short /u/ in the word /ˈpuri/			
I		u₀(uɔ) 40	— u̯(u+) 40	— u̯∩(u̯c) 30
II		u₀(uɔ) 30	— u(u) 40	— ɯ₀(ɯɔ) 30
III		u₀(uɔ) 30	— u(u) 40	
IV		u₀(uɔ) 30	— u(u) 30	— u̯∩(u̯c) 20
V		u₀(uɔ) 40	— u(u) 40	— u̯∩(uc+) 30

TABLE 8

Subject	Estonian over-long /o::/ in the word /ˈko::śi/
I	35 o(o) — 75 o(o) — 100 o(o-) — 45 o∩(o<-)
II	70 o(o-) — 130 o(o-) — 70 ω(ω)
III	40 o(o-) — 100 o(o-) — 30 o(o) — 30 ω(ω)
IV	30 o(o-) — 60 o(o-) — 30 ω(ω) — 40 ω(ω)
V	40 o∩(o<-) — 100 o(o-) — 70 o(o-) — 100 o(o) — 30 ω(ω+)

Subject	Estonian long /o:/ in the word /ˈko:śi/
I	35 o(o) — 75 o(o+) — 60 o(o) — 50 o∩(o<)
II	70 o(o-) — 60 o(o) — 40 ω(ω+)
III	40 o(o-) — 80 o(o) — 30 ω(ω+)
IV	30 o(o-) — 70 o(o) — 30 o∩(o<+) — 40 ω(ω+)
V	40 o∩(o<-) — 70 o(o-) — 60 o(o) — 40 o(o+) — 30 ω(ω+)

Subject	Estonian short /o/ in the word /ˈkośi/
I	30 o(o) — 25 o(o+) — 45 ω(ω)
II	30 o(o-) — 30 o(o) — 30 ω(ω) — 20 ω(ω+)
III	30 o(o-) — 30 o(o+) — 30 ω(ω+)
IV	30 o(o-) — 30 o(o) — 30 ω(ω+)
V	40 o∩(o<-) — 70 o(o) — 40 o(o+) — 50 ω(ω+)

TABLE 9

Subject	Estonian over-long /õ::/ in the word /ˈmõ::tu/
I	50 ë∘(ë>+) — 70 ë(ë-) — 70 ë(ë-) — 70 ë(ë) — 70 ë(ë+)
II	40 ɔ̃(ɔ̃) — 60 ë~(ë~) — 70 ë(ë) — 100 ë(ë-)
III	50 ë∘(ë>) — 100 ë(ë-) — 30 ë(ë) — 30 ë(ë+)
IV	30 ë∘(ë>) — 50 ë~(ë~) — 50 ë(ë) — 50 ë(ë-) — 60 ë∘(ë>+)
V	50 ë∘(ë>) — 70 ë~(ë~) — 100 ë(ë-) — 70 ë(ë) — 70 ë(ë) — 40 ë(ë+)

Subject	Estonian long /õ:/ in the word /ˈmõ:tu/
I	40 ë∘(ë>) — 60 ë~(ë~) — 60 ë(ë) — 50 ë(ë+)
II	30 ë∘(ë>) — 70 ë~(ë~) — 50 ë(ë+)
III	40 ë∘(ë>) — 60 ë(ë) — 30 ë(ë+)
IV	50 ë∘(ë>) — 70 ë(ë) — 50 ë(ë+) — 30 ë(ë+)
V	60 ë∘(ë>) — 100 ë~(ë~) — 50 ë(ë+) — 40 ë(ë+)

Subject	Estonian short /õ/ in the word /ˈmõtu/
I	30 ë∘(ë>) — 30 ë(ë) — 30 ë(ë+)
II	30 ë∘(ë>) — 40 ë(ë) — 40 ë(ë)
III	30 ë∘(ë>) — 30 ë(ë) — 40 ë(ë+)
IV	30 ë∘(ë>) — 30 ë(ë) — 30 ë(ë+)
V	40 ũ(ũ) — 60 ë(ë) — 40 ë(ë+)

fundamental pitch). The principal difference in the quality of separate segments which it was possible to record on the basis of auditory impressions in this case was a variation in the degree of closeness of articulation. In comparison with the characteristic segment [e̝] ([e̞]) the spectral composition of the initial transitional segment [i̝] ([i̝]) shows a greater concentration of energy at relatively lower frequencies in the F_1 region (the peak shifts from about 400 cps to 250 cps); the peak of F'_2 at about 4000 cps is also somewhat more conspicuous (the rate of decay towards lower frequencies is greater). The auditory impression of a relatively more open articulation of the 3rd segment [e̞] ([e+]) is probably due to a marked fall in intensity in the 250 cps region, which is somewhat reinforced in the case of [e̝] ([e̞]); thus, relatively more energy would appear to be concentrated in a narrower and higher frequency band in the F_1 region. The *i*-like shade of the following segment [i̞] ([i̞]) appears to be due to a lower position of F_1 in comparison with the *e*-like segments. The greater closeness of the 5th segment [i̝] ([i–]) as compared with the preceding element is probably indicated by the even lower position of F_1 (shift of the peak from about 360 cps to 320 cps), the impression of retractedness being probably caused by a perceptible lowering of F'_2.

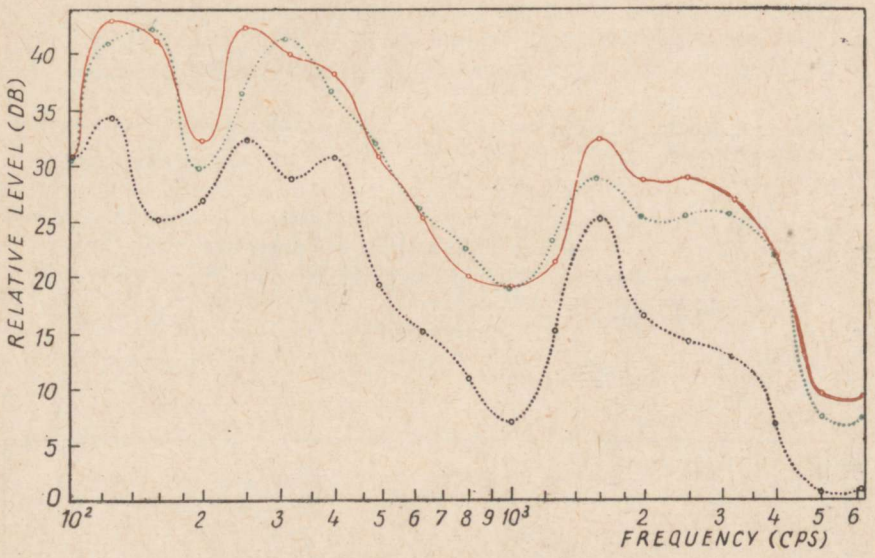

Fig. 3. Energy density spectra of different segments of Estonian over-long /ü::/ in the word /ku'pü::ri/. Subject II. ····· 1st segment [ü̞] ([y›+]) of 40 msecs duration; —— 2nd segment [ü] ([y]) of 60 msecs duration, ····· 3rd segment [ü̝] ([y̝‹]) of 30 msecs duration.

