TENSOPALATOGRAPHY DYNAMIC TECHNIQUE AND ARTICULATORY TENSION STUDY COMPARED WITH SPEECH ACOUSTIC PARAMETERS (SYLLABLE PRODUCTION IN SPOKEN SPEECH AS AN ARTICULATORY STRUCTURE)

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The paper presents phonetico-experimental data concerning dynamic tenso palatography technique which makes it possible to correlate the dynamic articulatory processes as the last link of the syllables, words, syntagmas in speech production with their physical characteristics. Analysed were tensooscillograph records of Russian syllables with the vowel "a" and with initial stop front lingual consonants differing in their hard, palatalized, voiced, voiceless and sonant features.

The study and a statistical analysis of the data received yielded in: 1. The syllable is produced as an articulatory integrity. 2. The syllable includes an aggregate factor manifesting itself in a lesser/greater homogeneity of the components due to muscular tension. 3. Syllables differ according to the mode their articulatory tension develops.

The Kiev State University Experimental Phonetics Laboratory (KSUEPHL) experimental phonetics study of over some recent decades has aimed at a detailed describing the speech production articulatory aspect which was due to both practical tasks (to understand articulatory standardization, to correct pronunciation) and an important objective dealing with syllable- and word-structure.

A syllable, a minimal structural unit of a spoken speech stretch, has an aggregate factor enabling to find its wholeness and continuity as an original chain structuring lexical and syntactical language events.

The study of syllables and words dynamic manifestations makes us possible to treat them resulting from the final chain speech production - one of the speech activity processes. An articulatory process thus turns out to be immediately related to the language (phonological) speech study: the syllable/word articulation presupposes the producing of language units functioning as spoken text components elsewhere.

The academecian L.V.Shcherba theory suggests that the syllable production and division is dependent on the muscle tension impulses which are responsible for a consonant power changeability within a syllable. /10, 4/

This hypothesis experimental test made us to design a technique enabling us to record articulatory tension and its progress within a syllable, a word and word sequence.

The papers and books on phonetics have not yet had experimental evidence concerning the tension growth within a syllable, though the syllable peak (a vowel in most languages) is believed to be made with the most tension possible. There were some ideas presented as to the consonants articulation heterogeneity which is due to the tension. /10/

Yet there are no data available on vowels heterogeneity based on the feature in point. The consonants tension is assumed to result from their being voiceless/voiced; from the syllable being stressed/unstressed; from their position in a syllable or a word (opening/closing). /3, 1, 2, 4, 9, 10, 8/

Strong-ended consonants, voiceless and consonants in stressed syllables opening a word are believed to be more tense.

The KSUEPHL has designed a technique for the tongue pressure on the palate (palatum durum) to be investigated.

The power exercised by the tongue muscle is known as a mechanical one. Thus with consonants this power can be defined as the pressure upon some rigid surface. A technique combining tensometric processing with palatography and oscillography has been created to answer a number of points: how articulatory tension changes in lingual consonants within articulated syllables and words; the way the muscle tension manifests itself within a syllable; what the syllable peak is (whether it is a definite and the most tense point, the attainment of which is immediately followed by a relaxation, or whether it is a segment more or less elongated); the way the motor impulse of muscle tension is being produced, whether there is the incessability of the impulse and what it is

manifested in.

The technique is called tensopalatography.

The technique in point (see first described - 7) makes it possible to correlate the physical characteristics of speech (of syllables, words and sense groups) to simultaneously registered articulatory organs movements. The oscillogram is recording not only acoustic signals but the tongue pressure impulses upon the roof of the mouth as well, which when analysed can appreciate the articulatory tension, the articulatory duration and compare these features with signals acoustic duration.

The sensory (sensing) elements in the pressure electric measuring elements were minute (2 mm base) wire tensometres. /7/

The measuring elements taring enabled us to value the tongue pressure impulses. The recording apparatus used was a rotating mirror oscillograph. The oscillograph record simultaneously showed pressure signals from two measuring elements and the speech acoustic picture. (Comp.12 and 5).

