WITHIN-WORD ARTICULATORY EFFECT OF VOWEL ROUNDING

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ABSTRACT

Unrounded Russian vowel phonemes are occasionally pronounced as rounded in unstressed positions when one of the following vowels is rounded. Such pronunciations are considered to be standard, although these vowels are usually not perceived as rounded by naive speakers of Russian. The research is aimed at investigating the underlying articulatory lip gestures. The experimental material consisted of audio and EMA recordings of 82 phrases read five times by two female and two male speakers in a soundproof studio. The analysis of EMA data showed that there is a single monotonous lip closure and protrusion gesture over the whole unstressed part of phonological word starting at the beginning of unstressed part of the word and ending at the last rounded vowel of that unstressed part. The stressed rounded vowel, on the contrary, does not cause rounding of the preceding vowels.

Keywords: Rounding, coarticulation, unstressed vowels, Russian, electromagnetic articulography.

1. INTRODUCTION

The aim of this paper is to explore anticipatory coarticulation effect of rounded vowels on articulation of the preceding sounds in speech.

Starting from Öhman's [11] groundbreaking research of V-to-V coarticulation, this phenomenon has been widely investigated. V-to-V coarticulation depends on the language [4], [5], coarticulated vowels and intervening consonants [13], prosodic context [6], age of speakers [14]. Recent research showed the possibility of long-distance vowel-to-vowel coarticulation [9], [1].

This study investigates the extent of V-to-V coarticulation in case of rounded vowels. The rounding is chosen as it is neutral to tongue gestures.

Perkell made a research of lip movement onset prior to onset of voicing of /u/, regardless of the number of 'neutral' consonants in /$V_{unrounded}C_nU$/ utterance and showed that dental consonants do not block coarticulation in terms of lower lip protrusion. But what if there were vowels in between?

Standard Russian is known for strong reduction of unstressed vowels [2], [3], [7]. There are two degrees of vowel reduction depending on the position within a word: (1) immediately pretonic or word-initial; (2) other pretonic or post-tonic positions. Vowels /o/ and /ɑ/ are produced as [ə] in non-immediately-pretonic syllables after vowels and non-palatalized consonants.

In Russian, unstressed vowel /ɑ/ tends to be rounded in the vicinity of rounded vowels. It was proved by the acoustic analysis [3] and easily perceived by native speakers of Russian. This pronunciation was named alternative in the notes to the recent pronunciation dictionary of Russian [10, p. 942]. As Bondarko noted, "a specific type of labial vowel harmony is observed when an unstressed allophone of an unrounded phoneme preceding another unstressed but rounded one is also produced as rounded" in a pre-tonic part of a word in connected speech [3, p. 266], e.g, 'голубому' /gɑluˈbomu/ (dat.sg.masc 'blue') tends to be pronounced as /guluˈbomu/.

The aim of the study is to analyse lip gestures produced in [ɑ*u] sequence, when different number of vowels and consonants occur between [ɑ] and [u]. The analysis is done by means of electromagnetic articulography (EMA).

2. METHOD AND MATERIAL

2.1. Data acquisition

We acquired articulatory data by means of electromagnetic articulography (EMA; AG501, Carstens Medizinelektronik) with a sampling rate of 1.25 kHz together with synchronized audio at 25.6 kHz. Standard procedures developed by Cartens Medizinelektronik for head movement correction were applied. The speech was recorded in sound-proof studio. We attached three sensors to the tongue: tongue tip (TT), tongue mid (TM) and dorsal region of the tongue (TB). Two sensors were placed on the upper and lower lips (UL, LL). One sensor was placed to the lower incisor (JAW) to capture jaw movement and estimate lip protrusion. Three reference sensors were attached to the nose ridge and on the mastoid process behind both ears to correct head movements.

2.2. Speakers

We have recorded four speakers aged 25-35: two female and two male. As reduction patterns, including rounding of unstressed vowels, differ in standard Russian and some dialects [2], [7], we recorded only speakers of standard Russian who were born in Moscow or Saint Petersburg and have spend most of their life in the native cities.

2.3. Corpus design

A specially designed set of 84 sentences was used as a material for the recordings. The sentences were composed to demonstrate the influence of the following factors on vowel rounding.

