An Ultrasound Investigation of Secondary Velarization in Russian

by

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B.A., Minsk State Linguistic University, 2009

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Abstract

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The present study aims to resolve previous disputes about whether or not non-palatalized consonants exhibit secondary velarization in Russian, and if so what this corresponds to articulatorily. Three questions are asked: 1) are Russian non-palatalized consonants velarized or not? If so, 2) what are the articulatory properties of velarization? and 3) how is the presence or absence of secondary velarization affected by adjacent vowels? To answer these questions, laryngeal and lingual ultrasound investigations were conducted on a range of non-palatalized consonants across different vowel contexts. The results of the study show that 1) Russian non-palatalized consonants are not pharyngealized in the sense of Esling (1996, 1999, 2005), 2) /l/ and /f/ are uvularized, 3) /s/ and /ʂ/ can feature either uvularization or velarization. The study also shows that secondary articulations of Russian non-palatalized consonants are inherent rather than dependent on vowel context.

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Chapter 1

Introduction

The issue of secondary velarization in Russian has always caused a fair amount of controversy among researchers. Secondary velarization is an articulation characterized by the raising of the back of the tongue towards the soft palate. Some researchers claim it to be a feature of all Russian non-palatalized consonants (Knyazev 2002, Kasatkin 2007, Kodzasov & Krivnova 2001, etc.), while others attest to velarization of only a subset of consonants (Baudouin de Courtenay 1913/1914, Bogoroditsky 1930, Skalozub 1963, etc.) or reject it altogether, except for [ɫ] (Matusevich 1976, Ladefoged & Maddieson 1996). Bolla (1981) considers Russian non-palatalized consonants pharyngealized, rather than velarized. Most complete and systematic experimental investigations of Russian consonants are rather old and rely on older technology, e.g. palatography, X-ray, odontography (Skalozub 1963, Bolla 1981). More recent studies of secondary articulations have employed MRI [1] (Kedrova et al. 2008, 2011) and EMMA [2] (Kochetov 2002, 2009), however they have yielded limited results due to small subsets of consonants used (e.g. Kochetov 2002, 2005, 2009; Kedrova et al. 2008, 2011) and/or a single vowel context [a] (Kochetov 2002, 2005, 2009). In the present study, we took into consideration the limitations of previous studies and have made an attempt to design a methodology that could move towards resolving the debate in the phonetic literature. We present the first articulatory study after Skalozub (1963) and Bolla's works (1981) that has aimed at a systematic investigation of a large set of Russian non-palatalized consonants across different vowel contexts. We used *lingual* and *laryngeal* ultrasound imaging, a modern safe and non-invasive

[1] MRI - Magnetic Resonance Imaging
[2] EMMA - Electromagnetic Midsagittal Articulometer (Perkell et al. 1992)

technique, to examine tongue shape and larynx height during the production of Russian non-palatalized consonants. The goal of an ultrasound investigation was threefold: to determine 1) whether Russian non-palatalized consonants are velarized or not, and if so 2) what the articulatory properties of velarization are, and 3) how the presence or absence of secondary velarization is affected by adjacent vowels. We elicited Russian CV sequences, where C was a voiceless non-palatalized fricative, namely [f, s, ʂ, x], or the lateral [l], and V was the vowel [a] or [ɛ]. The choice of these vowels is explained by investigation of the phonotactics of Russian CV sequences, which suggests a certain articulatory conflict between Russian hard consonants and the front vowel [ɛ].We hypothesized that the reason for this is that Russian non-palatalized Cs are velarized and this gesture conflicts with the fronted tongue position during [ɛ]. The velar consonant [x] and the tongue rest position were used as reference points for determining velarization and uvularization on extracted tongue contours.

The results of the study suggest that all Russian non-palatalized consonants are *uvularized* and in some cases *velarized*. The study also suggests that Russian non-palatalized consonants are not pharyngealized. Interestingly, the data analysis showed no influence of the following vowel on the tongue shape of the preceding consonant, which suggests that the secondary articulation, i.e. *uvularization* (and *velarization*), to the extent that it exists, is inherent to the consonant and not simply an effect of the adjacent vowel.

This study increases our understanding of the articulation of Russian non-palatalized consonants. It also provides a visual tool for phoneticians, teachers and learners of the Russian language for teaching appropriate articulation of non-palatalized consonants.

The remainder of the paper provides the details of the study outlined above. Chapter 2 provides the background on velarization in Russian and discusses the sources of disagreements found in the phonetic literature; section 3 lays out the methodology of data collection and data analysis. Section 4 presents the results. In section 5, we provide the discussion of results. Finally, in section 6, we conclude about the major findings of this study.

Chapter 2

Background on velarization

Section 2.1 focuses on the relations between velarization and palatalization in Russian; section 2.2 discusses two diametrically opposing views on the presence/absence of secondary velarization in Russian non-palatalized consonants; section 2.3 outlines the ideas of pharyngealization of Russian non-palatalized consonants rather than their velarization; section 2.4 discusses the possible influence of vowels on secondary velarization; section 2.5 attempts to identify the sources of disagreements found in the phonetic literature. Section 2.6 summarizes the sources of the dispute, outlines how the limitations of previous studies have been addressed in the present paper and introduces the terminology adopted in the present research.

2.1 Velarization in contrast to palatalization

The phonetic system of the Russian Standard language, as well as of most Russian dialects, is characterized by the phonological opposition of consonants according to the differentiating feature ‘softness/hardness’. Few consonants are not involved in this opposition. In general, Russian distinguishes 33 consonantal phonemes. However linguists differ in their classification of seven additional consonants because they occur only in phonologically predictable contexts or in foreign words, and are therefore frequently considered allophones (Gildersleeve-Neumann & Wright 2010:431). Table 1 below shows the consonant inventory of the Russian language as presented in Gildersleeve-Neumann & Wright (2010). Unlike Gildersleeve-Neumann & Wright (2010), we assume that post-alveolar fricatives in Russian are retroflex, rather than alveo-palatal, based on Hamann’s observations (2002a, 2002b, 2004) and on our own data. Therefore, in the present study we use the IPA symbols [ʂ] and [ʐ] symbolizing retroflexes, rather than [ʃ] and [ʒ] as in Table 1 below.

Table 1. Classification of Russian consonant phonemes and allophones by place and manner of articulation; shaded phones are defined as allophones by the majority of linguists (Akishina & Baranovskaya, 1990; Andrews, n.d.; Hamilton, 1980; Kedrova et al., 2002) (retrieved from Gildersleeve-Neumann & Wright 2010:431).

		Place													
		Labial				*Coronal*						*Dorsal*			
		Bilabial		*Labio-dental*		*Dental*		*Alveolar*		*Alveo-palatal*		*Palatal*		*Velar*	
Manner	*Voicing*	*Hard*	*Soft*	*Hard*	*Soft*	*Hard*	*Soft*	*Hard*	*Soft*	*Hard*	*Soft*	*Hard*	*Soft*	*Hard*	*Soft*
Stop	voiceless	p	p^j			t	t^j							k	k^j
	voiced	b	b^j			d	d^j							g	g^j
Fricative	voiceless			f	f^j	s	s^j			ʃ			ʃ^j:	x	x^j
	voiced			v	v^j	z	z^j			ʒ			ʒ^j:	ɣ	
Affricate	voiceless							ts					ʧ^j		
	voiced							dz					ʤ^j		
Nasal	voiced	m	m^j			n	n^j								
Lateral	voiced					l	l^j								
Trill	voiced							r	r^j						
Glide	voiced												j		

In the international literature, the opposition of ‘soft’ vs. ‘hard’ consonants is often referred to as the opposition of ‘palatalized’ vs. ‘non-palatalized’ consonants. Palatalization is a secondary articulation, characterized by the raising of the middle part of the tongue towards the palate. Bondarko (2005) maintains that such terminology distorts the essence of the opposition: phonetically, articulatory and acoustic correlates of ‘softness’ depend on the characteristics of each particular consonant. The only common feature the soft consonants possess is the [i]-transition into the following vowel, which carries the information on consonant softness at the perceptual level. However, equating this transition with ‘secondary palatalization’ is an unwarranted simplification. According to Bondarko, one can speak of secondary articulation only in the case of labials because the main, labial articulation is to a certain degree independent of the secondary articulation, i.e. palatalization. In the cases of consonants involving tongue articulation, the impact of palatalization is so strong that a new, different type of consonant in terms of place and/or manner of articulation emerges: for example, 'soft' coronal stops are affricated; the palatalized trill is characterized by the absence of taps and increased noise components, i.e. it approximates a fricative; palatalized velar consonants are practically not velar any more, as the active part of the tongue is greatly advanced (see table 2). Bondarko (2005) therefore argues that the term 'soft' is more appropriate when speaking about Russian palatalized consonants as it includes all the changes these consonants undergo in terms of place and manner of articulation.

Table 2. Type of change consonants undergo under the influence of palatalization

hard	**soft**	**type of change**
p	p^j	secondary articulation added
t	t^j	manner: stop → affricate
k	k^j	place: velar → palatal
r	r^j	manner: trill → fricative

According to Knyazev (2002), on the phonetic level the majority of soft consonants are characterized by secondary palatalization (whatever the precise characteristics may be – see above), while hard consonants are characterized by secondary velarization, except for [k, g, x], which are inherently velar. Velarization can be described as a narrowing between the back of the tongue and the soft palate, i.e. in the part of the vocal tract where the Russian vowels [ɨ] and [u] are articulated (Knyazev 2002:87). As with palatalization, the degree of velarization of different consonants differs. According to Knyazev (2002), [l, ʂ, ʐ] have the highest degree of velarization, which is why they are sometimes called 'bifocal' consonants, i.e. the consonants with two focuses, stressing the involvement of the back part of the tongue in their production. Other researchers stress the bifocal character of only [ʂ] and [ʐ] (for details see Scherba 1957, Matusevich 1976).