To choose indicator position on the palate plate there has been made a standardization of consonants and vowels articulatory contacts according to the Russian speech sounds palatography evidence taken from the KSUEPHL phonetical archives. The contacts in question were grouped into three types. Each of the three speakers, the participants of the experiment, had three separate palates specially made. Each of the palates with two (front and side) detectors attached to it served as an integrate detector (see fig.1) through the two channels of which the oscillograph record had sig-

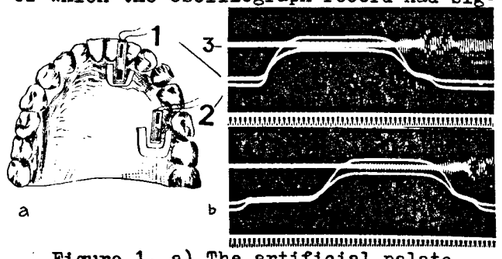

Figure 1. a) The artificial palate with the front and side pressure detectors; 1 - front detector, 2 - side detector. b) Tensooschillograph record of the syllables /t'a/, /d'a/; 1, 2 - pressure signal from the pressure detectors, 3 - acoustic signal from the microphone.

nals registered. The registered tongue pressure signals looked like impulses having the front, the peak and the cut-off of their own. The impulses did not superimpose with acoustic signals boundaries.

The impulse form and such of its parameters as amplitude and peak duration burdened with one or several pedestals, constantly varied due to the syllable components structure.

Different impulse forms were analysed; this resulted in descerning six impulse types: 1) a rectangular one having the peak length with relatively low amplitude; 2) a triangular one having a minimal peak duration, an increasing front and a descending cut off; 3) a bell-formed one also having a minimal peak yet having soft prominent front lines and cut off; 4) impulses with a complicated compound form having but one peak; 5) complex impulses with two peaks; 6) blending impulses having adjoining peaks. (See fig.2).

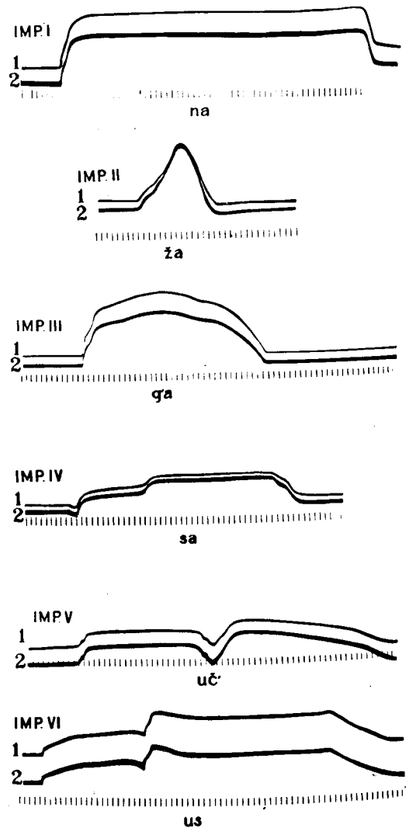

Figure 2. Types of the impulses.

Further tongue pressure impulses analysis and measuring made us have the parametres as follows: a front duration, a peak duration, an articulatory integrated duration, an impulse amplitude peak. The front duration and the pressure increase velocity were defined as correlated values: the less the duration the greater the velocity and consequently, the higher pressure at the syllable beginning.

The cut off duration determined the pressure descending time, tension heterogeneity/homogeneity at the juncture of a consonant and a vowel. The angle between the zero-th and the beginning front line as well as the front duration indicated the pressure progress speed; the angle growth corresponds to the pressure increase speed growth.

The impulse peak duration was interpreted in terms of: a) a peak line uniformity/non-uniformity; b) the duration of the level part of the peak; c) the existence of the rise peak followed by a lesser part of a peak duration.

The uneven peak line growth indicates the uneven pressure manifestation with its maximum observed within a relatively stable segment.