1. Presence of a labial consonant before the vowel (‘попугай’, /**pɑ**puˈgaj/, nom.sg ‘parrot’) or its absence (‘голубой’, /**gɑ**luˈboj/, nom.sg.masc ‘blue’).
2. The position of a rounded vowel which may influence the current vowel in terms of rounding, either in the following syllable (‘голубой’, /g**ɑ**l**u**ˈboj/, nom.sg.masc ‘blue’) or in the next but one (‘годовую’, /g**ɑ**d**ɑ**ˈvuju/, acc.sg.fem ‘annual’).
3. Occurrence of both vowels within one word (‘попугай’, /p**ɑ**p**u**ˈgaj/, nom.sg ‘parrot’) or in adjacent words (‘папа купил’, /ˈpɑp**ɑ** k**u**ˈpil/, nom.sg ‘father bought’).
4. Position of the vowel relative to stress: non-immediately-pretonic (‘голубой’, /g**ɑ**luˈboj/, nom.sg.masc ‘blue’), immediately-pretonic (‘голубка’, /g**ɑ**ˈlupkɑ/, nom.sg ‘dove’), stressed (‘каску-то’, /ˈk**ɑ**sku tɑ/, acc.sg ‘the hard hat’), and post-tonic syllable (‘по нескольку’, /pɑ ˈnʲesk**ɑ**lʲˈku/, ‘by several’).
5. A phrase position of a word: initial, middle, final, and in isolation.

Each sentence was read by the speakers four times (twice slowly and twice fast). The speech rate was controlled by slide demonstration time: 3 seconds for slow speech and 1.5 seconds for fast speech. In total, each speaker read 336 sentences and 84 isolated words or word pairs (for cases of adjacent words, see factor #3 described above). The slides with sentences and words were randomly presented to a speaker.

2.4. Labeling

All the recordings were manually annotated by a phonetician. Precision of annotation was the main focus. Phonetic transcription of the data was done based on auditory and acoustic analysis. Each phrase was annotated in a minimal required way as follows.

- The target word or two adjacent words were labelled (in case of possible rounding at word boundaries).
- The target word or words were segmented into the actually pronounced sounds.
- Orthoepic phonetic transcription was done for each word.
- Broad transcription was done for each pronounced sound.
- Orthoepic and broad transcription tiers were aligned with each other.

Note, that the preliminary analysis of the annotation showed that some pretonic and post-tonic vowels including the investigated ones were not pronounced at all.

2.5. Measurements

The articulatory movements were obtained for each articulator by means of mview algorithm developed by Mark Tiede [15]. Two kinds of labial gestures were measured. First, lip aperture (LA)—the Euclidean distance between the sensors attached to the upper and lower lips. Second, lip protrusion of the lower lip (LP)—the Euclidean distance between the sensors attached to the lower lip and jaw. Both articulator's movements and tangential velocities were used to describe articulatory gestures. We have investigated lip gestures leading to vowel rounding depending on the factors described in section 2.3, primarily on the position of a vowel within a word.

Each vowel was automatically characterized with estimates of the most prominent values of LA and LP. The estimation procedure was the following. First, we extracted lip movement within the vowel boundaries. The extracted movement was modelled by a quadratic polynomial. The position of the most prominent extremum of lip movement was defined as the point where the derivative of the calculated polynomial equalled zero. These values were calculated for both LA and LP.

3. RESULTS

The analysis of our data showed that the major factor influencing anticipatory coarticulation is stress. Neither a stressed /ɑ/ is influenced by the following /u/, nor a stressed /u/ influences the preceding /ɑ/, see Table 1 and Table 2. Figure 1 illustartes that immediately-prestressed /ɑ/ is not rounded in presence of the following stressed /u/.

There is an evidence for anticipatory coarticulation between vowels in pretonic and post-tonic ɑCu

Figure 1: LA and LP kinematics while speaking ‘голубка’, /gɑˈlupkɑ/, ‘dove’.

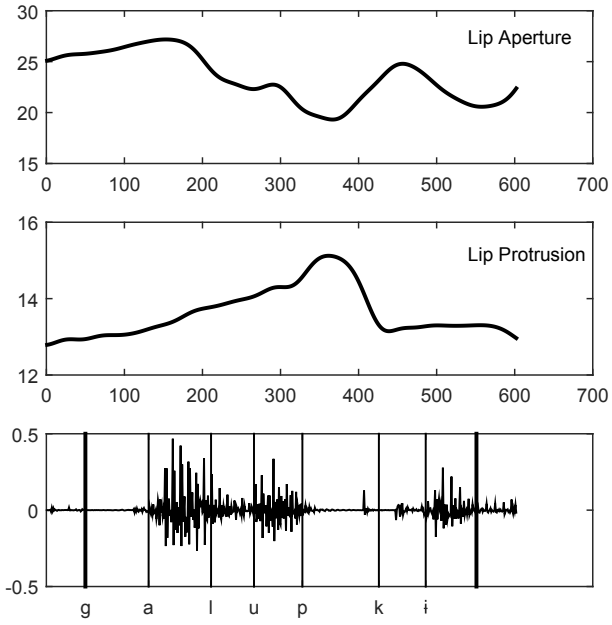


Figure 2: LA and LP kinematics while speaking ‘голубика’, /gɑluˈbʲikɑ/, ‘blueberry’.