Fig. 3 gives energy density spectra of different segments of Estonian over-long /ü::/ in the word /ku'pü::ri/ as pronounced by Subject II (low bass voice). This vowel begins with an over-rounded element [ü̞] ([y›]). An acoustical consequence of the closer and more active labialization is the suppression of intensity in the higher frequencies (the band 2000—4000 cps). During the transition from the characteristic segment [ü] ([y]) to the following consonant, a weak unrounding of the element [ü̝] ([y̝‹]) (accompanied by a slightly more open degree of articulation) appears to be matched on the acoustical level by a rise in F_1; the peak shifting from about 250 cps in the case of [ü] ([y]) to about 320 cps in that of [ü̝] ([y̝‹]).

In Fig. 4 are presented energy density spectra of different segments of Estonian over-long /ö::/ in the word /'pö::ra/ as pronounced by Subject II. The transition [ö̝] ([ø̝])

from the preceding consonant to the characteristic segment is characterized by a closer degree of labialization than it is usual for [ö] ([ø]) as well as by a somewhat closer articulation (in comparison with the characteristic segment). An acoustical correlate of the closer labialization is probably the very considerable lowering of F'_2 (note the conspicuously

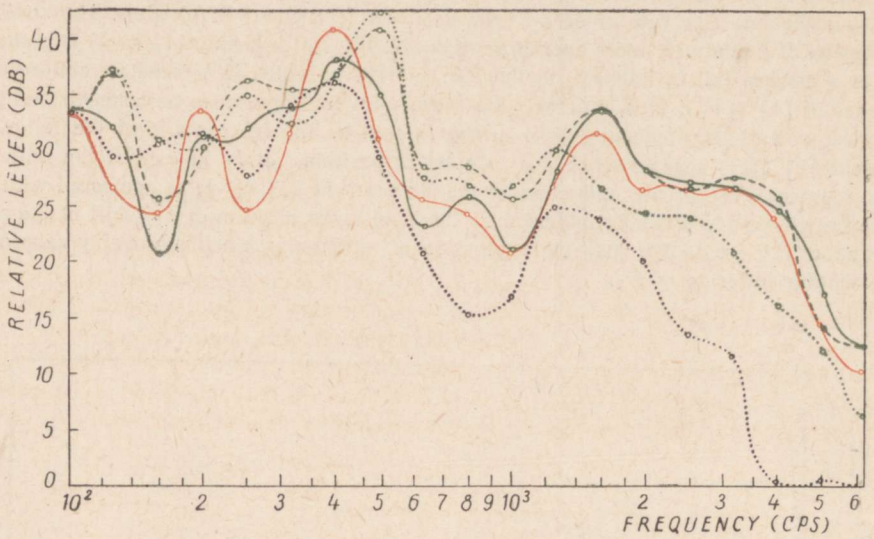

Fig. 4. Energy density spectra of different segments of Estonian over-long /ö::/ in the word /ˈpö::ra/. Subject II. ····· 1st segment [ü̯] ([y̯]) of 30 msecs duration; —— 2nd segment [ö] ([ø]) of 70 msecs duration; ——— 3rd segment [ö̯ˀ] ([ø̯ˁ]) of 70 msecs duration; – – – 4th segment [ö̯ˆ] ([ø̯ˁˁ]) of 50 msecs duration; ····· 5th segment [ɔ̯̂] ([ɛɔ̯]) of 30 msecs duration.

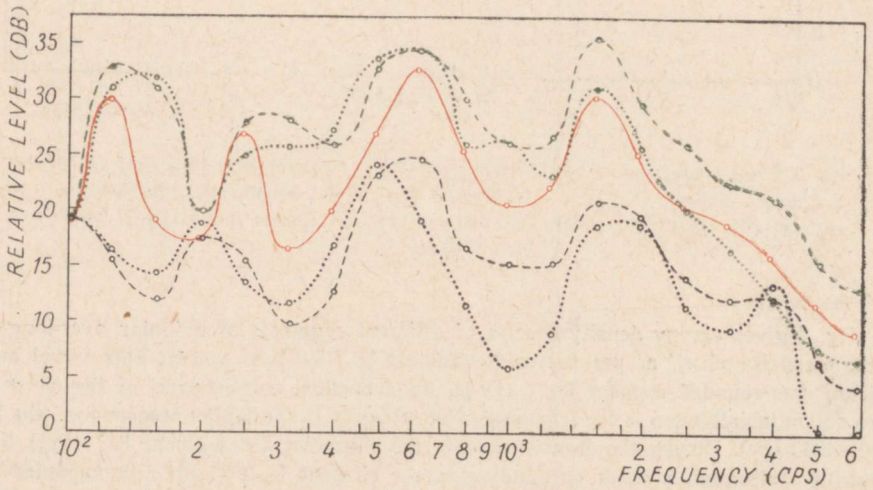

Fig. 5. Energy density spectra of different segments of Estonian over-long /ä::/ in the word /ˈkä::ru/. Subject II. ····· 1st segment [e̯] ([e̯]) of 30 msecs duration; – – – 2nd segment [ɛ] ([ɛ]) of 30 msecs duration; —— 3rd segment [ä̯] ([æ̯]) of 70 msecs duration; – – – 4th segment [æ] ([æ̝]) of 40 msecs duration. ····· 5th segment [æ̯] ([æ̯˗]) of 30 msecs duration.

greater rate of decay in the 2000—4000 cps band); the more active labialization and the greater closeness of articulation may likewise be responsible for the relatively greater reinforcement of the lower frequencies in the F_1 region. The auditory impression of the comparatively more open and slightly unrounded 3rd segment [ö̜˷] ([ø̜˷]) may be caused by the relatively greater intensity of the frequencies at about 500 cps in the F_1 region. The increasing delabialization of the vowel during the following segment [ö̜˄] ([ø̜‹–]) possibly leads to an increase in F_1, the acoustical consequence of a somewhat retracted articulation may be a somewhat greater intensity of the relatively lower frequencies (below 1800 cps) in the F'_2 region. The even more retracted articulation which is noticeable immediately during the transition from the vowel to the following consonant — 5th segment [ö̜̂] ([ɛ›–]) — probably causes the F'_2 region to shift towards lower frequencies.

Fig. 5 presents energy density spectra of different segments of Estonian over-long /ä::/ as pronounced by Subject II in the word /ˈkä::ru/. The articulation of this vowel is characterized by a movement of the organs of speech from a relatively close and front position in the initial portion of the vowel towards extreme openness in the culminational phase of phonation; this being followed again by a narrowing of articulation during the transition to the following consonant (with a supplementary shade of somewhat retracted articulation in the final portion of the vowel). These changes in the cavity system are matched by the following changes in the spectral distribution of acoustic energy. In the case of the 1st segment [e̜] ([e̜]) F_1 is the lowest and F'_2 the highest, the *e*-like quality of the segment being indicated also by the reinforcement region at about 4000 cps. In the