The dichotomy mentioned by Knyazev (2002), however, is not straightforward. The secondary velarization of Russian consonants has been a much debated issue since the beginning of experimental exploration of the Russian language. Some researchers argue for the existence of the opposition between palatalized and velarized consonants in the Russian language, though they mention varying degrees of velarization in different consonants (Kasatkin 2007, Kodzasov & Krivnova 2001, Bondarko 2005, Bolla 1981 etc.). Other phoneticians, relying on their perceptual observations and experimental data, conclude that Russian hard consonants may be either velarized or not (Baudouin de Courtenay 1913/1914, Scherba 1957, Brok 1910, Bogoroditsky 1930, Skalozub 1963, Jones &Ward 1969, Kochetov 2002). Yet another group of researchers do not recognize velarization of Russian consonants, except for the lateral [l] (Matusevich 1976, Ladefoged & Maddieson 1996). A detailed examination of questions related to Russian velarization is provided in Sections 2.2-2.5.

2.2 Velarization vs. no velarization

There is no full agreement among researchers about velarization of non-palatalized consonants in Russian. It is generally accepted that Russian hard consonants show some amount of velarization. Harris (2006:145) defines velarization as ‘a more or less simultaneous secondary articulation made by backwards and upwards movement of the back of the tongue towards the soft palate.’ He mentions that the phonetics literature on velarization is often confusing due to a number of terms used for the velarized consonants, such as ‘broad’, ‘hard’, or ‘dark’ as opposed to non-velarized consonants, called ‘palatalized’, ‘slender’, ‘soft’, or ‘light’. Harris (2006) notes that none of these terms makes sense phonetically and warns of the serious mistake of calling the non-velarized consonants palatalized since the non-velarized consonants may simply have no secondary articulation. In this paper, we use the terms ‘hard’ and ‘soft’, the term ‘soft’ referring to palatalized consonants, ‘hard’ referring to ‘non-palatalized’ consonants that can be either plain (this term is used by Kochetov, 2002 for consonants that are not palatalized and not velarized) or velarized. There are two IPA diacritics for velarization: one is [~], which is also used to symbolize pharyngealization; the second is the small raised voiced dorso-velar fricative symbol [ˠ] (Ladefoged 1993). The acoustic effects of velarization are a rise in the first formant, a lowering of the second formant, and a rise in the third formant (Fant 1960).

Bondarko (2005:8) notes an erroneous belief that there is an opposition between hard and velarized consonants in Russian. She provides an example from Laver (1994:333-334) where the Moscow accent was analyzed:

[dal] ‘distance’ vs. [dalˠ] ‘gave’

Laver describes [l] in the first word as plain, while in the second word, he classifies it as velarized. Bondarko corrects this observation noting that the consonant in the first word is not hard, but soft; the consonant in the second word is hard and indeed velarized. She mentions that strong velarization of the lateral sonorant [l] has been noted by all phoneticians.

Ladefoged & Maddieson (1996:361) state that the number of languages which clearly involve contrastive velarization is quite small. They mention that velarized consonants occur contrastively in several Malayo-Polynesian languages spoken in Micronesia. As an example, the authors name Marshallese, the inventory of which has plain and velarized nasals and liquids. Among stops the contrast is restricted to bilabials. As for Russian, Ladefoged & Maddieson (1996) mention that it is often said to have the contrastive opposition of palatalized (‘soft’) and velarized (‘hard’) consonants. Their study of the available X-ray images of the articulations in question (Skalozub’s data, 1963) has led them to the conclusion that the term ‘velarized’ may only be appropriate for the lateral /l/. The same opinion is held by Matusevich (1976).

In the 1960s, Skalozub conducted the most detailed and systematic phonetic study of Russian consonants to date. Her experiments included X-ray imaging, oscillography, indirect palatography and odontography. In her book «Палатограммы и рентгенограммы согласных фонем русского языка» (‘Palatograms and X-ray tracings of Russian consonant phonemes’), Skalozub (1963) discusses the opinions held among phoneticians of that time about the articulation of different types of consonants (e.g. labial plosives and fricatives, coronal plosives and fricatives, liquids) and presents the results of her own experiments aimed to verify those views.

Skalozub’s (1963) review of literature has suggested that velarization of labials is the least controversial among Russian hard consonants. Skalozub discusses the opinion in the phonetic literature about two places of articulation of Russian labial consonants: the labial gesture and the gesture of the back part of the tongue. Among the researchers acknowledging the secondary articulation of the back part of the tongue produced simultaneously with the main gesture (labial), i.e. velarization, are Baudouin de Courtenay (1913/1914), Bogoroditsky (1930), and O. Brok (1910). Baudouin de Courtenay (1913/1914) notes a slight velarization of Russian non-palatalized labial consonants. Brok (1910) assumes non-palatalized labial consonants (plosive and fricative) to have two places of articulation too, stating: ‘the tongue raises its back to the position of the vowel [u] simultaneously with the labial articulation’. However, the two researchers explain the nature of velarization differently. Baudouin de Courtenay (1913/1914) states that this secondary gesture of the back of the tongue is hardly noticeable, i.e. insignificant, and therefore he draws no connection between velarization and acoustic characteristics of non-palatalized labials. In his turn, Brok (1910) notes the direct dependence of the consonant timbre, its acoustic properties, on this secondary articulation, i.e. velarization. However, neither researcher's observations were supported by experimental data; rather, they were primarily based on the researchers' impressionistic observations of articulations. Bogoroditsky (1930) uses palatography to determine the tongue gestures during the articulation of Russian labial consonants. The palatograms of non-palatalized labial consonants appeared to be similar to that of the vowel [ɨ] and partially to labial vowels, i.e. [u] and [o]. Bogoroditsky also mentions that acoustically hard/non-palatalized labial consonants, especially plosives, in isolated position are characterized by an overtone resembling [ɨ]. All this suggests velarization of Russian non-palatalized labials. However, Skalozub (1963) notes that some researchers did not recognize the secondary velarization of Russian labials. Among them was Ershov (1903), who on the basis of palatography overtly denied velarization of labial consonants.

Velarization of the lateral [l] has also been debated in the phonetic literature. Skalozub mentions Scherba (1910), who rejects the secondary articulation of [l] based on his experimental data. Bogoroditsky (1930) and Ershov (1903) do not mention anything about velarization in their experimental studies, while Thomson (1911) and Brok (1910) attest to the raising of the back part of the tongue. Fricative consonants [ʂ] and [ʐ] are sometimes called sounds with a second focus (Skalozub names Baudouin de Courtenay 1913/1914 and Scherba 1957 with this respect). Such terminology stresses the involvement of two places of the tongue in their articulation, the second focus presumably being a strong velarization. Matusevich (1959, 1976) calls [ʂ] a fricative with a second back focus. In her book 'Современный русский язык' ('Contemporary Russian Language') (1976:137-138), she states that Russian [ʂ] has two sources of frication noise: the first is in the stricture between the tongue tip and the hard palate, and the second is in the stricture between the back part of the tongue and the soft palate, i.e. approximately in the place of articulation of [x]. [ʐ] is characterized by the same articulation but it is weaker in its tenseness and is accompanied by voice.

To summarize, Russian labials, the lateral [l] and the consonants [ʂ, ʐ] have been discussed in the literature cited by Skalozub as possibly having velarization. Articulatory studies of other consonants were also reviewed by Skalozub, however they provide no mention of velarization of those consonants.

Skalozub (1963) conducted a number of experiments to solve the observed disagreements on secondary velarization. On the basis of her palatographic and X-ray data she concludes that all non-palatalized labials are velarized as the back part of the tongue is pulled back and raised to the soft palate. Though Skalozub acknowledges velarization of both labial fricatives and plosives, she mentions a different velarization for labial fricatives in comparison to plosives. This fact can be accounted for by a backward gesture of the lower jaw when producing labial fricatives. As a result, the tongue is more back and leaves bigger marks on the artificial palate during palatography than plosive labials. As for the lateral [l], Skalozub (1963) in her X-ray images observes a convexity at the back part of the tongue, near the base of the tongue root (maybe better described as *uvularization*), though she notices that this convexity may be in the tongue region beneath the soft palate. Thus she concludes that [l] is velarized. In general, contemporary studies of Russian phonetics (Ladefoged & Maddieson 1996, Kochetov 2005, Bondarko 2005) agree on the velarization of the non-palatalized (hard) [l]. Kochetov (2005), in his magnetic articulometer study of palatalized and non-palatalized Russian laterals and rhotics observes the differences in the tongue configurations of /l/ and/ l$^{j/}$: while the tongue front is raised to the hard palate for $/l^{j}/$, it is lowered for /l/. Kochetov concludes that this can be accounted for by the tongue dorsum backing and raising, that is by velarization, which corresponds to Skalozub's findings (1963).

Skalozub (1963:34) also investigated the fricatives [ʂ], [ʐ]. Basing on her X-ray data, she comes to the conclusion that [ʂ] and [ʐ] may be called consonants with two focuses. According to Skalozub's data, their first focus is formed by the raised tongue tip and the tongue front, however the second focus is located not at the back of the tongue, but rather at the mid-back: Skalozub observed a significant convexity of the tongue in the middle part of the oral cavity. Therefore, she calls [ʂ] and [ʐ] consonants with a second mid-back focus. However, Skalozub (1963) reported on one speaker, for whom the form of the tongue during [ʂ] and [ʐ] differed sharply from the articulation described above. More specifically, the tongue did not show any convexity and/or a hollow in the middle of the tongue. In other words, the tongue was flat. Despite such differences in the configuration of the tongue of [ʂ], [ʐ] across her subjects, Skalozub (1963) attests to the same acoustic impression produced by the consonants with a flat tongue and those with a convexity in the mid-back of the tongue. This fact implies that both tongue shapes can actually represent one and the same phenomenon. If Russian hard [ʂ], [ʐ] are velarized, contrary to Skalozub's (1963) conclusions, it can suggest that the concavity in the middle of the tongue is not the only articulatory correlate of velarization. Rather the two different tongue configurations, i.e. a flat tongue and the tongue with a hollow in the middle, can be articulatory correlates of velarization. This implication though needs verification.