The technique serves for describing and measuring the boundaries correlation between the syllables and word articulatory and acoustic duration. The tensooscillograph record of syllables with initial stop consonants displays the development of their first components - consonants; their acoustic signal being registered in zero-shape. It makes it interesting to describe coincidence/non-coincidence of the final segment in the pressure impulse and the start of the acoustic signal for the syllables differing in modal indications: the voiced beginning syllables, voiceless beginning syllables and sonant beginning syllables.

The basic indicator employed was an acoustic signal. All the impulse pressure observed after the acoustic signal switched on were assumed to be retarding or slow and had a minus index during the evaluating procedure. Plus index was attached to the parametres being ahead of the signal attack. Thus, the technique makes a foundation to investigate the problem of interdependent articulatory and acoustic features. /6/

Investigated were Russian vowel syllables and those with initial predorsal hard and dorsal palatalised stop consonants (the first type of impulses) (see fig.3). The analysis aims at having tension articulatory characteristics and its distribution within syllables, at the correlation of the articulatory and acoustic duration of syllables.

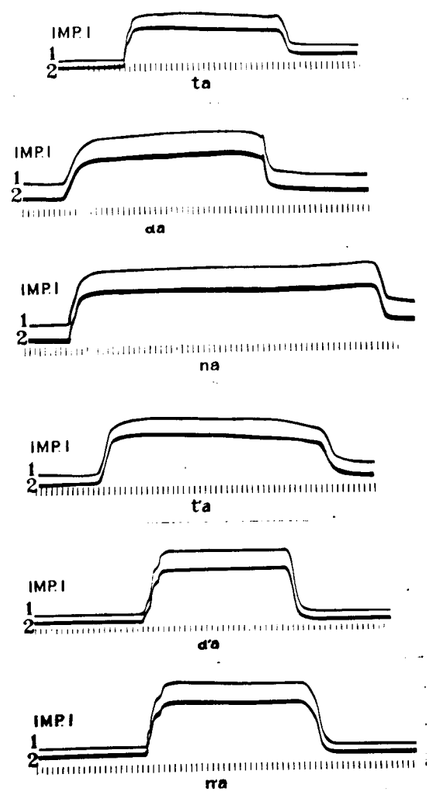

Figure 3. Impulses of the investigated syllables.

The syllable analysis based on impulses shape yielded the description to follow. The initial components of all syllables displayed on the oscillograph record took the shape of the first class impulses. Hard consonants syllables preferred the 1, 4 shape (rectangular impulse with a graduated front and a vertical cut off), syllables with initial palatalized stop consonants preferred the 1, 2 shape (rectangular with a stepped front and cut-off).

Initial voiceless hard syllables differed from those with initial voiced and nasal consonants by belonging to the 1, 4 class, while voiced and nasal consonants - to the 1, 2 class which indi-

cates the lack of identity in the growth and decline of tension in the syllables.

The palatalized stops syllables and those with voiced and voiceless differed from hard consonants syllables by their belonging exclusively to the 1, 2 class; however the voiced and voiceless cut impulse was usually longer. The homogeniety in the difference of voiceless and voiced syllables for both tested groups (hard and palatalized) shows that voiced and nasal syllables differ from voiceless as having a special, smoother tension growth at the consonant-vowel transition. The tension growth in voiceless syllables with initial hard and palatalized consonants is of overfall nature - an abrupt transition at the consonant-vowel boundary.

The analysis of all syllables with hard and palatalized consonants with respect to their impulses shape enabled us to distinguish long syllables impulse manifestations with retaining one and the same amplitude and a relatively unchanging manifestation of peak duration. Here belong the initial voiceless syllables and those with hard and palatalized consonants. The second group contains the syllables with the initial voiced and nasal consonants having the impulse shape whose tension is found less stable concerning their peak duration manifestation and respectively, a short period of homogeneous amplitude.

The first syllables have more consonantal features, the second group is of mixed character, i.e. of a consonant-vowel nature. We can now state that the tension change (the overfall during consonant - vowel juncture) is more pronounced with the voiceless syllables and less pronounced with the voiced syllables and those with the sonants. The tension change feature manifests reciprocal derivational relations between the syllable components.