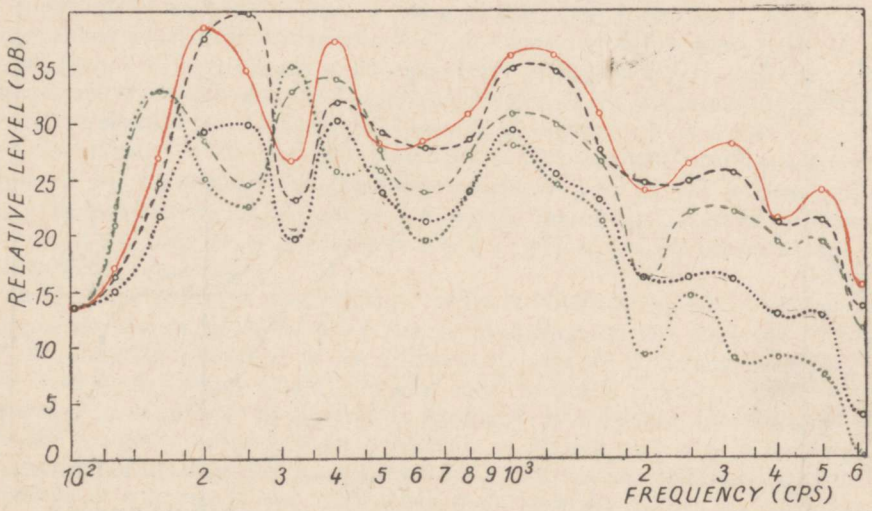

Fig. 6. Energy density spectra of different segments of Estonian over-long /a::/ in the word /ˈsa::ma/. Subject V. ····· 1st segment [a̜˷] ([a̜˷]) of 50 msecs duration; ----2nd segment [a] ([a]) of 70 msecs duration; —— 3rd segment [ɑ˷] ([ɑ˷]) of 80 msecs duration; – – – 4th segment [ɑ˜] ([ɑ˜]) of 40 msecs duration; ·–·–·–· 5th segment [ɔ̄] ([ɔ̄]) of 60 msecs duration.

spectral composition of the 2nd segment [ɛ̜] ([ɛ]) F_1 increases and F'_2 decreases (in comparison with the preceding segment). In the case of the characteristic segment [ä̜] ([æ̜]) the interval between F_1 and F'_2 is relatively the smallest. In the following segment [æ] ([æ̜]) F_1 decreases again and the intensity level of F'_2 grows. The spectral composition of the final transitional segment [æ̜] ([æ–]) shows a further decrease in the F_1 region and a fall in the relative intensity of the F'_2 region (it is possible that in the case of the last

two segments the auditory impression of their more advanced and retracted articulations respectively, may be connected with the respectively greater and lesser intensity levels of the F'_2 region).

In Fig. 6 are presented energy density spectra of different segments of Estonian over-long /a::/ in the word /ˈsa::ma/ as pronounced by Subject V. The initial transition of this vowel from the preceding consonant is characterized from the articulatory aspect by a relative closeness and advanced character, the auditory impression of its quality is approximately that of [a̟] ([a̟+]); as regards its acoustical aspect, the initial segment has a relatively low F'_1 (at about 1000 cps in this pronunciation). The relatively somewhat more open and less advanced articulation of the 2nd segment [a] ([a]) is probably matched by the greater concentration of energy in the relatively higher frequencies (in the proximity of 1280 cps) of the F'_1 region. The articulatory features of the 3rd segment [ɑ˷] ([ɑ˷]), 4th segment [ɑ̃] ([ɑ̃]), and 5th segment [ɔ̃] ([ɔ̃]) of this vowel are the location of the narrowest supra-laryngeal stricture within the pharynx and the gradual narrowing of this constriction. These features are matched on the acoustical level by a fall in the intensity of higher frequencies in the F'_1 region (cf., e. g., the relative intensity at about 1280 cps with the level of the peak of the formant region in the spectral composition of the 3rd, 4th and 5th segments respectively).

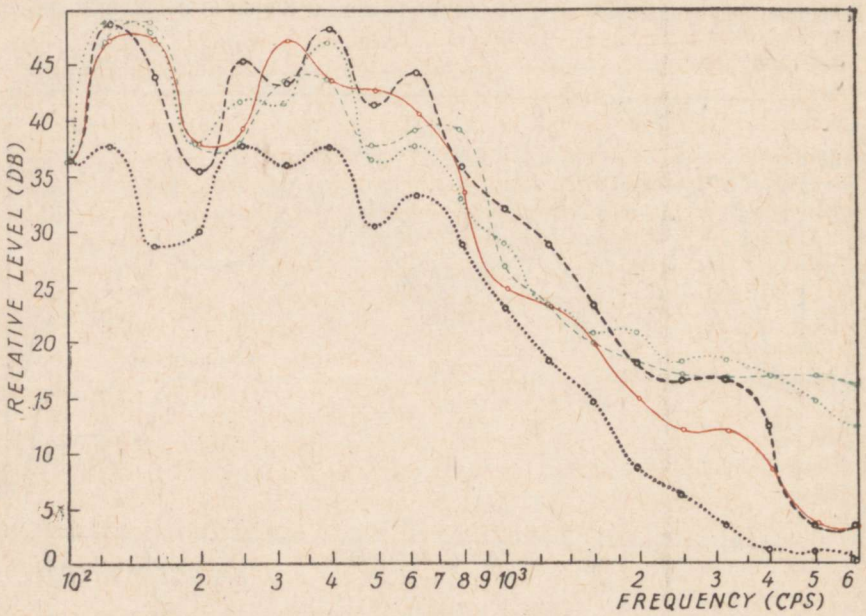

Fig. 7. Energy density spectra of different segments of Estonian over-long /u::/ in the word /ˈpu::ri/. Subject II. ····· 1st segment [uₒ] ([uₒ]) of 40 msecs duration; ---- 2nd segment [u] ([u]) of 40 msecs duration; —— 3rd segment [u̯] ([u̯-]) of 40 msecs duration; – – – 4th segment [u̯] ([u̯]) of 40 msecs duration; ····· 5th segment [u̯˷] ([u̯ᵉ]) of 40 msecs duration.

It is of special interest in this connection to observe the possible acoustical correlates of nasalization. An acoustical consequence of the widening of the velic stricture, i. e. of the coupling of the nasal, oral and pharyngeal cavities, seems to be the occurrence of a supplementary so-called nasal "formant" (at about 320—400 cps in the case of the given pronunciation). The intensity of this nasal "formant" increases and the intensity of the F'_1 region decreases with an increase in the degree of nasalization (cf. the change in the

relationship of the relative intensity of these formants in the spectral composition of the 3rd, 4th and 5th segments respectively). [A certain reinforcement at about 400 cps in the case of [a̰] ([a̰+]) and [a] ([a]) is probably merely a reinforced 2nd harmonic (note that its relative intensity is smaller than the intensity levels of both the fundamental pitch and the F'_1 region) which is present quite consistently in the case of vowels with a relatively more open articulation. One is led to the tentative assumption that this fact may also be connected in some way with the incompleteness of the velic closure present in the production of open vowels.[10] This may or may not be the case.] It is also noteworthy that, in distinction from unnasalized segments, nasalized segments have a more conspicuous supplementary reinforcement likewise in the proximity of 2500—3200 cps (note that the relative intensity of the peak of this region in comparison with the dip at about 2000 cps is higher in the case of the more nasalized 4th and 5th segments than in that of the 3rd segment).

A broadening of the reinforced F'_1 region towards relatively lower frequencies in connection with nasalization has also been recorded in some cases when the same word was pronounced by different speakers.

Fig. 7 gives energy density spectra of different segments of Estonian over-long /u::/ in the word /ˈpu::ri/ as pronounced by Subject II. The vowel begins with an over-rounded element [u◦] ([u›]); it is the smaller lip orifice that probably causes a decrease in F_1: the peak of this resonance region is located at about 250 cps, whereas in the case of the characteristic segment [u̯] ([u̯–]) it is at about 320 cps. As regards its tongue-position, hearing this initial segment in isolation produces the impression of a relatively more open narrowest stricture and of a somewhat more advanced articulation (in comparison with the characteristic segment). It may be assumed that these articulatory features have as their principal correlate the occurrence of F_2 as a separate reinforcement region at about 640 cps (F_2 and F_1 have merged in the case of the characteristic segment). The relatively higher F_1 and F_2 occurring in the spectral composition of the 2nd segment [u̯] ([u̯]) are probably responsible for the auditory impression of a relatively more open and more advanced articulation. The acoustical correlates of the somewhat more advanced articulation of the 4th segment [u̯] ([u̯]) (in comparison with the characteristic segment) seem to be the relatively higher position of F_1 and F_2. The certain amount of delabialization observed in the case of final transition [u̯~] ([u̯‹]) apparently causes a shift of F_1 towards higher frequencies.