In plosive coronals [t], [d], [n], Skalozub distinguishes a convexity of the back part of the tongue in comparison to the rest position. For [t] it is greater than for [d]. However, there is no explicit statement about whether this convexity corresponds to velarization or not. Moreover, no mentioning of the relative location of this convexity with respect to the soft palate is provided. Therefore there is no clear evidence of velarization in [t], [d] and [n]. This corresponds to Kochetov's (2002) findings. Skalozub's palatographic and X-ray data of the fricative coronals [s], [z] suggest some convexity and raising of the back part of the tongue simultaneous to the flattening of the front part of the tongue. However, again the author does not overtly state whether the raising occurs in the region of the soft palate. The description of the fricative coronals provided by Skalozub does not allow us to clearly interpret the convexity of the back part of the tongue as the manifestation of velarization.

Thus, Skalozub's (1963) investigations show that at least the lateral [l] and labials are velarized in Russian. Velarization is considered by different researchers to involve some tongue body gesture: either backward (posterior) tongue movement or raising of the tongue towards the soft palate, or both gestures simultaneously.

2.3 Velarization vs. pharyngealization vs. uvularization

There exists an opinion that the Russian non-palatalized consonants are not velarized but rather pharyngealized. Bolla (1981), for example, identifies *pharyngealization* as a secondary articulation relevant to non-palatalized Russian consonants.

'Pharyngealization' is often defined as a secondary articulation produced with a lowered retracted back (of the dorsum) and root of the tongue towards the back wall of the pharynx, usually somewhere between the uvula and epiglottis (J.G. Harris in J.E. Harris 2006:146). Moisik (2013:51) calls such an approach of determining pharyngeal articulations *'linguo-centric'*, because the action of the tongue takes primacy in such accounts, overlooking articulations in the lower vocal tract. In other words, retraction of the tongue root is often considered the main articulatory correlate of pharyngealization. Bolla (1981) adopts this *'linguo-*

centric' treatment of pharyngeal articulations and claims that his radiographic investigations have convinced him that pharyngealization is a more suitable term than velarization when speaking about Russian non-palatalized consonants because he has found the movement of the root of the tongue and the back of the tongue towards the pharyngeal wall to be more important than that towards the soft palate (Bolla 1981:70). He argues that this phenomenon occurs with a considerable constriction of the resonating chamber near the pharynx, while the size of the front part of the oral cavity is increased. According to Bolla, almost all Russian non-palatalized consonants are pharyngealized, even [k, g], except for [x, γ]. Russian [f] is strongly pharyngealized; [s] and [r] are mildly pharyngealized. Kasatkin (2001:314) also notes pharyngealization of 'hard' (non-palatalized) consonants, though he mentions that non-palatalized consonants may also be velarized.

Kedrova et al. (2008, 2011) also work within the 'linguo-centric' framework. An MRI investigation of Russian bilabial consonants [b] and [m], which according to the authors are often considered the most prominent type of Russian velarized consonants, allowed Kedrova et al. (2011) to conclude that [b] before the vowel [ɛ] is not only velarized but also pharyngealized at the same time. The authors state that this fact can be partially accounted for by the affected pronunciation during MR imaging, as well as by the position of participants who were lying in supine position. Kedrova's et al. (2008) MRI study of Russian palatalized vs. non-palatalized stops and spirants showed the raising gesture of the tongue dorsum in the front region and restriction of the tongue root in palatalized segments in contrast to considerable backing of the tongue in the non-palatalized segments, which could imply pharyngealization of hard consonants within the 'linguo-centric' approach to pharyngeal productions. However, recent laryngoscopic and ultrasound investigations of the lower vocal tract, i.e. the larynx, suggest that the Kedrova's way of determining pharyngealization (and that of her colleagues) is out-of-date.

Esling (2005:14) claims that it is not strictly anatomically correct to consider the movement of the tongue in the mouth independently of other articulators. Rather, these other articulators control what the tongue is doing. Esling (1996, 1999, 2005, etc) introduces the *Laryngeal Articulator Model* (*LAM*), which clearly distinguishes oral from laryngeal articulations. In this model, the tongue is not the primary articulator responsible for *pharyngealization*. Rather tongue *retraction* is a concomitant of pharyngeal (laryngeal) constriction. According to Esling (2005:26), the pharyngeal articulator is essentially aryepiglottic, which means that the active articulator(s) are the aryepiglottic folds constricting against the epiglottis. The constricted posture of the aryepiglottic folds is 'the principal mechanism that can be associated with the dominant auditory feature of *pharyngealization*' (Esling 1996:74). Thus, Esling distinguishes three essential components of *pharyngealization*: 1) aryepiglottic sphinctering, 2) tongue retraction and 3) larynx raising. The latter two components usually come together, because the muscle groups responsible for these gestures (the hyoglossus and the thyrohyoid muscles) are both attached to the hyoid bone, and 'their contraction both pulls the tongue down and back and pulls the larynx up and forward as the aryepiglottic folds compress' (Esling 2005:26). The natural, unmarked position of the larynx in pharyngeal sounds is raised (Esling 1996:80). The raising of the larynx in pharyngeal sounds had been attested to by Jones (1934) and Nolan (1983) prior to Esling's laryngoscopic investigations (see Esling 1996 for further details). Here it is worth mentioning that the larynx as a whole can be raised or lowered during pharyngeal stricture. However, according to Esling (1996), a lowered setting of the larynx together with pharyngealization would represent a marked deviation from natural anatomical tendencies, and thus 'would be a more difficult muscular relationship to maintain' (see the details in Esling1996, 1999).

In the present study, we adopt the *Laryngeal Articulator Model*, briefly outlined above. We assume that tongue *retraction* (as opposed to the more general term *tongue backward movement*) may only be observed 'after the laryngeal constrictor has been engaged' (Esling 2005:26). In the present study, we employ the label a '*backward gesture of the tongue'* or '*horizontal backing of the tongue'* to refer to any rearward tongue movement in the mouth cavity, while the term *retraction* is reserved exclusively for *pharyngealization*, which includes engagement of the larynx. Such differentiation of terminology usage is justified by the anatomical structure of the vocal tract (see the details in section 2.6.1).

The application of the Laryngeal Articulator Model implies that *pharyngealization* of any consonants in any data cannot be established until all or some of the components of the laryngeal constriction (see above) are detected. Such techniques as X-ray imaging, EMMA, MRI and *lingual* ultrasound imaging are problematic in this respect. As mentioned in the discussion above, Bolla's (1981) and Kedrova et al.'s (2011) claims are generally based on x-ray and MRI data respectively 'in which it is far easier to see action of the tongue than that of the larynx' (Moisik 2013:50). Most of the X-ray tracings omit the larynx profile entirely. Although MR-images can display some features of the larynx, the configuration of the aryepiglottic folds, vocal and ventricular folds are often not detectable. This implies that Bolla's and Kedrova's et al. conclusions about pharyngealization of Russian non-palatalized consonants are disputable.

It should be noted here that horizontal backing of the tongue can equally be a concomitant of *pharyngealization*, as a function of deeper laryngeal articulation, or an indication of *uvularization*, or *velarization*, as a function of oral articulation. Moisik (2013) defines *uvularization* as the narrowing of the lower vocal tract, particularly in the upper pharynx where the uvula is located. All of these articulatory gestures involve some rearward tongue movement, which suggests that previous investigations of the production of Russian non-palatalized consonants could have mistaken one articulation for the other. *Secondary* v*elarization*, *uvularization* and *pharyngealization* are anatomically triggered by two different muscle groups (i.e. the styloglossus vs. the hyoglossus), which explains different terms for the respective tongue gestures adopted in the present research (see the details in section 2.6.1).

Kochetov (2002) in his EMMA study of plain and palatalized Russian stops /p/, /p^j/ and coronals /t/, /t^j/ of three speakers found that the plain labial /p/ was characterized by a strong backing gesture of the tongue body but showed no raising of the tongue. Kochetov interpreted this as an indication of what he calls *partial velarization*. As for /t/, no tongue dorsum rearward movement was observed, which suggested the absence of velarization. The same essentially was found for other manners of articulation - /f/ and /m/ vs. /s/ and /n/. Kochetov (2009) discovered a more back position of the tongue body values for plain labials /p, m, f/ than for plain coronals /t, n, s/, which he took to suggest velarization for the labials and no such specification for the coronals. We interpret the findings differently: a strong backward movement of the tongue body in /p, m/ and /f/ can be considered an indication of *pharyngealization* of these consonants, if the laryngeal component is engaged, or of *uvularization*, if the larynx is not involved.

As can be inferred from the discussion above, the term 'velarization' is not always equal to articulatory velarization, in the sense that the term refers to different gestures for different researchers. While for some phoneticians any retraction of the tongue back towards the pharyngeal wall signifies 'pharyngelaization', for others this is an indication of 'velarization', or 'partial velarization'. The use of different terminology, namely understanding different things under one term, adds to the confusion surrounding Russian velarization. The terminology adopted in the present study is discussed in detail in section 2.6.1.

2.4 Velarization intrinsic to consonants vs. a result of adjacent vowels

Another point of disagreement among researchers with respect to Russian velarization lies in the question of whether velarization is an independent gesture, i.e. whether it is an inherent feature of non-palatalized (hard) consonants, or whether it is a consequence of coarticulation with adjacent vowels. Figure 1 below illustrates the vowel system of Russian. According to the Moscow phonology school, which represents the most popular view among researchers, in stressed syllables, Russian contrasts the five phonemes /i, e, a, o, u/ (Avanesov 1956:96, Padgett & Tabain 2005:2; Kodzasov & Krivnova 2001)[3].

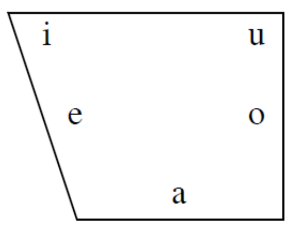

Figure 1. The inventory of Russian vowel phonemes.

