ELECTROMAGNETIC ARTICULOGRAPHY *

A New Approach to the Investigation of Palatalization in Russian

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ABSTRACT

Electromagnetic articulography (EMA) is a non-invasive method of investigating the movements of articulators inside and outside of the vocal tract. With this method, it is possible to register the articulatory movements of the tongue during on-going speech and to reveal the dynamic, speech-physiological aspects of palatalization in Russian.

INTRODUCTION

Palatalization is a linguistic phenomenon of wide occurrence. In a slavic language such as Russian, it is especially prevalant and has a (mor)phonemic significance. There are some theoretical linguistic investigations [1,2,4,5,7,8,9] and experimental studies [3,5,6] on palatalization in Russian. However, a direct recording of articulatory movements of the tongue, which modulate the vocal tract configuration underlying palatalization, is still lacking. EMA offers the possiblity of routinely sampling large amounts of speech data for empirically testing theories of palatalization specifically, as well as modelling speech production in general.

METHOD

EMA (Fig.1) is based on the physical principle that a magnetic field of an oscillating dipole decreases as a cubic function of increasing distance from its center [10,11,12]. The distance between a receiver and a transmitter coil can be determined by measuring the voltage induced in the receiver if the axis of both coils are parallel. Use of two transmitters allows calculation of the x / y coordinates of the receiver if the receiver does not tilt or twist. A third transmitter corrects falsification of the signal due to tilting or twisting of the receiver and enables precise localization of the receiver by iterative solution of non-linear equations.

The three transmitters (4 cm x 2 cm) are fixed on a helmet and positioned around the head of the subject in the midsagittal plane. The receiver coil (2 mm x 4 mm) can be attached to the tongue with a tissue adhesive (Histoacryl blau). The signals from the receiver are fed into the analog circuitry via a thin copper wire (0.13 mm).

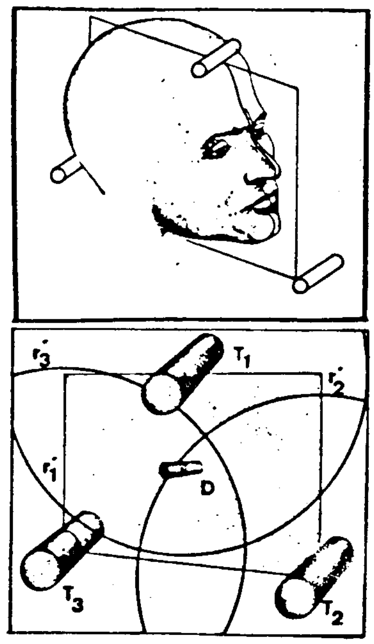

Fig.1. Electromagnetic Articulography. Fig.1a. Three transmitter coils (T) are fixed around the subject in the midsagittal plane. Fig.1b. Tilting of the detector (receiver) coil (D) weakens the signal and the radius (r) seems to be greater. A third transmitter corrects this effect and the unique solution of the non-linear equations is iteratively approximated.

The temporal resolution depends on the sample rate (up to 1 kHz), which was 125 Hz for the present experiment. The spatial resolution of the system is 0.5 mm in the major working range.

A physiological frame of reference is necessary for a reasonable orientation and localization while examining the movement trajectories of the tongue. One reference selected is the profile of the palate, which is obtained by sliding a receiver coil in the midsagittal plane along the palate (Fig.2). The overlay plot of Fig.2 demonstrates the reliability of the recordings. Another physiological reference is the occlusion plane of the subject, which is close to the resting position of the tongue. All data are presented in a coordinate system in which the x-axis is parallel to the occlusion plane of the subject.

In the present experiment two receiver coils were positioned upon the central furrow of the tongue, one about 2 cm from the tip of the tongue and the other at the dorsum of the tongue. The subjects, who are native speakers of Russian, were then requested to repeat various types of syllables in Russian, including: 1). non-palatalized consonant plus vowel <CV>, 2). palatalized consonant plus vowel <C'V> (the palatality is indicated by an "apostrophe"), 3). syllable with [j]-insertion between consonant and vowel <C(')jV>.