In Fig. 8 are presented energy density spectra of different segments of Estonian over-long /o::/ as pronounced in the word /ˈko::ši/ by Subject II. The transition [o̯] ([o̯–]) from the preceding consonant to the characteristic segment is characterized by a relatively closer (and possibly also a somewhat more retracted) articulation, the acoustical consequence of which may be observed in the Figure as a notable shift of the F_2 region (500—800 cps band) to the immediate proximity of F_1, and also as a relatively greater reinforcement of the lower frequency components of the F_1 region. It is possible that the delabialization recorded on the basis of auditory impression during the transition [ω] ([ω]) from the characteristic segment to the following consonant is represented in the spectrogram by a perceptible increase in F_2: the peak occurs here at about 800 cps as compared with 640 cps in the case of the characteristic segment.

Fig. 9 presents energy density spectra of different segments of Estonian over-long /õ::/ in the word /ˈmõ::tu/ as pronounced by Subject I. The most probable acoustical correlate of the nasality of the initial transitional segment [ẽ◦] ([ẽ›+]) of this vowel is the noticeable reinforcement at about 320 cps; an additional reason for that may be a certain labialization of the transitional sound. It is possible that an acoustical consequence

[10] For details of the occurrence of this articulatory feature, see G. Liiv, On Qualitative Features of Estonian Stressed Monophthongs of Three Phonological Degrees of Length. "Eesti NSV Teaduste Akadeemia Toimetised — Ühiskonnateaduste Seeria" ["Transactions of the Academy of Sciences of the Estonian S.S.R.", Series of Social Sciences], Tallinn, 1961, Nos. 1, 2, pp. 41—66, 113—131.

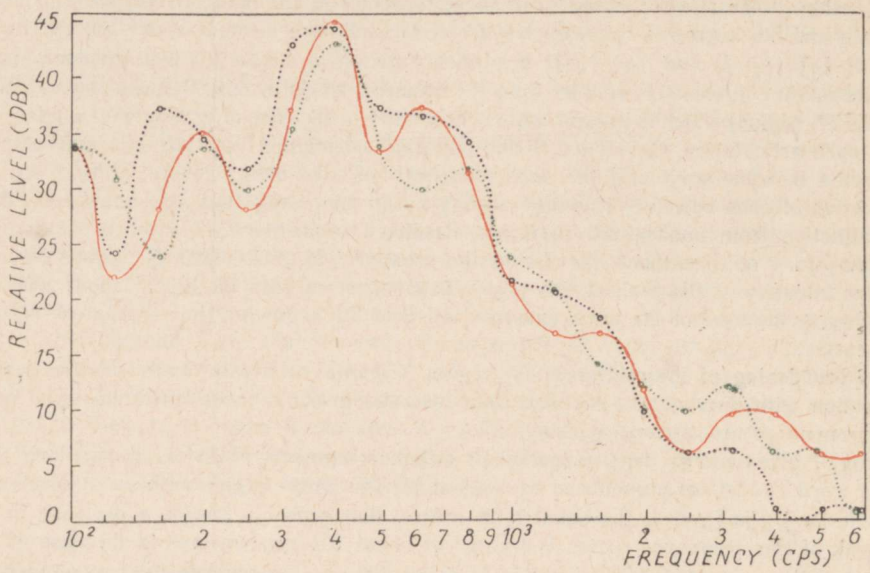

Fig. 8. Energy density spectra of different segments of Estonian over-long /o::/ in the word /ˈko::si/. Subject II. ····· 1st segment [o̝] ([o̝-]) of 70 msecs duration; —— 2nd segment [o̞] ([o̞-]) of 130 msecs duration; ····· 3rd segment [ω̝] ([ω]) of 70 msecs duration.

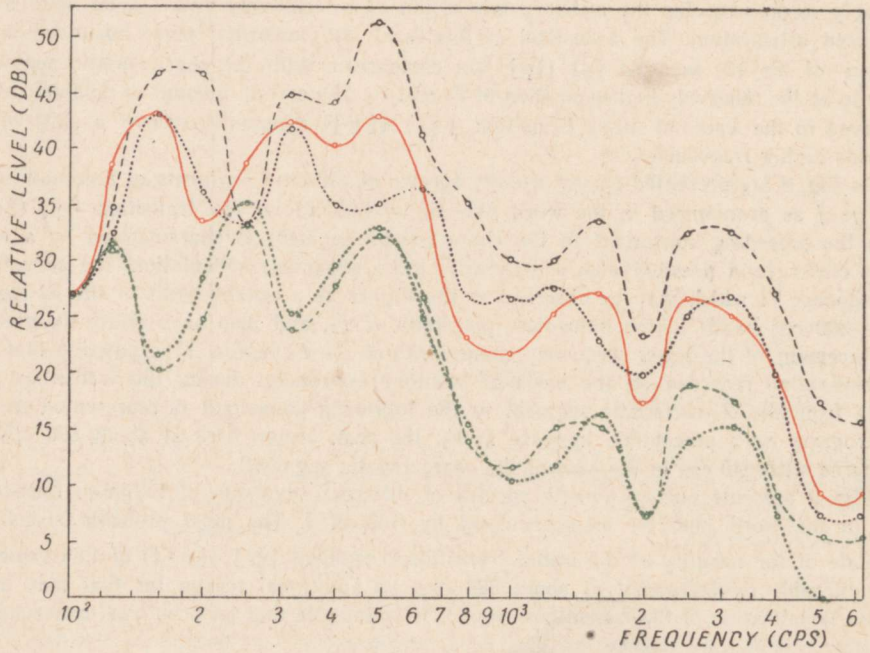

Fig. 9. Energy density spectra of different segments of Estonian over-long /õ::/ in the word /ˈmõ::tu/. Subject I ····· 1st segment [e̝ₒ] ([ẽ>+]) of 50 msecs duration; - - - 2nd segment [e̝] ([ẽ-]) of 70 msecs duration; —— 3rd segment [e̞] ([ẽ-]) of 70 msecs duration; — — — 4th segment [e̞] ([ë]) of 70 msecs duration; ····· 5th segment [e̝] ([ë+]) of 70 msecs duration.

of labialization may be seen in the decrease of F_2: the peak occurring here in the proximity of 1280 cps as compared with about 1600 cps in the case of the characteristic segment [e̯] ([e̞–]). The relatively more advanced placement of the tongue may be responsible for the higher position of F_3: the peak of this reinforcement region is at about 3200 cps in comparison with about 2500 cps for the characteristic segment. The auditory impression of the somewhat more open phonation of the 2nd segment [e̯] ([ë–]) is probably due to a relatively higher position of F_1: the peak occurs here at about 500 cps, the weighted average of the visible maxima occurring at 320 cps and 500 cps in the spectrum envelope of the characteristic segment, however, is about 416 cps. It is possible that the greater reinforcement of the relatively higher components of the F_3 region indicates a somewhat less retracted articulation in comparison with that of the characteristic segment. The auditory impression produced by a relatively more open articulation of the 4th segment [e̯] ([ë]) can probably be attributed to the relatively higher position of F_1 at about 500 cps (it is possible that a certain reinforcement at about 250 cps in the case of the 4th and 5th segments is merely a reinforced 2nd harmonic). The shift of F_2 and F_3 towards relatively higher frequencies is probably an acoustical correlate of the more advanced articulation recorded as the result of the auditory estimation of the final transitional segment [e̯] ([ë+]).[11]