Phonetically though, these phonemes correspond to a larger number of allophones. According to Bolla (1981:62), ‘the Russian vowel system is basically determined by two factors: a) the palatalized or non-palatalized character of the consonantal environment, which determines

[3] The Leningrad phonology school argues for the six-phoneme analysis of Russian vowels (Scherba 1950, Matusevich 1976).The debate rests on the status of [ɨ]. The Moscow phonology school considers it to be the allophone of /i/, while the Leningrad phonology school argues for the status of [ɨ] as a separate phoneme (see details in Scherba 1950, Matusevich 1976). In our study we follow the Moscow phonology school and assume that [ɨ] has /i/ as an underlying representation.

sound quality, and b) stress, on which quantity (duration) depends'. Figure 2 below takes into account the above mentioned factors. It shows the Russian vowel system as presented by Bolla (1981:62). The circles delineate the allophones of the five vowel phonemes from Figure 1. The shaded quadrangle highlights the reduced vowel [*i*], in Bolla's notation, used in unstressed syllables exclusively after palatalized consonants[4].

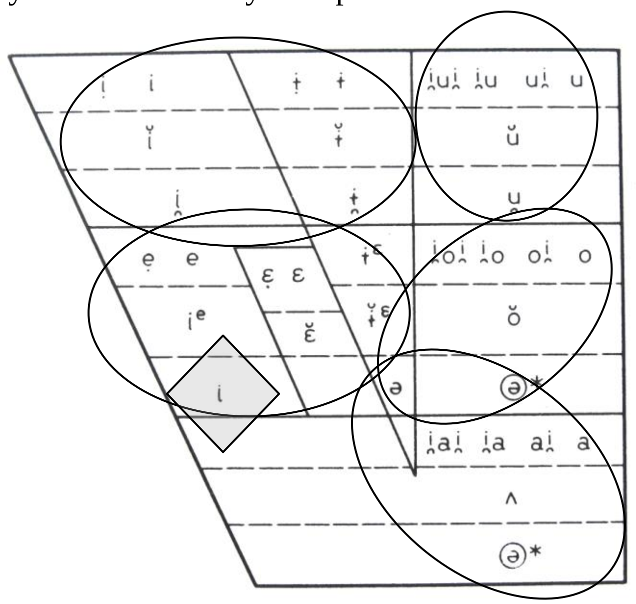

Figure 2. The Russian vowel system (reproduced from Bolla 1981:62), where [^{i}a] – forward shift of articulation in the initial phase of vowel production; [a^{i}] – forward shift of articulation in the final phase of vowel production; . – variety of more close articulation, ˘ – short sound, ‿ – reduced or weakly articulated sound.

The way Russian vowels are presented in Figure 2 is not exactly accurate in terms of vowel dispersion, i.e. distribution of vowels within the IPA (the International Phonetic Association) vowel quadrilateral. The locations of the vowel [ə] marked by the asterisk are unexpected. Usually, the symbol [ə] is used in the IPA transcription to denote the neutral mid-central vowel in the middle of the vowel chart and is often called 'schwa'. In Figure 2, however,

[4] Note: Bolla does not follow IPA conventions; as a result it is sometimes difficult to interpret his notation.

[ə] occupies three different locations. Bolla (1981) does not explain what the asterisk means. Possibly, it is used to suggest that [ə] might be regarded as a member/allophone of the Russian /a/-phoneme or of the Russian /o/-phoneme.

Bolla (1981:60) mentions that the position of the vowel in relation to the stressed syllable of the word determines whether the vowel is long, short or reduced in Russian: 1) *long* vowels are used in *stressed* position; 2) *short* vowels are used in the syllable immediately preceding the stressed one, in the *unstressed* absolute initial and absolute word final position after a non-palatalized consonant (short vowels are marked with ˘ in Figure 2)[5]; 3) *reduced* vowels are used in other *unstressed* syllables (reduced vowels are marked either with ̮ or are represented by a central vowel [ə] and front [*i*] in Figure 2)[6]. According to Bondarko (1998), the average duration ratio for stressed, prestressed and unstressed vowels in Russian is 4:2:1 respectively.

Not all Russian vowels can occur with all consonants. Bolla (1981:61) notices that it is a general rule in Russian that palatalized (soft) consonants cannot be followed by central vowels [ɨ, ɨ̣, ɨ̆, ɨ̮, ɨᵋ, ɨ̆ᵋ] and [ə], or by open [ɛ, ɛ̣, ɛ̆]. Front vowels [i, ị, ĭ, iᵉ, i̮] and [e, ẹ] are only used with palatalized consonants. [*i*] in a shaded rhombus in Figure 2 is a reduced sound which is also used only with palatalized consonants. The back vowels [a], [o], [u] can be used with palatalized consonants too, however in this case they require a so-called 'linking' [i̮]-like sound (Bolla 1981:61). This 'linking' [i̮]-like sound appears in the initial and/or final phase of the vowel in environments containing palatalized consonants. Thus we can conclude that only [ɨ, ɨ̆, ɨ̮, ɨ̣, ɛ, ɛ̆, ɛ̣, ɨᵋ, ɨ̆ᵋ, a, ʌ, o, ŏ, ə, u, ŭ, u̮] in Figure 2, can be used with non-palatalized consonants in Russian. In

[5] Bolla (1981:60) calls this position the primary weak position.
[6] This position is defined as the secondary weak position by Bolla (1981:60).

stressed position, these vowels are represented by five main allophones, namely by [ɨ, ɛ, a, o, u]. In our study, vowels [ɛ] and [a] are the focus, as [ɛ] is the least retracted vowel and [a] is the most retracted vowel that can co-occur with hard consonants.

Russian linguists traditionally employ the Cyrillic script to transcribe Russian consonants and vowels, which does not conform to the IPA notational system. For example, Knyazev (2002), when discussing the historical changes in the Russian phonological system that lead to the emergence of the phonological contrast between soft and hard consonants, suggests that this phonological contrast was the result of dropping of the vowels /ь/ and /ъ/, in weak (i.e. in the unstressed) positions. The symbols /ь/ and /ъ/ are used to denote the two reduced sounds that are the possible realizations in secondary weak position of Russian vowels with central and low tongue position. /ь/ is a front reduced vowel, occurring only after soft consonants, and corresponding to the vowels [e], [a], [i] in the stressed position. It is close to [i], and better corresponds to [ɪ] in the IPA transcription. /ъ/ is a central reduced vowel, occurring only after hard consonants, and corresponding to the vowels [a], [o] in the stressed position. In its articulation it occupies the position in the middle between [a] and [ɨ], and corresponds to [ə] in the IPA transcription (Avanesov, 1972). Before /ь/ and /ъ/ were dropped, there was no systematic opposition in consonant inventory according to softness/hardness: palatalized consonants were produced before front vowels, including /ь/, while 'neutral' consonants, articulated without the raising of the front and back of the tongue (i.e. non-palatalized but also non-velarized), were presumably produced in other positions, including before /ъ/. Dropping /ь/, /ъ/ moved the contrast to the consonants, as a contrast between palatalized consonants (from /ь/) vs. non-palatalized consonants (from /ъ/). Once the palatalized vs. non-palatalized consonants were contrastive, the necessity to effectively differentiate soft consonants from hard consonants on the perceptual level might have lead to the appearance of secondary velarization of phonologically hard consonants (Trubetskoy, 1960:153). Thus Knyazev (2002) acknowledges the opposition of palatalized and velarized consonants and considers this dichotomy the most prominent typological feature of the Russian language as it is spoken today. Here it is worth mentioning that orthographically the symbols 'ь' and 'ъ' are used only with consonants.

The most accurate available IPA representation of Russian vowels which can be used to explain the velarization phenomenon is provided by Trofimov & Jones (1923). It is presented in Figure 3 below. This chart illustrates the phonemes, marked by black dots, and their allophones, marked by large, small and encircled red dots. Large red dots represent the principle members, i.e. the main allophones of the phonemes, small and encircled red dots denote subsidiary allophones. Here it is worth mentioning that Jones & Trofimov (1923) distinguish six vowel phonemes in Russian: /i, a, o, u, ɨ/ and /ɛ/. As mentioned above, in the present study we distinguish five vowel phonemes. Also, the present study uses the symbol /e/ for the underlying [e] and [ɛ] vowels contrary to /ɛ/ employed by Trofimov & Jones (1923).

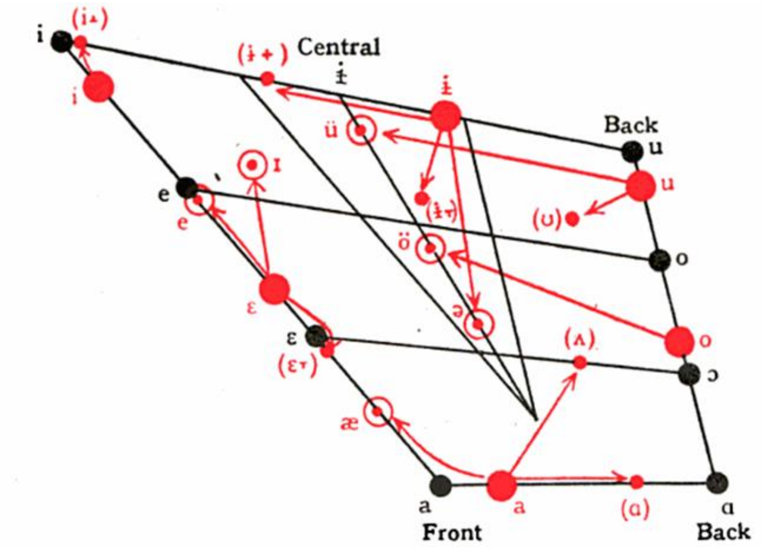

Figure 3. Russian vowel chart. *Black dots* represent the Cardinal vowels. *Red dots* (large, small encircled and not) represent the allophones in stressed and unstressed positions). The arrows radiate from the point representing the principle member, i.e. the *main allophone* of a phoneme; ˔ - is used to represent a *raised* vowel, ˕ - a *lowered* vowel, ˖- a *fronted* vowel; ¨ – a *centralized* vowel, i.e. *fronted or advanced* (retrieved from Trofimov & Jones 1923:55).