The analysis of voiceless syllables on the one hand and of voiced and sonant ones on the other hand presents them as having different growing modal features.

This brought to the measuring and analysis of the parameters describing the modal features growth: the front duration, the cut off duration, the amplitude value, the peak duration, the correlation between the peak duration and that of the amplitude; the correlation of the front duration and that of the amplitude; the correlation of the cut-off duration and that of the amplitude. Taken into account was the correlation of integral impulse length and the syllable acoustic length.

Initial voiceless hard syllables and those with initial palatalized consonants are different classes in terms of their absolute mean front length: the front length in hard syllables (HS) is constantly lesser than that in palatalized syllabless (PS) which shows a greater pressure growth in the initial segment of HS. The absolute value of HS mean cut-off duration is less than that of PS mean cut-off duration, the length of HS and PS cut-off being less than that of the front.

With PS the front is longer than the cut-off, while both segments impulses are longer than their HS counterparts. This evidence distinguishes syllables according to the degree of tension at the consonant-vowel juncture. With PS this is of less contrast nature yet having a relatively greater growth velocity, which can be read in the front-cutoff ratio (FC ratio). /F > C/

Relative values resulted from the comparison of the peak duration and the maximum amplitude of voiceless HS impulses and those of PS can be written as follows: $\frac{\tau_{\ell}}{J_{max}}$ HS > $\frac{\tau_{\ell}}{J_{max}}$ PS

The comparison of the front and the amplitude F/A and the cut-off and the amplitude C/A with HS and PS positively distinguishes HS into a type with a more tense first component growth, when combined with the vowels it becomes more prominent (contrastive). The latter characterizes occlusion as a consonant marker.

The analysis of the parameters realizing the tension dynamics describes the initial syllable components as a process capable to affect the acoustic signal duration.

There is a regular greater articulatory impulse and acoustic signal duration, observed in PS, while HS show lesser articulatory and acoustic signals duration respectively. The second group of syllables with initial voiced consonants, hard and palatalized, and sonants, hard and palatalized, recorded with identic amplification and from the same artificial palate, was described similarly.

Tendencies discovered while analysihg voiceless syllables proved to be regular for syllables with initial voiced and sonorous consonants. First of all it has to do with the following parameters correlated: the front duration /the amplitude value; the cut-off duration / the amplitude value; the peak length / the amplitude value; a total articulatory duration / a total acoustic duration.

As it was already mentioned, the voicelees syllables are contrasted to those of the voiced and the nasal for having different modal dynamic features.

A common feature both for voiced and for sonant syllables impulses is the peak duration and the amplitude ratio. The ratio can be written as follows:

$$\frac{\tau_{\ell}}{J_{max}}(da) > \frac{\tau_{\ell}}{J_{max}}(na)$$

Similar exponents ratio of the parameters in point were found when D'A and N'A were compared. The parameters comparison show greater ties of the hard voiced and the palatalized voiced consonants with a vowel to follow.

The tension of the voiceless stops, of the voiced consonants and the nasal sonants is growing in different ways, which displays both intrinsic features of each consonant and the syllable features as the articulatory entireties. The greatest liasion of the components is observed in the voiced syllables (which is indicated by the cut-off value and the amplitude cut-off ratio).

The voiced and the nasal syllables are contrasted to the voiceless ones as a special modal class of syllables, the chief feature of which being realized in greater derivational ties between the components.