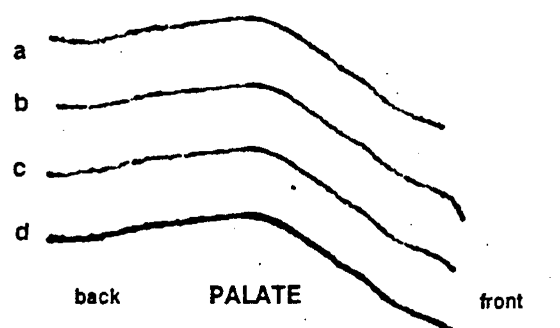

Fig.2. Three consecutive recordings of the midsagittal profile of the palate of a subject facing to the right. Fig.2a-c: Single plots. Fig.2d: Overlay plot.

RESULTS

The Russian vowels <i> and <y> deserve special attention with respect to palatalization in Russian: the consonant which precedes the vowel <i> is always palatalized, while the consonant which precedes the vowel <y> can never be palatalized. It is disputed whether they should be treated as allophones. Fig.3 compares the tongue positions of these two vowels.

For articulating the vowel <i>, the forward and upward movement occurs mainly at the front of the tongue, whereas for the vowel <y> the backward and upward movement occurs mainly at the back of the tongue. In order to determine the precise tongue position at a certain point in time, acoustic signals and movement signals, which are recorded synchronously during the experiment, are compared. For both vowels, the baseline of the tongue position shows the resting position of the tongue, which is approximately in the same plane as the occlusion plane, and is therefore parallel to the x-axis of the coordinate system. As a rule, both vowels are pronounced when the tongue reaches its highest position. The tongue position of <i> differs from that of <y> in that the tongue as a whole lies further forward. This is in accordance with the phonetic description that [i] is a high front vowel and [y] is a somewhat high and relatively back vowel. It is noticeable that the distance between the two receiver coils changes not only from vowel to vowel but also from time to time during speech movement.

In traditional static phonetics, the tongue tends to be simplified as a rigid mass, which moves at the same time in the same direction. In fact, the tongue is a heterogeneous mass so that different parts can move at the same time with different amplitudes and in different (or even opposite) directions.

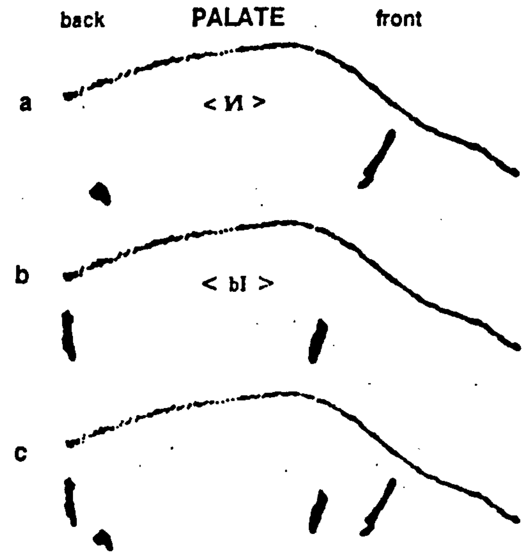

Fig.3. Tongue Positions of Russian Vowels. Fig.3a: <i>. Fig.3b: <y>. Fig.3c: <i> and <y>.

Since palatalization is closely related to high front vowels, it is generally treated as a regressive assimilation through high front "vowels", especially through the vowel [i] or the glide [j]. But the formulation of such a rule of palatalization is opaque in Russian, because, in Russian, palatalized consonants do not occur exclusively before high front vowels, and, furthermore, non-palatalized consonants also occur before high front vowels. Neeld (1973) suggested an addition of rules to solve the problem of opacity [8]. This means - in the case of Russian - an insertion of the glide [j] must be postulated. Yet the Russian phonology requires a fine distinction between palatalization and [j]-insertion, e.g.: <s'em'i> (gen. sig. of "seven") and <s'em(')ji> (gen. sig. of "family") are a minimal pair. This dilemma of static phonology can be solved by investigating the dynamic aspects of palatalization with EMA. Fig.4 and Fig.5 demonstrate the distictions between palatalization and [j]-insertion.