The only vowels in Figure 3 used with Russian non-palatalized consonants in a stressed position are [ɛ, ɛ̞, a (ɑ), o, u, ɨ, ɨ̞, ɨ̟]. The vowels [ɨ̞] and [ɛ̞] are of special interest here. [ɨ̞] is a lowered variant of [ɨ]. According to Trofimov & Jones (1923), this variant of [ɨ] occurs after labial and labio-dental consonants [p, b, m, f, v] and also after [l]. The authors notice that this variety of [ɨ] can also be symbolized by [ɨ̞], signifying a ‘retracted’ vowel [ɨ]. It is slightly diphthongized, ‘beginning almost as far back as [ɯ]’ (Jones & Ward 1969:33). The lowered variant of [ɛ], i.e. [ɛ̞], never occurs after or before soft consonants. Jones & Ward (1969:41) mention that ‘some researchers of Russian phonetics consider it to be slightly retracted from a fully front position, which they believe is most evident after the consonants [ʃ, ʒ, ts]'[7]. Lowering and backing of [ɨ] after or between labials and [l], and lowering and backing of [ɛ] after [ʂ, ʐ, ts] suggests that these consonants might exhibit a secondary articulation at the back of the mouth. The presence of secondary *velarization, uvularization or pharyngealization,* all of which presume the involvement of the back of the tongue, could explain the change in the quality of these vowels: the articulatory gesture of the tongue back could produce the articulatory conflict with the anterior tongue position during the articulation of front and central vowels [ɛ] and [ɨ], resulting in lowering and backing of these vowels. This would also imply the intrinsic nature of secondary articulations of Russian hard consonants.

Still the inherent nature of secondary articulation(s) of Russian consonants is denied by a number of researchers. Jones &Ward (1969:79), based on their perceptual observations, conclude that hard Russian consonants are particularly affected by a following /u/, /o/ and /ɨ/ vowel. Before /u/ and /o/ the allophones of hard consonants are accompanied by liprounding ('labialization'), which is somewhat greater before /u/ than /o/, and by raising of the back of the tongue into the u-position ('velarization'). Consonants formed in this way are said to be 'labio-velarized'. According to Jones & Ward, all Russian hard/non-palatalized consonants are labio-velarized before /u/ and /o/, and are velarized before /ɨ/. This implies that the authors consider velarization to be a gesture caused by a surrounding vowel context and not an independent consonantal articulation.

Similarly to Jones & Ward (1969), Matusevich (1976) claims that the position of the back of the tongue dorsum does not play any significant role in the articulation of hard/non-palatalized labials and depends primarily on the following or preceding vowel or consonant and is very

[7] Note that, in this paper, we use retroflex symbols for Russian post-alveolar fricatives, namely [ʂ] and [ʐ].

individual. The same holds true for all Russian hard consonants, except for the lateral /l/, which she considers to be the only velarized Russian consonant. Matusevich does not mention any velarization for dental stops, fricatives and the trill [r]. [k] and [g] are velar consonants, which means that their primary gesture is in the velar region (the tongue body has a constriction with the soft palate), which excludes the possibility of secondary velarization. It is worth mentioning here that Matusevich draws most of her conclusions about Russian velarization on the basis of Skalozub's data (1963).

As can be seen from the above discussion, velarization in Russian is a controversial issue. Phoneticians have not come to a single decision on which Russian non-palatalized consonants are velarized and which are not, and what the exact place of articulation of these consonants is. Most researchers seem to agree on a strong velarization of [l]. Many researchers notice a certain amount of velarization in labials (Bogoroditsky 1930, Skalozub 1963) though there are a few studies rejecting it (Matusevich 1976, Ladefoged & Maddieson 1996). A number of researchers distinguish pharyngealization of Russian non-palatalized consonants. Some of those studies acknowledge only pharyngealization of Russian consonants (Bolla 1981), while other studies accept the possibility of velarization and pharyngealization in one consonant simultaneously (Kasatkin 2001, Kodzasov & Krivnova 2001). Some researchers draw a connection between velarization and the surrounding context, which suggests that velarization cannot be called an inherent feature of Russian non-palatalized consonants (Jones & Ward, 1969), while other phoneticians do not mention the dependence of velarization on the preceding or following vowels and consonants. All these observations allow us to conclude that velarization in Russian has not been fully understood yet: a number of issues remain unresolved.

2.5 Sources of disagreements

The studies discussed in the previous sections use various methodologies to investigate the Russian consonant system. This fact may be partially responsible for the different views among researchers on Russian velarization. In this section, we take a closer look at the methodological designs of the available articulatory studies and attempt to highlight the sources of disagreements. The subsections below correspond to previous sections.

2.5.1 Velarization vs. no velarization

One problem with recent studies on the articulatory properties of Russian consonants is that they look only at a limited subset of consonants (e.g. Kochetov 2002, 2005, 2009; Kedrova et al. 2008, 2011). This fact does not allow drawing coherent conclusions about secondary velarization in Russian. For example, Kochetov's (2002, 2005) EMMA studies of Russian consonants (labials, spirants, liquids) examine voiceless plosives [p], [t], voiceless fricatives [s], [f], nasal sonorants [m], [n], and liquids [l], [r]. Kedrova et al. (2011) investigate only two consonants, the labials [b] and [m].

Most complete and systematic experimental investigations are rather old, conducted by Skalozub (1963) and Bolla (1981). As mentioned in previous sections, leading up to Skalozub's work, there had been a number of disputes among researchers with respect to Russian phonetics (Bogoroditsky 1930, Ershov 1903, En'ko 1912, Scherba 1957). In order to sort them out and to create a more systematic articulatory description of consonants, Skalozub (1963) conducted a series of experiments. As noted in section 2.2, her methodologies included artificial palatography (i.e. using artificial palates), odontography, X-ray imaging and partial oscillography. The data were collected from 4 participants, all born in different parts of Russia. In contrast to previous studies, Skalozub conducted a more consistent investigation of Russian consonants with conditions maximally controlled. First, all palatalized and non-palatalized consonants were examined in syllables and words, which contributed to the naturalness of production. Second, all non-palatalized consonants were studied in a stressed syllable and in the neighbourhood of one vowel: either followed/preceded by [a] or flanked by [a] on both sides, which contributed to the consistency of the data and comparability of consonants. A single vowel context enabled the researcher to compare different articulatory tongue movements of different consonants with the tongue in rest position and to draw relevant conclusions, for example, about the degree of tongue backing or fronting. This was done by means of superimposition of the tongue contours extracted from X-ray images of each sound onto the contour of the tongue at rest. Tongue contours were extracted by putting tracing paper onto the X-ray image which was placed on a tripod for retouching, and simply redrawing the tongue shape onto the paper. Third, during palatography each consonant was examined at the beginning and the end of a word/syllable, which took into account the influence of word position on the articulatory characteristics of consonants. Fourth, Skalozub used a combination of methods to investigate Russian sounds, which contributed to the reliability of her data and conclusions. It is unclear how controlled previous studies had been.

Bolla (1981) also conducted a series of phonetic experiments to study Russian consonants and vowels. His research was based on palatography, linguography, labiography, X-ray imaging, oscillography and spectrography. The type of palatography Bolla conducted is called ‘mirrored palatography’ (Bolla, 1981), or direct palatography (Harris, 2006:71), or basic palatography (Ladefoged, 2003:36). It is different from the one used by Bogoroditsky (1930), Scherba (1957) and Skalozub (1963) in that it is a fairly simple technique which involves painting of the tongue with a dark substance and observing the area where the paint has been transferred onto the palate with the help of a mirror inserted in the mouth approximately at an angle of 45 degrees. The reflection in the mirror is photographed and then analyzed. In comparison to using artificial palates, mirrored palatography has numerous advantages: a) it affects the naturalness of articulation to a smaller degree; b) it represents the articulation of not only the palate but also of the teeth and the tongue; and c) a photograph can contain more information than a drawing made of the artificial palate (Bolla, 1981:28-29). Bolla collected data from 5 participants (4 females and 1 male). No mention of their age or place of origin is provided. All the stimuli were real words and word combinations, with the sounds of interest in a stressed position (generally at the beginning of a stressed syllable, except for [p] which was examined at the end of a word). The non-palatalized consonants were followed by [a], except for 2 cases where the consonants of interest were followed by [ɨ] and [ɛ]: the labial [b] was analyzed before [ɨ], while the affricate [dʒ] was investigated before [ɛ]. It is unclear why Bolla investigated [p] at the end of the word, and why [b] and [dʒ] were analyzed in a different vowel context, i.e. before [ɨ] and [ɛ] respectively. Perhaps, this fact can be partially accounted for by the researcher's desire to use real words. However, the Russian language has examples of words with the sequences of these consonants and the vowel [a], which could have contributed to the consistency of Bolla's data. Still the researcher does not explain his choice of stimuli.

Obviously, the experiments conducted by Bogoroditsky, Ershov, En'ko, and Scherba[8] were smaller in scope (in terms of participants and methods) and did not use sophisticated equipment. These facts may account for the differences in opinions observed in the literature. To sum up, different stimuli, i.e. different consonants investigated, may be partly responsible for disagreement in whether or not there is velarization in Russian (see section 2.2).

[8] Bogoroditsky (1930), Scherba (1957) and Ershov (1903) conducted palatographic studies of Russian sounds, En'ko (1912) conducted an X-ray investigation.

