MRI-based contrastive study of nasal and oral labial consonants' articulations in Russian

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Abstract

The MRI-based contrastive investigation of Russian nasal and oral hard and soft labial consonants' articulations was carried out upon original technology elaborated for real-time MRI visualization of the speech articulation dynamics. A crucial distinctive role of the velum configurations has been proved for this type of Russian consonantal production. Main differences between palatalized and non-palatalized articulatory patterns of the experimental consonants were depicted and some coarticulation constraints resultant from compatibility of various elements in CV clusters propounded.

1. Introduction

Experimental investigation of Russian nasal articulations has been until nowadays fragmentary and mainly based upon rather ambiguous interpretation of acoustic data. The only direct observation of articulatory processes in Russian speech dates back to the 1960s-1970s, when L. Skalozub, being a single Russian experimentalist in the field of direct observation of articulatory processes, completed a series of wide-ranging studies of articulation dynamic models using x-ray processing of natural speech [1]. One of the main targets of her investigation of Russian articulation patterns was a comparison of articulation dynamics of non-palatalized ("hard") and palatalized ("soft") consonantal pairs. The experimental data consisted of manually traced profiles of the articulatory tract observed during phonation of various Russian consonants in certain frame sets (CVC, C'VC, etc.). One of the sidelines of her large-scale investigation of Russian consonantal articulations was processing of articulation profiles of palatalized and non-palatalized consonants of various places of articulation and their potential clustering. Thus, she published some footnotes upon articulatory patterns of labial stops, nasal bilabial sonant [m] included. Skalozub hypothesized that all Russian hard labial and labiodental consonants ([v], [f], [m], [b], [p]) form a single class from the articulatory point of view. She also stated that the vocal tract contours drawn upon x-ray filming of soft and hard consonants in experimental sessions of producing natural and pseudo speech stimuli differed drastically either in stationary phase of a sound or in its dynamic deployment (motor stereotyping). Furthermore, these vocal tract configurations revealed a sort of commonalities in overall contour typical for all palatalized consonants independent of the place of articulation, that L. Skalozub defined as dorsal articulation posture in the pre-palatal section of the articulatory tract [2]. However, at that time a substantial insufficiency in the data prevented L. Skalozub from more specific investigation of various types of consonants, therefore numerous significant aspects of the Russian speech articulation processes – labial and nasal articulations and co-articulation processes among them – remain still unexplored. Our current research aims to fill this gap.

The current research of nasal and non-nasal labial consonants' articulations forms an integral part of a broader magnetic resonance imaging investigation of the complete inventory of articulatory motor patterns representative for contemporary Russian language pronunciation practices. Currently there is a considerable deficiency of authentic experimental research of Russian articulatory patterns based upon on-line MR-imaging techniques either for the vocal or consonant system of the Russian language. The first and unique precedent MRI-based research of the Russian vowels and consonantal articulatory patterns, as well as pilot investigation of main anticipatory coarticulation models observed during anticipatory and carry-over pausal fragments in-between speech production activity (pre-adjustment and succeeding articulatory movements for various vowels' production), has been recently reported in [3]. In this paper we expose for discussion some new results of a contrastive MRI investigation of Russian nasal and oral non-palatalized and palatalized labial consonant's articulations (namely, comparison between articulatory patterns of the Russian hard phonemes [m], [b] and their soft counterparts [m'], [b']). The research in question differs from previous investigation of the Russian consonantal production processes both in technology (MRI vs. X-ray cinematography) and methodology (natural speaking vs. pre-regulated phonation), as well as in its local targets (multiple subjects, unbounded time frame vs. restricted number of speakers, limited time frame) and experimental material (random speech samples vs. targeted sampling).

2. MRI specifications and experimental methodology

Technical parameters of MRI experimental sessions were as follows: MR scanning activity was executed by the pulse sequence 'gradient echo' on sagittal cut with the slice thickness of 9 mm and to a field of view 200*120 mm. Under these conditions it has become possible to obtain MR images with 2.7 frames in a second and with 3 mm in-plane resolution. All MRI experiments were realized on a 0.5 T MR system (Tomikon S50 "Bruker") at the Research Center for MRI and MRS of Moscow State University. The speaking subject was lying in supine position with his head placed inside the receiver coil of the MRI unit. Consistently with generally accepted MRI experimental techniques simultaneous audio recordings taken via a microphone fixed on a receiver's coil close to the speaker's mouth have been arranged. As this recording was strongly dominated by the MR scanning machine noise a parallel recording of the starting points of MRI sequences was also previewed. The recordings were delivered to two expert phoneticians as a two-channel oscillogram along with recording of the same speech stimuli in a studio, enabling therefore precise timing of an MR image with a particular phase of phonation for future identification and labeling.