The Duration of the Characteristic Segment and Transitional Segments of Vowels in Different Degrees of Length

The average absolute duration of the characteristic segment is about 40 msecs in vowels of the first degree of length, 63 msecs in vowels of the second degree and 77 msecs in vowels of the third degree. Consequently, the ratio between the average absolute durations of the characteristic segments of vowels of the first, second and third degrees is 1.00 : 1.58 : 1.93; the ratio of the corresponding durations of the characteristic segments of vowels of the second and third degrees is 1.00 : 1.22. The duration of the characteristic segment constitutes, on the average, 37% of the total duration of vowels of the first degree of length, 36% of the total duration of vowels of the second degree and 31% of the duration of vowels of the third degree. Thus, the relative duration of the characteristic segment in vowels of the first and second degrees of length is approximately the same, decreasing, however, in the case of vowels of the third degree.

The average absolute durations of the transitional segments between preceding consonants and the characteristic segments are about 32 msecs in vowels of the first degree of length, 53 msecs in vowels of the second degree and 75 msecs in vowels of the third degree. The ratio of the average absolute durations of the transitional segments referred to in the case of vowels of the first, second and third degrees of length is 1.00 : 1.66 : 2.34. In vowels of the second and third degrees of length the ratio of the corresponding transitional segments is 1.00 : 1.42. The duration of the transitional segments between a preceding consonant and the characteristic segment represents 31% of the total duration of a first-degree vowel, 30% of that of a vowel in the second degree and 30% likewise of the duration of a vowel in the third degree of length. Hence the relative duration of the transitional segments mentioned is approximately the same in all three degrees of length.

The average absolute durations of transitional segments occurring between a characteristic segment and a following consonant are: 35 msecs in vowels of the first degree of length, 63 msecs in vowels of the second degree and 104 msecs in vowels of the third degree. The ratio of the average absolute durations of such transitional segments in vowels of the first, second and third degrees of length is 1.00 : 1.80 : 2.97; the ratio of the corresponding transitional segments in vowels of the second and third degrees of length is 1.00 : 1.65. Thus the increase in the absolute duration of transitional segments between

[11] The continuous spectral display of the changes in the quality of the same vowel in the pronunciation of the same speaker is given in G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length, Fig. XVII (Plate X).

the characteristic segment and a following consonant in the longer degrees of length of vowels is markedly greater than the corresponding increase in the absolute duration of transitional segments that come between a preceding consonant and the characteristic segment. This difference is especially striking if one compares vowels of the second and third degrees of length. The average duration of the transitional segments between the characteristic segment and a following consonant constitutes 32% of the total duration of vowels of the first degree of length, 35% of that of vowels of the second degree and 39% of the total duration of third-degree vowels. Thus the relative duration of the transitional segments referred to grows with an increase in the degree of length of vowels (see Fig. 10 illustrating the above-mentioned facts).

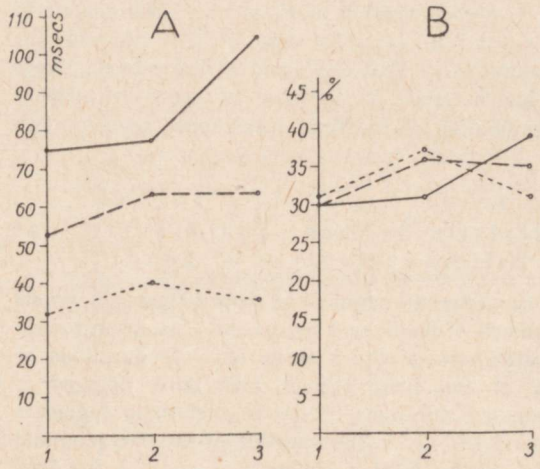

Fig. 10. Average absolute durations (A) and relative durations (B) of the characteristic segment and the transitional segments of vowels in different degrees of length.

A continuous line —— denotes over-long vowels, a broken line - - - stands for long vowels, and a dotted line . . . for short vowels. The ordinate denotes the absolute duration in milliseconds or the relative duration in percentage respectively. 1 — duration of transitional segments occurring between preceding consonants and the characteristic segments; 2 — duration of the characteristic segments; 3 — duration of transitional segments between the characteristic segments and following consonants.

The data presented above suggest that there is a comparatively loose (open) contact in the longer degrees of length. This difference seems to be most prominent between vowels of the second and third degrees of length. The evidence proves once again a relatively greater heterogeneity of the acoustic composition of vowels in the third degree of length.

3. SUMMARY

The auditory, oscillographic and spectral analysis of experimental language material has shown convincingly that the characteristic segments of stressed vowels in three phonological degrees of length also possess regular qualitative distinctions [12] which are in agreement with articulatory data obtained in the course of a series of experiments involving röntgenography, palatography and the filming of the external organs of speech.[13]

[12] In the present article the qualitative differences of the characteristic segments of vowels have largely been neglected in transcription. Transitional segments have been compared, above all, with the characteristic segments of the corresponding vowels and, consequently, the addition of diacritic marks to all symbols representing the characteristic segments would have rendered the transcription even more complicated (on the whole it has not been considered expedient to use different symbols to designate allophones in different degrees of length).

[13] For acoustical data on the qualitative differences of the characteristic segments of vowels in three degrees of length as well as on the acoustical features of isolated vowels, see G. Liiv, Acoustical Features of Estonian Vowels Pronounced in Isolation and in Three Phonological Degrees of Length. "Eesti NSV Teaduste Akadeemia Toimetised — Ühiskonnateaduste Seeria" ["Transactions of the Academy of Sciences of the Estonian S.S.R.", Series of Social Sciences], Tallinn, 1962, No. 1, pp. 63—97. An articula-

From the point of view of the phonological system, however, the differences in quality of vowels in different degrees of length are considered to be primarily concomitant phonetic phenomena that do not play a decisive role in the perception of the corresponding degrees of quantity.

In a brief summary of the analysis of the quantity of Estonian vowels [14], it should be reiterated that the average figures for the absolute duration of Estonian vowels in stressed (first) syllables are: first degree of length — 118.8 msecs, second degree of length — 204.4 msecs, and third degree of length — 240.4 msecs (each of these figures being the average of about 300 measurements). The ratios of the absolute average durations of the degrees of length in vowels of stressed syllables are as follows: 1.00 : 1.72 : 2.02 in the case of the first, second and third degrees of length; 1.00 : 1.18 in the case of the second and third degrees. The length contrasts given in earlier investigations based on measurements of words pronounced in isolation are evidently much exaggerated. The duration of a vowel in an unstressed (second) syllable is in inverse proportion to the duration of a vowel in a stressed syllable, whereas the total duration of the words (of the same structure) is approximately the same in all the three degrees of quantity. The average absolute duration of the vowel in a second syllable is 162.9 msecs in words of Quantity 1, 127.1 msecs in words of Quantity 2 and 93.1 msecs in words of Quantity 3. One may thus speak of three phonetical lengths of second-syllable vowels. Statistical data show that the mean values given are wholly reliable as regards the different durations of vowels in both stressed and unstressed syllables.[15]

The three degrees of quantity in Estonian are attended by different kinds of pitch patterns. Different pitch patterns in different degrees of duration do not play, however, a decisive role in the perception of the corresponding degrees of quantity, consequently, they have no phonological relevance. This is confirmed above all by

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tory analysis of vowels of different degrees of length is given in G. Liiv, On Qualitative Features of Estonian Stressed Monophthongs of Three Phonological Degrees of Length. "Eesti NSV Teaduste Akadeemia Toimetised — Uhiskonnateaduste Seeria" ["Transactions of the Academy of Sciences of the Estonian S.S.R.", Series of Social Sciences], Tallinn, 1961, Nos. 1, 2, pp. 41—66, 113—131.