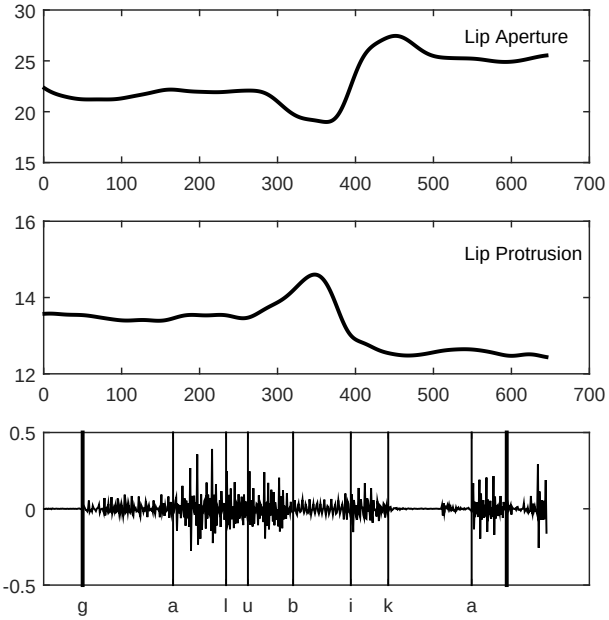


Table 1: Mean difference in LA and LP between V1 and V2 in V1CV2 sequence depending on the position relative to a word stress calculated in mm.

Position of vowels	Δ LA	Δ LP
pretonic V1 and V2	0.64	-0.12
pretonic V1 and stressed V2	2.45	-1.01
stressed V1 and post-tonic V2	1.64	-0.53
post-tonic V1 and V2	0.12	-0.06

Table 2: The relative number of vowels /ɑ/ produced as rounded /u/ in various word stress positions: 1—non-immediately-pretonic, 2—immediately-pretonic, 3—stressed, 4—post-tonic. All values are in percent.

Vowel	1	2	3	4
unrounded pron. (/ɑ/)	68.5	100	100	75.7
rounded pron. (/u/)	31.5	0	0	24.3

sequences (hereinafter ‘C’ - is any consonant), see Fig. 2. See that non-immediately-prestressed /ɑ/ is rounded and there is some kind of plateau on LA and LP plots along both syllables /gɑlu/.

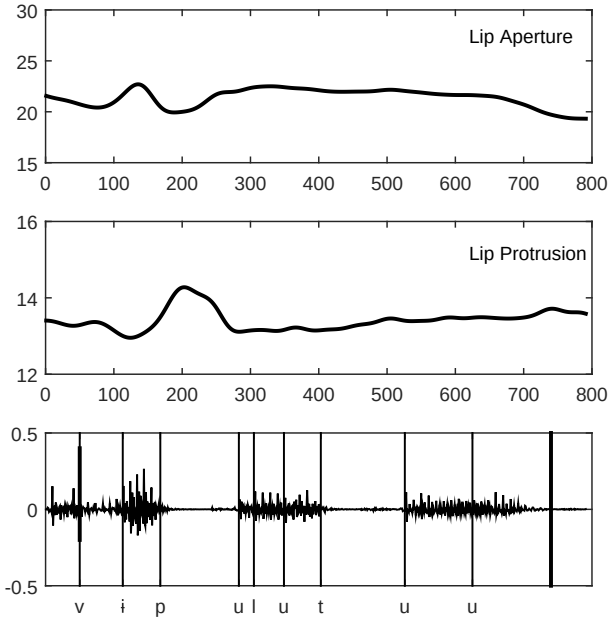
We have also found evidence for certain coarticulation between vowels in post-tonic ɑCɑCu sequences, see Fig. 3. Post-tonic non-final vowels /ɑ/ are of the 2nd degree of reduction and are realized as [ə]. It seems that [ə] in Russian is ‘neutral’ to lip rounding. From this point of view these [ə] realizations of /ɑ/ are opposed to immediately-pretonic [ʌ] realizations of the 1st degree of reduction of /ɑ/ as in Fig. 1. This must be tested further as there is one more position in the word with the 1st degree of reduction /ɑ/—initial pretonic. We have no words beginning with unstressed ɑCu (e.g. ‘акуратно’, /ɑkuˈrɑtnɑ/, ‘be careful’) in our material to investigate lip movements. Nevertheless, we expect no anticipatory coarticulation in these words either, as it is not mentioned in the pronunciation dictionary of Russian [10]. But of course it requires further testing.