It's well known that any MRI investigation of major part of consonantal production and coarticulation processes is facing two serious challenges: 1) very short duration of the occlusive phase of a stop or affricate consonant and overall velocity of articulatory movements, and 2) lack of MR signal from the teeth as objects consisting of solid calciferous tissue. The first problem could be mainly done by the on-line dynamic MRI technique, successfully applied in [4] and [5]. This technique relies on gated scanning of numerous repetitions of the same speech sequence to reconstruct the real articulatory movement progressing in time. Eventually, the reconstructed sequence of on-line MR images could be plotted from across several repetitions. As we've had at our disposal for each subject his/her audio-recordings of the phonation processes consistent with time-markers of the starting points of MRI launchings, the exact temporal tagging of every MR image as well as its linguistic interpretation became possible.

3. Experimental material

According to the previously tested and approved experimental instructions a speaking subject was asked to produce a series of VCCV sequences (Russian pseudo-words with the second vowel stressed) containing Russian consonants [b], [m], [b'], [m'] in the [a]_[a], [i]_[i] and [a]_[e] vocalic frame set, that is a[b:]**a**, a[m:]**a**; a[b':]**a**, a[m':]**a**; i[b':]**i**, i[m':]**i**; a[b:]**e**, a[m:]**e;** a[b':]**e**, a[m':]**e**, repeating each stimulus several times during a session of MR image acquisition at voluntary pace. The main interest was focused on the [a]_[a] and

[a]_[e] contexts, being minimal distinctive positions for hard and soft consonantal correlates. Another contrastive pair has been formed by a nasal and non-nasalized (oral) bilabial consonants ([m], [b]) and their palatalized counterparts [m'], [b']). The whole data set of MR images of the experimental stimuli collected through all experimental MRI acquisitions consisted of 500 MR-images: at 100 images with [ab:á] and [am:á] articulations, [ab':á] and [am':á], [ab:é] and [am:é], [ab':é] and [am':é], [am':í] and [ab':í] ones. Each MR-image from experimental dataset has been identified and ascribed to the corresponding phase of every phoneme's realization.

4. Results

Experimental data presented in our data set have a notable degree of articulatory contours' matching for each type of hard and soft consonants under investigation irrespective of most vocalic contexts. So, one could suppose that the observed motor stereotyping presumably resulted from a phoneme's inherent properties and far less from a specific phonetic context. Typical vocal tract configuration patterns of hard and soft labial nasal consonants under investigation are exposed on figure 1 and 2.

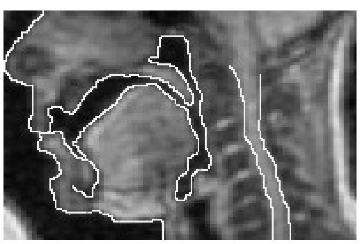

Figure 1: *MR-image of the occlusion phase of* [m] *with a manually traced contour (white line).*

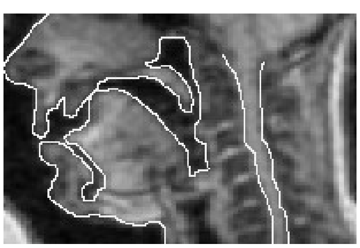

Figure 2: *MR-image of the occlusion phase of* [m'] *with a manually traced contour (white line).*

The same type of images of non-nasal consonants under investigation are exposed on figure 3 and 4.