[14] An analysis of the durational differences of the three degrees of length and the accompanying pitch patterns may be found in G. Liiv, Eesti keele kolme vältusastme vokaalide kestus ja meloodiatüübid [The Duration and Pitch Patterns of Estonian Vowels of Three Degrees of Length]. "Keel ja Kirjandus" ["Language and Literature"], Tallinn, 1961, Nos. 7, 8, pp. 412—424, 480—490.

[15] As the variation dispersions of the durations in stressed vowels of the second and third degrees of length do not differ essentially ($F = \frac{\sigma^2_{t_1}}{\sigma^2_{t_2}} \approx 1.08$), there were grounds for doubting whether the results of the series of observations referred to constitute two independent series or whether there is variation of one and the same phenomenon. It therefore proved necessary to compare the arithmetical averages of these series of observations by means of the Student t-test. Since in this case

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{\Sigma(x_{1i} - \bar{x}_1)^2 + \Sigma(x_{2i} - \bar{x}_2)^2}{n_1 + n_2 - 2}}} \cdot \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 10.9,$$

where $\bar{x}_1$ is the arithmetical mean of the first series of observations (of the durations of vowels of the second degree of length); $\bar{x}_2$ — the arithmetical mean of the second series of observations (of the durations of vowels of the third degree of length); x_{1_i} — the value of the i-th observation of the first series; x_{2i} — the value of the i-th observation of the second series; n_1 — the number of observations in the first series; n_2 — the number of observations in the second series; — consequently the arithmetical means of the series differ essentially. As the dispersions of all the other series of observations already differ considerably from one another, there is no need to compare their arithmetical means.

auditory tests where a definite pitch pattern when changing durational relations is not an insurmountable obstacle in identifying a word with a shortened vowel as being of a different degree of quantity than the original word. A further corroboration of the same is the relatively greater variation of pitch patterns.

One may also assume that the differing contact between vowel and following consonant [tight (close)/loose (open) contact] plays a certain role in distinguishing first and foremost the second and third degrees of quantity. This opinion is corroborated by the facts mentioned above in this paper as well as by a series of other observations: auditory tests, approximately the same duration of vowels in the third degree of length before stops and spirants, some visual observations from the sonagrams, kymographic and oscillographic curves, certain evidence of a relatively consistent and conspicuous drop in intensity in the last portion of third-degree vowels.

From the point of view of the perception of the quantity of a word the ratio of the duration of the vowel in the stressed syllable to that of the vowel in the unstressed syllable appears to be the most significant feature. The ratio of the average durations of vowels in stressed and unstressed syllables is approximately 0.73 : 1.00 in the first degree of quantity of words (the mean value of the ratios of single measurements is 0.75 : 1.00); 1.60 : 1.00 in the second degree (the mean value of single measurements is 1.58 : 1.00) and 2.58 : 1.00 in the third degree (the mean value of the ratios of single measurements is 2.76 : 1.00). It is obvious that the ratios for the durations of vowels in stressed and unstressed syllables of different degrees of quantity contrast much more markedly than do the durations of vowels in stressed syllables alone. This seems to suggest the greater importance of such contrasts in the process of the perception of different degrees of quantity. This opinion is corroborated by auditory tests, where possible changes have been observed in the perception of degrees of quantity under different conditions when certain segments of vowels in stressed or unstressed syllables were removed from a magnetic tape by gating out, thus reducing the vowel durations. A further corroboration of the same is the relatively smaller variation of these ratios (this is true with regard to both the mean values of observations as well as the ratios of single measurements).[16] From the point of view of language structure it is interesting to note in this connection that there are no ternary quantitative appositions of Estonian monosyllabics as there is no support contributed by a second syllable.

The analysis of any relative figures shows that the first and second degrees of quantity are more contrasted as regards duration than are the second and third degrees, whereas the differences in many qualitative features associated with quantity appear to be comparatively greater between the second and third degrees of quantity.

There seem to be sufficient grounds for believing that the ratios between the durations of vowels in stressed and unstressed syllables may be interpreted phonologically as three supra-segmental quantity structures of Estonian words, consequently, the quantity in Estonian seems probably to function first of all on the level of word structures.[17]

Academy of Sciences of the Estonian S.S.R.,
Institute of Language and Literature

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[16] The range of variation (comprising 90% of all single measurements) of the ratios of the duration of a vowel in a stressed syllable to that of a vowel in an unstressed syllable is 0.45 : 1.00 to 1.13 : 1.00 in the case of words of Quantity 1; 0.93 : 1.00 to 2.24 : 1.00 for words of Quantity 2 and 1.83 : 1.00 to 3.97 : 1.00 in the case of words of Quantity 3. The overlapping of fluctuation ranges of ratios referred to in the case of words in the first and second degrees of quantity (0.93 : 1.00 to 1.13 : 1.00) includes approximately 14% of single measurements for words of Quantity 1 and 8% of words of Quantity 2; the corresponding overlapping between the words of the second and third degrees of quantity (1.83 : 1.00 to 2.24 : 1.00) comprises approximately 20% of single measurements of words of Quantity 2 and 18% of ratios for words of Quantity 3.

[17] In view of what has been said above, one cannot agree with, e. g., R. T. Harms's treatment along structuralistic lines which phonemicizes both long

EESTI KEELE KOLMES VÄLTUSASTMES ESINEVATE VOKAALIDE AKUSTILISEST STRUKTUURIST

G. Liiv

Resümee

Käesolevas töös jälgitakse eesti keele kolmes fonoloogilises vältusastmes esinevate pearõhuliste monoftongide kvaliteedi muutumist fonatsiooni jooksul auditiivse, ostsillograafilise ja spektraalanalüüsi põhjal. Lähemalt on analüüsitud siirdesegmentide akustilisi tunnusjooni. On määratud vokaalide karakteerse segmendi ja siirdesegmentide nii absoluutne kui relatiivne keskmine kestus kolmes fonoloogilises vältusastmes.

See, mida me tavaliselt mõistame teatava foneemi esinemuse all teatavas sõnas, moodustub tegelikult tervest reast kvaliteedilt erinevatest elementidest (näiteid eesti keele erivälteliste vokaalide kvaliteedi muutumisest fonatsiooni jooksul on ostsillogrammidena esitatud joon. I—VI). Kuigi me kõnevoolus õige sageli ei märka vokaalide struktuuri heterogeensust, on kõnesoleva nähtuse füüsikaliste karakteristikute tundmisel kõne automaatse (masina)analüüsi seisukohalt esmajärguline tähtsus.