There are a number of cases in our material when anticipatory assimilation goes across word boundaries. Figure 4 illustrates this phenomenon presenting pronunciation of adjacent words ‘палата-то голубого’ (ward blue), which are a part of a sentence ‘Палата-то голубого цвета’ (The ward (has) blue colour). The words are not only separate phonological words here, but they have no direct syntactic link between them as the word ‘голубого’ (blue) is syntactically connected with the following noun ‘цвета’ (colour). Nevertheless, they are pronounced with one lip movement. One can see that two post-tonic syllables of the first word and two pretonic syllables of the second word are pronounced with one lip movement: there is a plateau on LA plot and a single monotonous rise of LP plot. The cases are

rear—less than 10 %, but they are evidence for long-distance anticipatory coarticulation in Russian.

4. DISCUSSION AND CONCLUSIONS

Figure 3: LA and LP kinematics while speaking ‘выполотую’, /ˈvɨpɑlɑtuju/, ‘weeded out’.

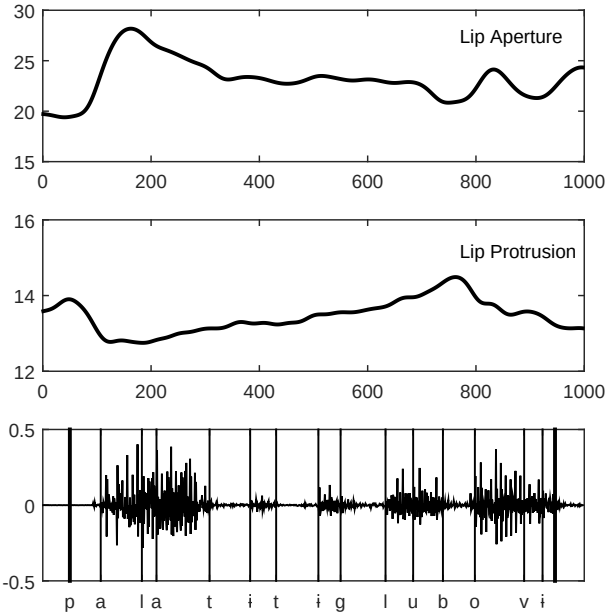


The amplitude of lip protrusion in our data does not exceed 2 mm, which is very small in comparison with sensor size and the confidence interval of spatial measurements. Thus speaking about lip protrusion we can only speak of tendencies, but cannot propose a coarticulation model of lip movements triggered by rounded vowels. In our experiment we followed the well-established design of EMA recordings developed at the Institute of Phonetics and Speech Processing, Ludwig-Maximilians Universität and Haskins Laboratory. The places to attach the ‘lip’ sensors are the middle of vermilion border of the lips. These points do not move much relative to the alveolar process, where ‘jaw’ sensors are attached. The better points would be the procheilon for the upper lip and its counter point on the lower lip. The problem is that in this case sensors would clash with each other during pronunciation of labial stops. So far we see no perfect solution for this problem.

The LA and LP gestures are not completely straight from one vowel to another, there are fluctuations caused by consonants that reflect underlying speech motor control processes or air-flow, as it was discussed earlier by Perkell [12] and Fuchs with colleagues [8].

Our experimental results show the allophone [ə] of /ɑ/ in Russian is anticipatory assimilated with the following /u/. Moreover this anticipatory assimilation may influence two [ə] in a row. It means that not only consonants may be ‘neutral’ to lip rounding, but vowels as well. Our results showed the difference between two degrees of vowel reduction in Russian from articulatory point of view, as /ɑ/ of the 1st degree of reduction ([ʌ]) is not rounded due to anticipatory coarticulation.

Figure 4: LA and LP kinematics while speaking ‘палата-то голубого (цвета)’, /pɑˈlɑtɑtɑ gɑluˈbovɑ/, ‘the ward (has) blue (colour)’.



The anticipatory assimilation in Russian may be up to 500 ms long and go across word boundaries. This argues for the possibility of long-distance spreading harmonies in case of no blocking phenomena even in languages with no vowel or consonant harmony.

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