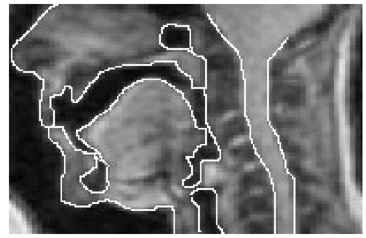

Figure 3: *MR-image of the occlusion phase of* [b] *with a manually traced contour (white line).*

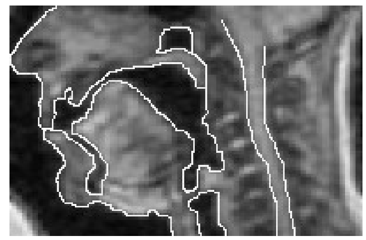

Figure 4: *MR-image of the occlusion phase of* [b'] *with a manually traced contour (white line).*

A juxtaposition of articulatory contours for phonemes [m] and [b] is exposed on figure 5.

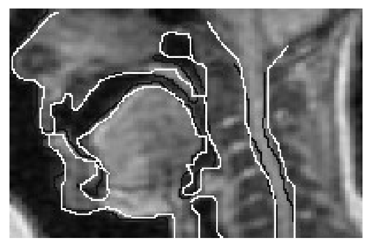

Figure 5: *MR-image of the occlusion phase of* [m] *with a contour of the* [b] *occlusion phase.*

A juxtaposition of articulatory contours for phonemes [m'] and [b'] is exposed on figure 6.

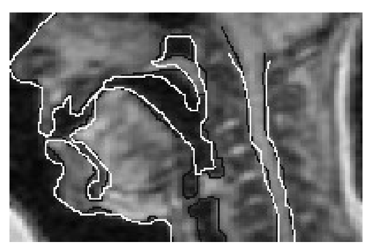

Figure 6: *MR-image of the occlusion phase of* [b'] *with a contour of the* [m'] *occlusion phase.*

5. Discussion

Our experimental data present a considerable grade of image matching within each class of hard and soft labial consonants, either nasal or non-nasal. Thus, the only differences between nasal and non-nasal labial consonants' articulations seem to be determined exclusively by specific configuration and position of the soft palate (velum) and the larynx (higher in palatalized nasals). Another noteworthy observation deals with apparent nasalization of the vowel [a] in the frame set with nasal consonants, as all the vowel's articulatory contours in a data set of 100 items revealed certain degree of vowel's nasalization, indicated on an image by the fact that the passage to the nose cavity has not been fully closed. It is worth also mentioning that Russian phonological system does not have nasalized vowels as special phonemes. The opinion that the articulation of vowel [a] in Russian is generally characterized by an incomplete closure of the velum (see also [6]) has not been confirmed in the experimental dataset of other speakers.

The hypothesis on completely diverse articulatory patterns for majority of hard and soft consonants in Russian has been also strongly supported by our experimental data (see juxtaposition of consonants' contours on figure 7).

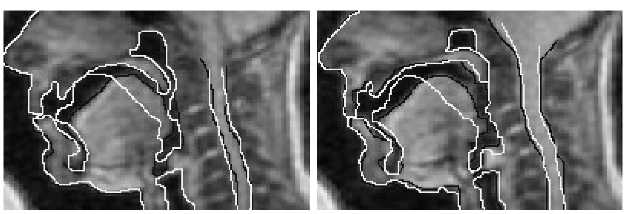

Figure 7: *MR-image of the occlusion phase of* [m] *with the contour of the* [m'] *occlusion phase (left) and of* [b] *with the contour of the* [b'] *occlusion phase (right).*

We suppose this differences being the main reason for strong phonotactical constraints observed in the modern Russian language pronunciation practice. The Russian standard pronunciation dictionaries contain only very few words with the hard labial nasal consonant [m] or bi-labial stop consonant [b] preceding vowel [e] within the single syllable: [mer] (city mayor), [mejnstr'ím] (mainstream), [ber] (rem), [bekvakál] (back-vokal). It is worth mentioning that most of these words are recently adopted into Russian, or form a minimal distinctive pair (as for "city mayor"). In the absolute majority of other foreign adoptions of frequent occurrence in Russian a palatalized consonant phoneme within a CV cluster [m] + [e] or [b] + [e] is recommended as a standard pronunciation: [m'éd'ium] (medium), [b'eʒ] (beige), [b'ekón] (bacon), etc.

5. Conclusion

The methodological and technological approach elaborated in current investigation of nasal and oral labial consonants in Russian has proved its validity and could be recommended for implementation in the cases where other methods of direct on-line observation of articulatory processes are not available. Preliminary observations on the physical nature of compatibility constraints for various Russian articulations would serve as a basis for further research in the field.

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