On the oscillograph records of the syllables with initial voiceless, voiced and nasal consonants different types of relations between the articulatory peak duration and the amplitude peak (see A); between an integrate duration of the tension impulse and the acoustic duration signals (see B) is regularly indicated as follows:

A $\frac{\tau_{\ell}}{J_{max}}(ta) > \frac{\tau_{\ell}}{J_{max}}(da) > \frac{\tau_{\ell}}{J_{max}}(na)$

B $\frac{\tau_{art}}{\tau_{ac}}(ta) > \frac{\tau_{art}}{\tau_{ac}}(da) > \frac{\tau_{art}}{\tau_{ac}}(na)$

The most autonomous (see A and B) are the initial voiceless components; the voiced and the sonant syllable enable us to assume a noncontrastive, relative homogeniety of the components (see above C/A; F/C) which brings about a greater interdependence between them and is manifested in the vowel duration growth. The similar relations are likely to have resulted from its greater articulatory tension. The intersyllabic relations between the syllable components is based on the feature of a higher or lower homogeniety of the articulatory tension development. Therefore the syllable is articulated as a naturally organized integrity of interdependent components. The syllable has an agregate factor manifesting itself in a greater or lesser similarity of the syllable components based on the muscular tension, which fins its expression in a specially structured impulse of the tongue pressure.

There is born a possibility to classify syllables in terms of relations of their components. In the class of syllables with hard consonants it looks as follows: DA > NA > TA.

The analysis evidence suggests that the tensopalatography is suitable for studying the tension feature in its dynamic manifestation within the articulated syllable, word and sense group. The factor working within the syllable and uniting its components undoubtedly proves not only the articulatory entirety of the syllable, but also its predetermination in speech production.

The table of syllable tension impulses. Parameters and ratios

Syllables / Parameters	ta	da	na	t'a	d'a	n'a
Front (F) msec	36	59	61	64	91	118
Cut-off (C) msec	34	50	52	58	65	65
Amplitude (A) mm	43	42	41	37	36	32
Articulatory duration of signal (D art.) msec	348	325	325	352	326	339
Acoustic duration of signal (D ac.) msec	334	438	420	310	452	448
Parametres ratios						
Front:Cut-off	1,1	1,2	1,3	1,1	1,4	1,9
Front:Amplitude	0,8	1,4	1,5	1,7	2,5	3,7
Cut-off:Amplitude	0,8	1,2	1,3	1,6	1,8	2,1
D art.: D ac.	1,0	0,7	0,8	1,1	0,7	0,8

Note: the table gives statistic data obtained from tensooscillograms with constant amplification on the same artificial palate of one speaker.

REFERENCE

I. Абеле А. К вопросу о слоге. "Slavia", Ш, I924, с.I-34.

2. Богородицкий В.А. Фонетика русского языка в свете экспериментальных данных. Казань, I930. - 356 с.

3. Бодуэн де Куртенэ И.А. Введение в языковедение. В его кн.: Избранные труды по общему языкознанию. М., I963, т.2, с.246-293.

4. Зиндер Л.Р. Общая фонетика. М., I979. - 3II с.

5. Кузьмин Ю.И. Динамическое палатографирование. - Вопросы психологии, I963, № I, с.I37-I4I.

6. Лийв Г., Ээк А. О проблемах экспериментального изучения динамики речеобразования: комплексная методика синхронизированного кинофлуографирования и спектрографирования речи. - Изв. АН Эст.ССР, I968, т.I7. Биология, с.78-I02.

7. Рузга З. Электрические тензометры сопротивления. М., I964, с.I5-44.

8. Рушковская Л.М., Скалозуб Л.Г. Артикуляция звонких и глухих согласных в слогах русской речи: (По данным кинорент-

генографирования). - Русское языкознание, Киев, 1981, вып.2, с.94-100.
9. Скалозуб Л.Г., Лебедев В.К. Тензометрирование как прием исследования давления языка на нёбо при речи. В кн.: Механизмы речеобразования и восприятия сложных звуков. М.-Л., 1960, с.56-62.
10. Щерба Л.В. Фонетика французского языка. М., 1953. - 311 с.
11. Sawashima M.Temporal Patterns of Articulatory and Phonatory Controls. - Ann.Bull.RILP, 1979, 3, p.1-13.
12. Stetson R.H., Hudgins C.V. and Mosos E.R. Palatograms change with rates of articulation, 1940, Arch.neerl.phonet. exper., 16: 52-62.