2.5.2 Velarization vs. pharyngealization

A major disagreement between Skalozub (1963) and Bolla's (1981) opinions is observed in the issues of velarization/pharyngealization of Russian non-palatalized consonants. Skalozub (1963) attests to velarization of some hard consonants (e.g. labials and the lateral [l]), while Bolla (1981) claims pharyngealization of all non-palatalized consonants, except for [x, γ]. As mentioned in section 2.3, judging from his X-ray data, Bolla (1981) concludes that 'the movement of the root of the tongue and the postdorsum towards the pharyngeal wall is more important than that towards the soft palate'. A closer examination of the data presented in the books of these researchers and the equipment they used in their experiments allows us to infer about the factors that could have influenced their respective results, apart from overlooking activity of the larynx (see the details in section 2.3). First, the comparison of the X-ray images presented by the authors demonstrates obvious differences in the quality of the pictures and the possibility of reading them. It is worth mentioning that Bolla used photoradiograms and cineradiography taken with more sophisticated equipment than did Skalozub, namely a Siemens apparatus (Sirescop 2) with a picture intensifier. Its exposure time was only 0.04 seconds, corresponding to 40 ms. Such exposure time allows for capturing the quick articulation of Russian stops, which have an average closure duration of approximately 20-120 ms. Cineradiography allowed the researcher to catch the workings of the articulatory organs in their dynamic process. Skalozub used tomofluorography with an exposure time of 1.25-2 seconds (corresponds to 1250-2000 ms). During X-ray imaging Skalozub's participants had to change their natural production of consonants so that their articulation could be X-rayed[9]: they had to

[9] Skalozub investigated both voiced and voiceless plosives and fricatives in her X-ray study. She does not mention any limitations of this set of consonants, however one should note that a sustained articulation of voiced consonants might affect tongue position.

prolong the articulation of fricatives[10] and hold the occlusion phase in plosives for a longer time than in natural speech. These adjustments may partially account for the observed differences between Skalozub's and Bolla's conclusions.

An additional factor has to do with the technique used to optimize images. The images obtained from tomofluorography are characterized by different optical density of film blackening, which depends on the individual characteristics of the participants. In order to obtain optimal optical density, the exposure had to be changed for different speakers and possibly for different phonemes. More importantly however, Skalozub mentions problems with determining muscle contours forming the pharynx in the process of redrawing profile schemes from the X-ray images. To get a better image a special method of printing the images was used. Specifically, different exposures of the film were employed to allow for different contrasts of the organs of the vocal tract: more exposure was used for imaging of the soft palate and lips, and less exposure was used for the tongue, the contours of which are more contrastive. The fact that the contours of the pharynx are not clear on the tomofluorograms may explain why Skalozub does not draw any conclusions with respect to pharyngealization: the images obtained were not reliable enough to draw such inferences.

Finally the fact that Bolla considers even the velar sounds [k, g] to be pharyngealized suggests that Skalozub and Bolla also use different terminology. Bolla considers any rearward tongue gesture to be pharyngealization, while Skalozub analyzes any backward movement of the tongue in combination with its raising gesture; she is not explicit in her conclusions with respect to pharyngealization of Russian hard consonants. Kochetov (2002) uses his own term 'partial velarization' with respect to the Russian labial /p/.

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[10] In Skalozub's stimuli for X-ray, fricatives were used at the end of monosyllabic word/syllable.

As can be inferred from the discussion above, the limitations of previous studies include either a limited set of consonants under investigation (Kochetov 2002, 2005, 2009, Kedrova et al. 2011), or old technology (Bogoroditsky 1930, Ershov 1903, En'ko 1912, Scherba 1957, Skalozub 1963, Bolla 1981), or mainly the [a] vowel context (see section 2.5.3 for details), and generally disregard for the laryngeal activity, all of which makes data analysis and their interpretation hard. Different methodologies and different terminology may be responsible for the disagreement about velarization vs. pharyngealization (see section 2.3).

2.5.3 Intrinsic velarization vs. vowel effects

With the exception of Kedrova et al.'s (2011) study, all the studies discussed above use a single vowel context, i.e. the vowel [a]. This poses a definite problem to the interpretation of the results of X-ray and palatography because [a] is an inherently pharyngealized vowel. Therefore it can affect the articulation of non-palatalized consonants, namely their retraction. To fully understand the production of hard consonants, it is important to use a range of vowels.

Kedrova's MRI research (2011) examined Russian bilabial consonants [b] and [m] in the vocalic contexts [a]_[a] and [a]_[ɛ]. Data came from 2 native speakers of Russian (male and female) producing VCCV sequences. The experiment showed that the images of both labial consonants looked relatively similar in the [a]_[a] frameset, except for the position of the soft palate. However, there were distinct differences in tongue position and form of the tongue of [b] and [m] in the [a]_[ɛ] frameset: [b] showed a greater degree of velarization than [m]. Kedrova et al. (2011) assume that the difference between the articulation of [b] and [m] is determined by the specific configuration and position of the soft palate (the velum is raised in [b], while it is lowered in [m]) as well as by the conflicting articulation of the consonant's velarization and the articulation of the vowel [ɛ]. As mentioned in section 2.3, on the basis of this MRI investigation, the authors conclude that [b] before [ɛ] is not only velarized but also pharyngealized at the same time, which they explain by the participants' supine position during MRI.

As can be noted, Kedrova et al.'s (2011) study makes use of a contemporary technique, i.e. MRI, which allows researchers to look at articulators in the process of speech without harming people, in comparison to X-ray imaging. The researchers investigated [b] and [m] before the vowel [ɛ], which allowed them to observe differences in secondary articulation of the hard consonants in a new vowel context. The authors examined only two consonants and in a limited vowel environment, which does not make their investigation more reliable than previous studies. However, a different result for the consonants in a different vowel environment, namely that of the vowel [ɛ], suggests that vowels affect *velarization*, *uvularization* or *pharyngealization* of consonants, at least of labials. The investigation of non-palatalized consonants in sequences with a range of vowels can shed valuable light on the intrinsic nature of secondary articulations in Russian.

Kochetov's (2002, 2005, 2009) studies of Russian consonants employ another new articulatory method, i.e. EMMA, to examine Russian consonants. As mentioned in section 2.3, Kochetov's studies (2002, 2005, 2009) showed a backward movement of the tongue body in [p], [m], [f], [l]. However, this fact can be accounted for by the impact of the adjacent pharyngealized vowel [a]. In addition, because the stress in Kochetov's (2002) study was not fully controlled (as the author mentions himself), the articulation of consonants under investigation in the unstressed words/syllables could have been affected by reduction and thus not exhibited a clear secondary gesture.

Finally, Figure 3 suggests that secondary articulation of Russian non-palatalized consonants is intrinsic. As discussed in section 2.4, Jones & Ward (1969) claim that the vowels [ɨ] and [ɛ] are realized as lowered [ɨ̞] and [ɛ̞] after [p, b, m, f, v, l] and [ʃ (ʂ), ʒ (ʐ), ts] respectively. This can be explained by the articulatory conflict between the secondary articulatory gesture in the hard consonants with the fronted tongue position in [ɨ] and [ɛ], which results in backing of the vowels. This implies that at least Russian labial, labio-dental, retroflex consonants and the lateral [l] might feature secondary velarization.

To summarize, the disagreement about velarization/pharyngealization of non-palatalized consonants may be partially accounted for by possible vowel effects.

2.6 General summary

As can be concluded from the discussion above, there is no consistency in the methodologies used to examine velarization, as well as in the interpretation of velarization. Previous articulatory studies of Russian consonants give controversial information on secondary velarization of non-palatalized consonants. This controversy can be accounted for, first and foremost, by different terminology employed by researchers, implying different tongue gestures under the term 'velarization' and overlooking examination of larynx engagement in the production. Methodological design is another source of disagreements: a single vowel context, namely that of the vowel [a], could have affected the backing gesture of the tongue, causing the researchers to draw inappropriate conclusions about inherent secondary articulations of Russian consonants. Word-level stress is another factor that might have affected the results of previous studies: failure to control for stress could have caused vowels and consonants to be reduced in unstressed position. Consonant reduction could have been manifested in their loss of distinction in place or manner of articulation, or in unclear (not exhibited) secondary articulation. Numbers of participants, as well as their origin, and age are another source of disagreements found in the phonetic literature.

It should be mentioned here that in her discussion of Russian labials (1963:18), Skalozub makes a valuable observation in terms of setting up the current study: to prove the secondary velarization of labials she suggests comparing the palatograms of [pa, pɨ, pu, po, ba, bo, bu, bɨ] with the tongue rest position. Comparing the palatograms of [pa] with that of the rest position, Skalozub observes the differences in the marks left on the artificial palate during palatography. She notices that in rest position the tongue has a bigger contact area with the palate, 'while during the articulation of labials it touches only the back corners of the palate, approximately at the place where the hard palate borders on the soft palate'(1963:18). Skalozub interprets this fact as a proof of retraction and raising of the back of the tongue to the palate, which suggests velarization of labials. Skalozub notices that the superimposition of the contours [p], [b], [m] and that of the rest position, extracted from X-ray images, as well as superimposition of [p] and the vowels [a] and [ɨ] helped to establish more or less definitely the direction of the tongue movement during [p]. She states that the comparison of X-ray images of [p] and [ɨ] shows more retraction for [p]; the height of the tongue in [p] is higher than in [a] but lower than in [ɨ], which again proves the existence of secondary articulation in labials. In this discussion, Skalozub does not mention whether she made the palatograms of [pa, pɨ, pu, po, ba, bo, bu, bɨ] and whether she compared them with each other and with the rest position by means of superimposition of those contours (the Appendix does not include these data, and [pa, pɨ, pu, po, ba, bo, bu, bɨ] are not included in the list of stimuli provided in the book). In our study we do this explicitly: we superimpose tongue contours extracted during the production of Russian hard consonants onto each other and the tongue position at rest (the methodology and results are provided and discussed in chapters 3-5).

The present study has taken into account the limitations of previous studies as discussed above: it uses relatively new imaging techniques, namely *lingual* and *laryngeal* ultrasound imaging. *Lingual* ultrasound allows for natural speech, easy identification of tongue gestures and digitized data analysis. *Laryngeal* ultrasound elucidates the activity of the larynx. We investigate a range of consonants in consonant-vowel sequences, i.e. we address the limited scope in terms of consonants and vowels studied previously. Six subjects participated in our research (in comparison to four speakers in Skalozub's (1963) investigation, five speakers in Bolla's (1981) study, three speakers in Kochetov's (2002) study, etc). However, the origin of participants was not controlled due to the small population of native Russian speakers in Victoria BC, Canada.