In the case of the palatal fricatives, the front of the tongue moves to a greater extent in comparison with the back of the tongue. The articulatory movements of the front of the tongue for the non-palatalized *palatal fricative* <Sa> are the parts of the trajectories, in which movement from the position for the palatal fricative <S> at the top directly down to the position for the vowel <a> occurs. The curved trajectories forward and upward are the preparatory movements of the tongue for pronouncing the target syllable. During the silent period, the tongue first returns to its resting position and then the front of the tongue moves backward and upward in order to reassume the initial position of the palatal fricative <S>. The trajectories for the palatalized <S'a> are loops which differ from those of the non-palatalized <Sa> in that the initial position for the palatalized consonant <S'> already lies more at the front at the very beginning of the articulatory movements.

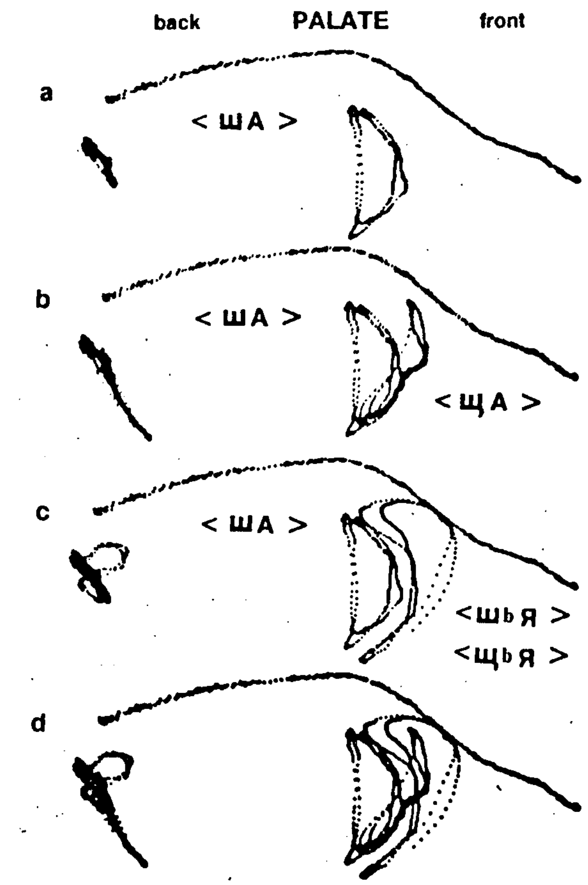

Fig.4. Palatalization of the palatal fricative <S>. Fig.4a. Non-palatalized <Sa>. Fig.4b. Non-palatalized <Sa> vs. palatalized <S'a>. Fig.4c. Non-palatalized <Sa> vs. <S(')ja> (with [j]-insertion). Fig.4d. <Sa>, <S'a> and <S(')ja>.

Although <Sja> and <S'ja> are written differently in cyrillic orthography, acoustic and articulatory investigations do not show any difference between them. Phonologically, the palatalized consonant and the corresponding non-palatalized consonant are neutralized in the position before an inserted [j]. The articulatory movement for <S(')ja> is no longer a nearly "straight line" but becomes a very bent curve. This indicates that the syllable contains three segments instead of two. Before the front of the tongue reaches its final goal, which is the area for the vowel [a], it passes an intermediate station, which is the area for the glide [j]. The initial position and the final position of the articulatory movements and even the preparatory movements of the trajectories of <Sa> and <S(')ja> coincide with each other. When we compare the trajectories of all three syllables, we find that the trajectories of the palatalized <S'a> lie just between those of the non-palatalized <Sa> and those of <S(')ja>.

All these three syllables <Sa>, <S'a> and <S(')ja> have the vowel [a] in common. The turning points at the bottom of the trajectories of the articulatory movements of these three syllables lie fairly close to each other. Yet at the same time there are still some deviations. A detailed study of the trajectories together with the acoustic signals shows that the vowel [a] is pronounced before as well as after the turning point is reached. Thus, there is not a single point but a whole area in which the vowel [a] may be produced. This means: speech production requires on the one hand precise tongue movement when sounds are to be differentiated, but allows on the other hand a certain degree of freedom when sounds are not to be differentiated.