Kolmes fonoloogilises vältusastmes esinevaid eesti keele pearõhulise silbi monoftonge vaadeldi kahesilbilistes sõnades, mille mõlemad silbid olid lahtised. Viimaseid ei häälda nud katseisikud kui üksiksõnu, vaid kui lausefoneetiliselt enam-vähem identseid lauseosi: kindla kõneviisi jutustavate jaatavate lausete esimeste sõnadena väljaspool loogilist lauserõhku. Kestuselt vastandatav vokaal esines kolmes vältusastmes täpselt samasuguses konsonantümbritsuses. Keelematerjali analüüsil on piirdutud eesti ühiskeele Tallinna häälduse ga.

Kolmes vältusastmes esinevate vokaalide karakteerseid ja siirdesegmente analüüsiti kuuldeliselt separaatori abil viie katseisiku hääldu se põhjal. Ostsillogramme valmistati kolme isiku poolt häälda tud keelematerjalist. Siirdesegmente on spektraalselt analüüsitud nelja isiku hääldu se alusel. Aparatuurist kasutati separaatorit (segmentaatorit), ostsillograafi МПО-2, firma Standard Telephone & Cables Ltd. (London) helisageduste spektromeetrit, mudel 74100-A, seeria № 22603, ja 48 filterkanaliga dünaamilist spektrograafi ning selle lisaseadist, mis võimaldab saada amplituudväärtuste läbilõikeid. Katsed tehti Leningradi Riikliku Ülikooli eksperimentaalfoneetika laboratooriumis 1959. aastal. Käesolevas artiklis käsitletavate probleemide raames on analüüsitud üle 300 spektri.

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and over-long vowels as geminate clusters, the over-long degree of length being due only to postposed stress, i. e. stress on the second component of the cluster. The over-long degree of length is represented in phonological transcription by two letters and a grave accent above the second element (see R. T. Harms, A Descriptive Grammar of Estonian. Chicago, 1960). A similar phonological manner of the notation of vowels in the third degree of length was suggested by V. Hallap in a paper read on February 18, 1962, at a meeting of the Society of the Mother Tongue (Emakeele Selts). V. Hallap regards vowels of the second degree of length as geminate clusters and third-degree vowels as geminate clusters to which a "supra-segmental phoneme denoting the third degree of length" has been added. The present writer finds that experimental data do not warrant such a theoreticized distinction and interpretation. At any rate one cannot speak of the incidence of stress on the second component of the so-called clusters (i. e. on the second half of the third-degree vowels) because the possible acoustical correlates of stress are all contra-indicated in this case (a fall in fundamental pitch and a fall in intensity, a certain blurring of vowel quality).

As regards the changes in intensity as a whole within vowels of different degrees of length, the experimental material of the present work (visual estimation of about 200 oscillograms) in no way corroborates I. Lehiste's assertion that there are as many clearly discernible peaks of energy within a vowel as are designated by the numeral of the degree of length of the pertinent vowel (see I. Lehiste, Segmental and Syllabic Quantity of Estonian. "American Studies in Uralic Linguistics", Indiana University Publications, Uralic and Altaic Series I, 1960, pp. 21—82, esp. p. 25). On the contrary, one may actually note with interest that there is a certain difference in the dynamics of changes in intensity within vowels of different degrees of length, the general trend of the rise and fall in intensity appearing to coincide somewhat with simultaneous changes in fundamental pitch (for pitch patterns, see G. Liiv, Eesti keele kolme vältusastme vokaalide kestus ja meloodiatüübid, pp. 488—490, Fig. 9). The foregoing statement may, of course, prove to be but a tentative suggestion, and a reliable determination of the phenomenon calls for a further series of experiments.

Andmed kolmes fonoloogilises vältusastmes esinevate vokaalide eri segmentide kvaliteedi ja kestuse kohta esitatakse ülevaatlikkuse ja lühiduse huvides tabelitena (1—9). Üldiselt võib märkida, et eristatavate segmentide arv ja kvalitatiivsete erinevuste põhitendents ning määr sõltuvad nii vokaalide eneste kvaliteedist kui ka nende foneetilisest positsioonist, s. o. erinevast konsonantümbritsusest. Muudel võrdsetel tingimustel tuleb järjekindlaid erinevusi vokaalide kvaliteedi muutumises registreerida sõltuvalt kestusest. Põhijoontes võib öelda, et vältusastme pikenemisega kaasneb vokaalide akustilise struktuuri suhteliselt suurem heterogeensus. Kõige ebastabiilsem näib olevat vokaalide kvaliteet III vältusastmes: üldiselt võib siin eristada kõige rohkem kvaliteedilt erinevaid segmente, sama vokaali eri segmentide kvalitatiivsed erinevusedki näivad olevat mõnevõrra suuremad, sageli võib registreerida ka mõnevõrra suuremat varieerumist eri isikute häältdustes. Näiteid vokaalide spektraalse koosseisu muutumisest fonatsiooni jooksul vt. joon. 1—9.

Eksperimentaalsete materjalide analüüs andis järgmisi preliminaarseid andmeid vokaalide karakteerse segmendi ja siirdesegmentide kestuse kohta eri vältusastmeis. Karakteerse segmendi keskmine absoluutne kestus I vältusastme vokaalidel on ca 40 msec, II vältusastme vokaalidel 63 msec ja III vältusastme vokaalidel 77 msec. I, II ja III vältusastme vokaalide karakteerse segmendi keskmise absoluutse kestuse suhe on seega 1,00 : 1,58 : 1,93; II ja III vältusastme vokaalide karakteerse segmendi vastava kestuse suhe on 1,00 : 1,22. Karakteerse segmendi kestus moodustab I vältusastme vokaalide kogukestusest 37%, II vältusastme vokaalide kogukestusest 36% ja III vältusastme vokaalide kogukestusest 31%. Seega on karakteerse segmendi suhteline kestus I ja II vältusastme vokaalidel umbes sama, kahanedes aga III vältusastme vokaalide puhul.

Eelneva konsonandi ja karakteerse segmendi vaheliste siirdesegmentide keskmine absoluutne kestus on I vältusastme vokaalidel 32 msec, II vältusastme vokaalidel 53 msec ja III vältusastme vokaalidel 75 msec. I, II ja III vältusastme vokaalide nimetatud siirdesegmentide keskmise absoluutse kestuse suhe on 1,00 : 1,66 : 2,34; II ja III vältusastme vokaalidel on vastavate siirdesegmentide kestuse suhe 1,00 : 1,42. Eelneva konsonandi ja karakteerse segmendi vaheliste siirdesegmentide kestus moodustab vokaali kogukestusest I vältusastmes keskmiselt 31%, II vältusastmes 30% ja III vältusastmes samuti 30%. Seega on nimetatud siirdesegmentide suhteline kestus kõigis vältusastmetes umbes sama.

Karakteerse segmendi ja järgneva konsonandi vaheliste siirdesegmentide keskmine absoluutne kestus on I vältusastme vokaalidel 35 msec, II vältusastme vokaalidel 63 msec ja III vältusastme vokaalidel 104 msec. I, II ja III vältusastme vokaalide nimetatud siirdesegmentide keskmise absoluutse kestuse suhe on 1,00 : 1,80 : 2,97; II ja III vältusastme vokaalide vastavate siirdesegmentide kestuse suhe on 1,00 : 1,65. Seega on karakteerse segmendi ja järgneva konsonandi vaheliste siirdesegmentide absoluutse kestuse juurdekasv vokaalide pikemates vältusastmetes märgatavalt suurem vastavast juurdekasvust eelneva konsonandi ja karakteerse segmendi vaheliste siirdesegmentide absoluutse kestuse osas; see erinevus ilmneb eriti selgesti II ja III vältusastme vokaalide võrdlemisel. Karakteerse segmendi ja järgneva konsonandi vaheliste siirdesegmentide keskmine kestus moodustab vokaalide kogukestusest I vältusastmes keskmiselt 32%, II vältusastmes 35% ja III vältusastmes 39%. Seega pikeneb nimetatud siirdesegmentide suhteline kestus vokaalide vältusastme suurenedes (vt. ka joon. 10).