2.6.1 Terminology used in our study

As can be inferred from sections 2.1-2.5, the term *'velarization'* has been used inconsistently with respect to the Russian language. However this inconsistency of terminology can be traced in the phonetic literature in general. *Secondary velarization* is commonly defined as the raising of the back of the tongue towards the velum (Laver 1994; Ladefoged 1993, etc.). Ladefoged (1993) states that *secondary velarization* is associated with the raising of the back of the tongue. Whereas Harris (2006:145) defines *velarization* as 'a more or less simultaneous secondary articulation made by backwards and upwards movement of the back of the tongue towards the soft palate', thus implying the involvement of two articulatory gestures in secondary velarization simultaneously: rearward and upward. As for *pharyngealization*, a lot of researchers associate it exclusively with the *retraction* of the tongue towards the pharyngeal wall (e.g. Ladefoged 1993, Hamann 2002), without consideration of laryngeal engagement.

Here it is worth mentioning that the term *'retraction'* is also used by speech researchers incoherently, generally to denote any rearward movement of the tongue. Hamann (2002:14) comes to the conclusion that the term *'retraction'* as applied to the movement of the tongue body 'seems to subsume two secondary articulations: *velarization and pharyngealization*'. This is not entirely correct within the *Laryngeal Articulator Model* adopted in the present study. In our study, we assume that *velarization* and *pharyngealization* are two distinct articulations. As mentioned in section 2.3, the *Laryngeal Articulator Model* divides the vocal tract into two components: oral and laryngeal. Figure 4 below represents a revised phonetic cross-sectional diagram of the vocal tract together with laryngeal constriction as opposite in direction to oral strictures (retrieved from Esling 2005:22).

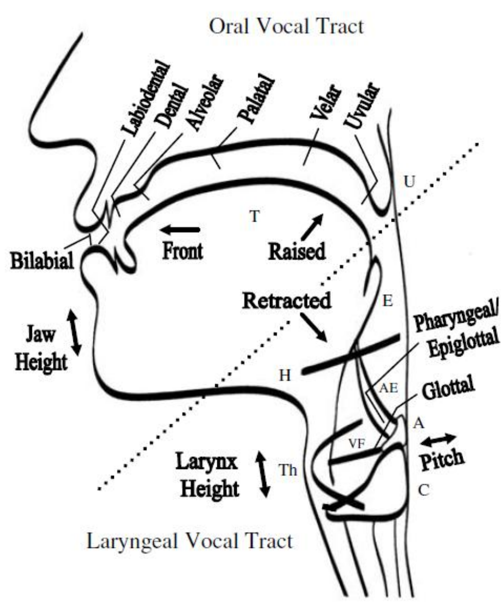


Figure 4. The diagram of the vocal tract representing the oral and the laryngeal articulators; A – arytenoids cartilage, C – cricoid cartilage, E – epiglottis, H – hyoid bone, T – tongue, Th – thyroid cartilage, U – uvula, VF – vocal folds. Retrieved from 'There are no back vowels: The laryngeal articulator model' by J.H. Esling 2005, *Canadian Journal of Linguistics*, 50, p. 22.

Figure 4 demonstrates three principal directions of tongue movement: *retraction, raising* and *fronting*. *Retraction* of the tongue belongs to the laryngeal component. Therefore, in the present study, we reserve the label *'retraction'* for a *backward* movement of the tongue as a function of *pharyngealization*. The other two principal directions of movement of the tongue, namely *raising* and *fronting*, are oral. Esling (2005:19) mentions that anatomically the three directions of lingual movement are performed by three major extrinsic lingual muscle groups: the genioglossus, the styloglossus, and the hyoglossus (see Figure 5 below). The genioglossus is responsible for pulling the tongue body forward, the styloglossus for pulling the tongue up and back, and the hyoglossus for pulling the tongue toward the larynx. Different work performed by the three muscle groups justifies the use of different terminology for the three lingual gestures.

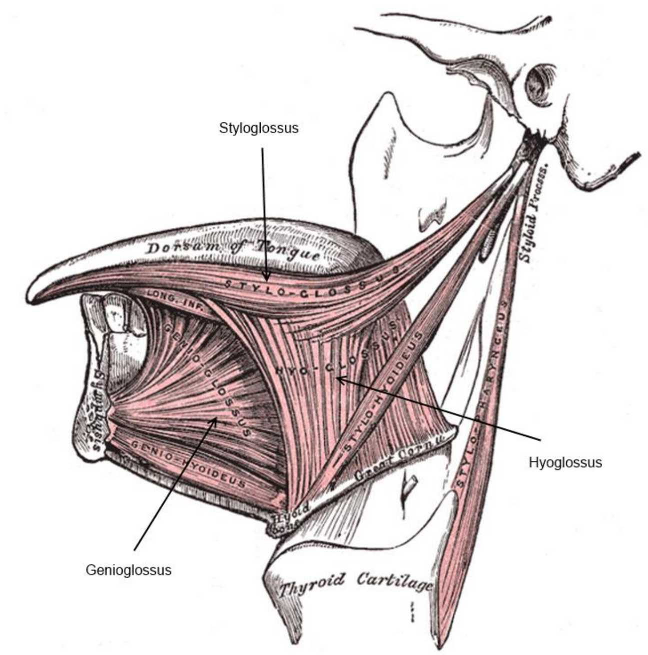


Figure 5. Muscles groups responsible for *fronting*, *raising* and *retraction* of the tongue.

Both the *styloglossus* and the *hyoglossus* induce backing of the tongue body, however the *styloglossus* in addition pulls the tongue body in the upward direction, i.e. raises the tongue, while the hyoglossus presses the tongue down, i.e. retracts it. Therefore, these articulatory gestures are respectively called *'raising'* and *'retraction'* within the Laryngeal Articulator Model, thus highlighting different anatomical mechanisms involved. Tongue *retraction* in this case is a function of *laryngeal constriction*: it occurs in response to constriction of aryepiglottic folds and raising of the larynx. In its turn, the label '*raising'*, when speaking about lingual articulations, implies 'the positioning of the tongue when it is *high'* (Esling 2005:18), and it does not suggest the involvement of the laryngeal mechanism.

In the present study we use three different terms for three distinct articulations: *secondary velarization*, *uvularization* and *pharyngealization.* The former two belong to the oral vocal tract, the latter refers to the laryngeal vocal tract and involves the engagement of the larynx (see Figure 4). As can be inferred from the discussion above, *secondary velarization* and *uvularization* involve *raising* of the tongue body, while *pharyngealization* entails tongue body/root *retraction* (see the details in section 2.3). It is worth pointing out here that velarization and uvularization have different stricture targets for raising. In *secondary velarization*, the tongue is raised towards the anterior part of the soft palate, while in *uvularization* the tongue is pulled further back, towards the posterior part of the soft palate. i.e. towards the uvula.

As can be concluded from Chapter 2, the exact articulation of Russian non-palatalized consonants has not been fully studied yet. The present study makes an attempt to shed light into the production of Russian hard consonants and resolve the debate in the phonetic literature. It combines the breadth of older studies with the technology of newer studies. Specifically, it uses ultrasound to systematically study a relatively large set of consonants across different vowel contexts.

Chapter 3

Methodology

This study was designed to answer three main questions:

1) Are Russian non-palatalized (hard) consonants velarized?
2) How do neighbouring vowels affect secondary velarization? More specifically, is velarization an inherent feature of hard consonants or it is a consequence of coarticulation with the following vowel?
3) If Russian consonants are ‘velarized’, what does this correspond to articulatorily: *velarization*, *uvularization* or *pharyngealization*?

Data were collected with ultrasound, a technology that has been used in studies of speech production since the 1960s - 1970s, when it first came into regular clinical application. The advantage of ultrasound imaging is that it is safe and non-invasive. In our study, we used l*ingual* and *laryngeal* ultrasound imaging. *Lingual* ultrasound is able to capture movement of the whole tongue in real time, thus enabling the study of the tongue root, the tongue body, and interactions between vowels and lingual consonants (Gick 2002). Examination of articulations in the oral vocal tract (see Figure 4) was the primary focus of this research. *Laryngeal* ultrasound can be used to image the state of the larynx during speech production. More specifically, laryngeal ultrasound provides a good tool for imaging larynx height, which can suggest the presence or absence of laryngeal constriction in the lower, i.e. laryngeal, vocal tract, and thus can attest to or refute pharyngealization. The only known investigation to date involving *laryngeal* ultrasound in speech research was conducted by Moisik, Lin & Esling et al. (2014). In the present study using laryngeal ultrasound, we make an attempt to answer the long-standing question whether Russian non-palatalized consonants are pharyngealized or not.

In order to limit the scope of the study, the research focused on the lateral [l] and voiceless fricatives [f, s, ʂ, x]. Although velarization of Russian [l] is the least controversial among researchers (Skalozub 1963, Mausevich 1976, Ladefoged & Maddieson 1996), this study aimed to verify and specify previous conclusions with respect to the precise articulation of this sound. Only voiceless fricatives were considered because they were expected to show less tongue dorsum fronting and thus represent a more neutral pharyngeal and tongue body setting in comparison to voiced fricatives. This idea was based on an MRI study of English voiced and voiceless fricatives conducted by Proctor et al. (2009) which revealed that pharyngeal volume was generally greater during the production of sustained voiced fricatives compared to voiceless equivalents. The authors showed that the expansion of the upper oropharynx in voiced fricatives was primarily caused by displacement of the tongue dorsum forward, as well as by displacement of the lateral pharyngeal walls. Plosives, affricates, nasals and the liquid [r] were excluded from the set of consonants considered. Plosives were excluded from the study due to limitations of ultrasound with respect to frame rate. Ultrasound machines typically have a relatively low frame rate of around 30 frames per second (FPS), which means that the time lapse between frames is approximately 33.3 ms. Stops are characterized by a relatively quick articulation. The average duration of the constriction phase of Russian non-palatalized stops varies from 20 to 120 ms, which suggests that the ultrasound frame rate of 30 FPS should be able to capture the short closing phase of a stop, but could also possibly fail for stops with closures shorter than 30 ms causing important gestural landmarks to be missing in the video. It is possible to capture higher frame rates. For example, Miller & Finch (2011) introduced the CHAUSA (Corrected High-speed Anchored Ultrasound with Software Alignment) computer system architecture for collection of high-speed ultrasound (US) able to increase the frame rate for data analysis from the standard video rate of around 30 FPS to 124 FPS. However, as an initial exploration of Russian consonants, we left plosives out to avoid the need for a more complex recording set-up, such as that used by Miller & Finch (2011). Affricates are complex sounds comprised of plosives and fricatives. There is a necessity to start with the examination of simpler sounds first to be able to make insightful inferences about more complicated data in the future. Nasals were excluded due to the involvement of the soft palate in their articulation, which could impede clear conclusions about the presence or absence of velarization (Kedrova et al. 2011). Finally, [r] was excluded from the list of consonants partly to reduce the scope of the experiment, and partly because it involves complex and rapid articulatory movement, possibly making it difficult to image accurately (similar to stops).