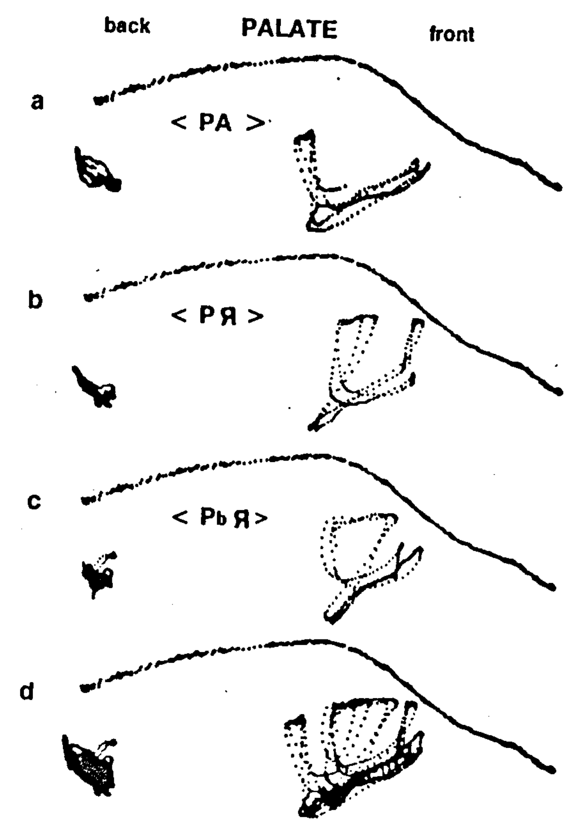

Fig. 5. Palatalization of <r>. Fig.5a. Non-palatalized <ra>. Fig.5b. Palatalized <r'a>. Fig.5c. <r(')ja> (with [j]-insertion). Fig.5d. <ra>, <r'a> and <r(')ja>.

The situation is similar when we compare <ra>, <r'a> and <r(')ja> (Fig.5). For articulating <ra>, the front of the tongue moves from its resting position first backward and then upward in order to form a constriction with the palate. Through interaction with the air flow, the tip of the tongue is set into vibration. Then it moves down to the area of the vowel <a> and then forward to its resting position. The trajectories of <r'a> differ from those of <ra> in that firstly, the constriction point of <r'a> lies (about 5 mm) more to the front and secondly, the front of the tongue moves somewhat forward in the direction to the position of the glide [j] after the tip of the tongue begins to vibrate. This forward movement is even greater for <r(')ja>. The difference is about 5 mm. On the whole, the trajectories of <r'a> lie again between those of <ra> and <r(')ja> and are more similar to those of <r(')ja> than to those of <ra>. This can be confirmed by data for many other consonants. Acoustically, palatalization and [j]-insertion resemble each other so much that most non-native speakers of Russian have difficulties distinguishing them.

DISCUSSIONS

The EMA investigation of the trajectories of tongue movements shows that there are similarities as well as differences between palatalization and [j]-insertion. It also shows that there are constants as well as variants in speech production. On the one hand, each sound requires a certain vocal tract configuration in order to be able to be distinct from other sounds in the language system. On the other hand, the various articulators are able to compensate for each other, so that each articulator has a greater degree of freedom. This speech-physiological interpretation of polymorphism supports the assumptions of generative phonology that even among distinctive phonemes in a language, there are still some overlapping of articulatory and acoustic elements.

In this sense, palatalization means the partial take-over of the acoustic and articulatory elements of the palatal glide [j] and, at the same time, differentiation from [j]-insertion. This means more exact spatial and temporal coordination between various articulators. Spatially, the trajectories of the palatalized consonant reach only the peripheral area of the glide [j], whereas those of the corresponding syllable with [j]-insertion pass through its center. The whole vocal tract is so configured for the palatalized consonant that it acquires the partial acoustic effect of a palatal fricative. At the same time, it is temporally so coordinated that the trajectories of the palatalized consonant pass the area for the glide [j] in approximately 20-30 msec less than the trajectories of the corresponding syllable with [j]-insertion. Thus, under certain circumstances the consonant and the short glide would be treated as a new consonant rather than two segments of a syllable.

In a broader sense, palatalization is a reduction of "extravagant" speech movements in the motor realization of the whole speech sequence. Since velar consonants and dental consonants require a greater extent of speech movement from the neutral position of the tongue than palatal consonants, they tend to be reduced to palatal consonants. This extended interpretation of palatalization can offer a unified explanation for palatalization at the phonetic level as well as palatalization at the historical, morphonemic level.

CONCLUSION

EMA investigation shows that palatalization can be treated in a wider framework of dynamic speech motor planning as an optimization of speech movement in the total planning of the whole speech sequence. This optimization of speech movements in various speech environments may result in a differentiation of the structure of a language.

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