Eksperimentaalne materjal viitab vokaali ja järgneva konsonandi suhtelisèlt lõdvale seondusele pikemates vältusastmetes, seejuures näib nimetatud erinevus olevat markantsem just II ja III vältusastme vokaalide vahel. Samuti kinnitavad esitatud andmed III vältusastme vokaalide akustilise struktuuri suhteliselt suuremat heterogeensust.

Eesti NSV Teaduste Akadeemia
Keele ja Kirjanduse Instituut

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К ВОПРОСУ ОБ АКУСТИЧЕСКОМ СОСТАВЕ ЭСТОНСКИХ ГЛАСНЫХ ТРЕХ СТЕПЕНЕЙ ДОЛГОТЫ

Г. Лийв

Резюме

В работе приводятся некоторые данные о неоднородности качества эстонских ударных монофтонгов трех фонологических степеней долготы, исходя из слухового, осциллографического и спектрального анализов. Более подробно проанализированы акустические признаки переходных сегментов. Рассматриваются средняя абсолютная и относительная длительности характерного сегмента и переходных сегментов в трех фонологических степенях долготы.

Фонема, как бы мы не воспринимали ее в том или ином слове, в действительности складывается из целого ряда элементов, различаемых по качеству (некоторые примеры неоднородности звучания эстонских гласных разных степеней долготы приведены в гра-

фическом изображении на осциллограммах рис. I—VI). Хотя в потоке речи мы часто не замечаем неоднородности состава гласных, физические характеристики этого явления имеют первостепенное значение для успешного решения задач автоматического различения речи.

Ударные монофтонги трех фонологических степеней долготы изучались в двухсложных словах (оба слога которых были открытыми), произносимых в определенном контексте, причем их синтаксическая роль и фонетическое положение во фразе были по возможности тождественны для всех случаев (первые слова повествовательных утвердительных предложений изъявительного наклонения вне логического ударения предложения). Гласный фонологически противопоставленных степеней долготы находился в одинаковом консонантном окружении. Исследовалось таллинское произношение эстонского литературного языка.

При слуховом анализе (с помощью сепаратора) характерных и переходных сегментов гласных трех степеней долготы были использованы звукозаписи пяти дикторов. Магнитофонная запись речевого материала в произношении трех дикторов была подвергнута осциллографической съемке. Данные о спектральном составе переходных сегментов получены на основе анализа произношения четырех дикторов.

Опыты производились в Лаборатории экспериментальной фонетики Ленинградского государственного университета в 1959 г. при помощи сепаратора (сегментатора), осциллографа МПО-2, треть-октавного спектрометра фирмы Standard Telephone & Cables Ltd. (London), модель 74100-A, серия № 22603, и 48-канального динамического спектрографа с устройством для получения мгновенных спектров. Всего проанализировано более 300 спектров.

Сведения о качестве и длительности отдельных сегментов приведены для краткости и наглядности в виде таблиц 1—9. В общем можно сказать, что число различаемых сегментов, основная тенденция и степень качественных различий отдельных сегментов зависят как от качества самих гласных, так и от их фонетического положения, т. е. от различного консонантного окружения. При прочих равных условиях следует отметить последовательные различия в неоднородности состава гласных в зависимости от длительности. В общем обнаруживается, что сравнительно бóльшая неоднородность звучания гласных сопутствует увеличению степени долготы. Наименьшая стабильность качества гласных выражается в третьей степени долготы: здесь обнаруживается наибольшее число различаемых по качеству сегментов, несколько больше здесь, видимо, и качественное различие отдельных сегментов того же гласного; сравнение экспериментальных данных, полученных от разных дикторов, часто обнаруживает несколько больший разброс, чем в случае первой и второй степеней долготы. Некоторые примеры изменения спектрального состава гласных на протяжении их звучания приведены на рис. 1—9.

Анализ экспериментальных материалов дает возможность привести следующие первоначальные данные о длительности характерного сегмента и переходных сегментов в разных степенях долготы. Средняя абсолютная длительность характерного сегмента гласных первой степени долготы составляет примерно 40 мсек, второй степени 63 мсек и третьей степени долготы 77 мсек. Средние абсолютные длительности характерного сегмента гласных первой, второй и третьей степеней долготы соотносятся как 1,00 : 1,58 : 1,93; отношение длительности характерного сегмента гласных второй и третьей степеней долготы равно 1,00 : 1,22. Длительность характерного сегмента составляет в случае первой степени долготы в среднем 37%, в случае второй степени — 36% и в случае третьей степени долготы — 31% общей длительности гласных. Следовательно, относительная длительность характерного сегмента гласных первой и второй степеней долготы примерно равна, но уменьшается в третьей степени долготы.

Средняя абсолютная длительность переходных сегментов от предшествующего согласного к характерному сегменту гласных первой степени долготы равна 32 мсек, второй степени — 53 мсек и третьей степени — 75 мсек. Отношение средней абсолютной длительности указанных переходных сегментов гласных первой, второй и третьей степеней долготы составляет 1,00 : 1,66 : 2,34; отношение длительности соответствующих переходных сегментов гласных второй и третьей степеней равно 1,00 : 1,42. Длительность переходных сегментов от предшествующего согласного к характерному сегменту составляет в случае первой степени долготы в среднем 31%, во второй степени — 30% и в третьей также 30% общей длительности гласных. Следовательно, относительная длительность упомянутых переходных сегментов примерно тождественна во всех степенях долготы.

Средняя абсолютная длительность переходных сегментов от характерного сегмента к последующему согласному в случае гласных первой степени долготы равна примерно 35 мсек, второй степени — 63 мсек и третьей — 104 мсек. Отношение средней абсолютной длительности указанных переходных сегментов гласных первой, второй и третьей степеней долготы составляет 1,00 : 1,80 : 2,97; отношение длительности соответствующих сегментов гласных второй и третьей степеней равно 1,00 : 1,65. Итак, увели-

чение абсолютной длительности переходных сегментов от характерного сегмента к последующему согласному в более долгих степенях гласных значительно больше, чем соответствующее увеличение абсолютной длительности переходных сегментов от предшествующего согласного к характерному сегменту. Указанное различие обнаруживается особенно отчетливо при сравнении гласных второй и третьей степеней долготы. Средняя длительность переходных сегментов от характерного сегмента к последующему согласному составляет в случае первой степени долготы в среднем 32%, второй степени — 35% и третьей — 39% длительности всего гласного. Следовательно, относительная длительность указанных переходных сегментов увеличивается в более долгих степенях гласных (см. также рис. 10).

Изученный материал указывает на сравнительно слабый отступ гласного перед последующим согласным [loser Anschluss; loose (open) contact] в более долгих степенях, причем это различие, видимо, больше между гласными второй и третьей степеней долготы. Приведенные данные подтверждают также, что гласные третьей степени долготы характеризуются наибольшей неоднородностью акустического состава.

Институт языка и литературы
Академии наук Эстонской ССР

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