In sections 3.1 – 3.4, we discuss the methods used in the *lingual* ultrasound study. The methodology employed in the pilot *laryngeal* ultrasound investigation is discussed in detail in section 3.5.

3.1 Lingual ultrasound: stimuli

3.1.1 Consonants used

In total, 5 consonants were studied representing labial, coronal and dorsal (retroflex and velar) sounds: [f], [l], [s], [ʂ], [x]. They were elicited in two vowel contexts: [a] and [ɛ]. Previous studies examined Russian consonants mainly adjacent to the vowel [a]. Although some studies did include vowels other than [a], namely [ɛ] (Kedrova et al. 2011), these did not seek to investigate in a systematic way the impact of adjacent vowels on secondary velarization of different types of Russian hard consonants. Thus, to the best of our knowledge, this is the first articulatory study after Skalozub (1963) and Bolla's works (1981) that has aimed at a systematic investigation of a comprehensive set of consonants across different vowel contexts.

3.1.2 Frequency data and the choice of adjacent vowels

The vowels [a] and [ɛ] were chosen by looking at the frequency of distribution of *consonant-vowel* (CV) sequences in Russian, based on 'A New Frequency Dictionary of the Russian Lexicon' (Lyashevskaya & Sharov 2009) as outlined below. We assumed that the analysis of frequency data would help us to identify phonotactic constraints on how hard consonants and vowels can combine in Russian. More specifically, low frequency of CV combinations, if found, would suggest the presence of some articulatory conflict between the consonant and the vowel. This conflict of articulatory gestures might in its turn be used to predict the presence/absence of secondary articulation(s), namely velarization/uvularization or pharyngealization. For example, given that [ɛ] is a front vowel, low frequency of C-[ɛ], where C is a non-palatalized consonant, might indicate 'backness' of this consonant.

The dictionary used was compiled on the basis of the National Russian Corpus, or NRC (2005) which incorporates over 300 million words. The dictionary itself includes frequency information of tokens (of words) and lemmas. Tokens in the dictionary were obtained by the process of tokenization, i.e. breaking the stream of texts up into words, including words written with Cyrillic and Latin letters and numbers written as Arabic and Roman numerals (Lyashevskaya & Sharov 2009). The sample size of the dictionary is 92 million tokens of words. Lemmas were obtained by lemmatisation, the process of uniting the tokens of words related paradigmatically and syntagmatically under one basic form, i.e. a lemma. In other words, a lemma is a headword of a dictionary entry (Hausmann 1977). The difference between tokens and lemmas is similar to the token-type relation. In general, 'the distinction between a type and its tokens is an ontological one between a general sort of thing and its particular concrete instances’ (Wetzel 2014). In other words, a type is a unique form of a word, while a ‘token’ is a concrete linguistic unit occurring in the text. However, according to Lehmann (2013), while the type-token relation is basic to corpus analysis, the relation of a text-word to a dictionary lemma is more abstract.

The dictionary used had definite limitations. First, the dictionary presented the frequency data of two-*letter* combinations, rather than two-*sound* combinations. This fact complicated deductions with respect to Russian phonotactics because Russian orthography does not always correspond to Russian pronunciation. For example, the Cyrillic letter «е» might correspond to [je], [e], [ɛ], [jɵ], [ɵ] or [ɪ] in pronunciation: «ель» [jelʲ] ‘spruce, fir-tree’, «фен» [fʲen] ‘hairdryer’, «ёж» [jɵʂ] ‘hedgehog’, «темп» [tɛmp] ‘tempo’, «Пётр» [pʲɵtər] ‘Pete’ (name), «перо» [pʲɪˈro] ‘feather’. Second, stress placement was not controlled for in the dictionary. This made the correspondence between two-letter combinations and CV sound sequences even less straightforward due to the process of phonological vowel reduction: some vowel contrasts are neutralized in unstressed position (for details see, e.g., Avanesov 1956:105-125; Padgett & Tabain 2005; Crosswhite 2000). Despite these limitations, the frequency data from the dictionary by Lyashevskaya & Sharov (2009) were used because they were the best available resource.

As mentioned in section 2.4., not all Russian vowels can occur with all consonants. Because in our study we were interested in non-palatalized (hard) consonants, only vowels [ɛ, ɨ, u, o, a] were relevant. The vowels [ɛ, ɨ, u] are not significantly affected by vowel reduction, as their articulatory target is preserved even when unstressed. As mentioned before, these vowels are used only after non-palatalized (hard) consonants in Russian and are represented exclusively by Cyrillic letters «э, ы, у»[11]. These facts allowed us to assume that the frequency of «C-э», «C-ы», «C-у» letter combinations were, on the whole, representative of the frequency of C-[ɛ], C-[ɨ], and C-[u] sequences. Although the frequency of «C-a» and «C-o» *letter* combination did not directly correspond to the frequency of C-[a] and C-[o] *sound* sequences due to the reduction of /a/ and /o/ in unstressed position, these data were still suggestive of the phonotactic tendencies observed in Russian.

The frequency of each CV combination in the dictionary was determined by Lyashevskaya & Sharov (2009) by calculating the number of each token per 1 million instances and then multiplying it by 92, as the total sample size was 92 million tokens (Lyashevskaya, Sharov, 2009:6). This frequency was then used separately to rank lemmas and two-letter combinations. The most frequent CV combination, where C is a non-palatalized consonant and V is a vowel, was assigned rank 1, the least frequent was given the rank 694 (the total number of CV combinations was 694). The ranking of two-letter CV combinations on the basis of their frequency is presented in table 3 below.

[11] An exception is made by the vowel [ɛ], which in rare cases maybe written as the letter «e», e,g. ‘темп’ [tɛmp] ‘tempo’.

Table 3. The ranking of Russian two-letter combinations (1 – the most frequent combination, 694 – the least frequent; C is a non-palatalized consonant, /a, o, u, i, e/ are underlying vowels)

IPA	C-/a/	Rank	C-/o/	Rank	C-/u/	Rank	C-/i/	Rank	C-/e/	Rank
b	ба	208	бо	82	бу	187	бы	87	бэ	685
p	па	126	по	5	пу	226	пы	334	пэ	-
d	да	50	до	60	ду	132	ды	239	дэ	-
t	та	22	то	2	ту	135	ты	139	тэ	683
v	ва	24	во	20	ву	230	вы	85	вэ	-
f	фа	347	фо	268	фу	468	фы	634	фэ	-
z	за	47	зо	216	зу	227	зы	263	зэ	-
s	са	121	со	66	су	181	сы	305	сэ	664
g	га	155	го	15	гу	255	гы	-	гэ	-
k	ка	19	ко	8	ку	118	кы	-	кэ	-
x	ха	248	хо	104	ху	404	хы	-	хэ	-
ts	ца	262	цо	397	цу	425	цы	378	це	174
ʐ	жа	191	жо	500	жу	364	жи	147	же	73
ʂ	ша	223	шо	351	шу	355	ши	151	ше	115
r	ра	9	ро	12	ру	81	ры	143	рэ	646
l	ла	31	ло	37	лу	158	лы	257	лэ	-
m	ма	75	мо	61	му	113	мы	160	мэ	608
n	на	4	но	3	ну	100	ны	45	нэ	694

The data in table 3 indicate that combinations of non-palatalized consonants with [ɛ] (shaded cells) are infrequent in Russian, except for [ʐ, ʂ, ts], which are the always hard (non-palatalized) consonants. This fact could be explained by an articulatory conflict between non-palatalized consonants and [ɛ] or by an overall low frequency of /e/ in Russian. To rule out the latter possibility, the frequency of palatalized C^jV syllables, where C^j is a palatalized consonant and V is [e] (the allophone of /e/ following C^j), were analyzed. The frequency data were again based on the ranking of two-letter combinations (Lyashevskaya & Sharov, 2009). The results are presented in table 4 below. Table 4 shows that C^jV syllables with [e] are frequent in Russian, which also suggests that /e/ is not infrequent across the board, but rather following hard consonants specifically.

Table 4. The ranking of C^j-/e/ syllables (from the most frequent to the least frequent)

C^j-/e/	бе	пе	де	те	ве	фе	зе	се	ге	ке	хе	ще	че	ре	ле	ме	не
Rank	123	91	42	28	44	286	283	69	253	231	484	134	57	16	36	54	11

As mentioned in section 2.1., palatalization is contrastive on most consonants in Russian, except for /ʐ, ʂ, ts/ which are always hard in Russian, and /j, tɕ/ which are always soft. A thorough examination of the frequency data in tables 3 and 4 suggests that the Russian language imposes a certain constraint on CV sequences, where C is a hard consonant and V is [ɛ], underlyingly /e/. This constraint prohibits the realization of the palatalization contrast on most C-[ɛ] combinations such that by and large non-palatalized consonants do not occur before [ɛ]. This fact led us to hypothesize that most Russian consonants are inherently velarized. In combination with [ɛ], which is the only front vowel used after hard consonants in Russian (see section 2.4, p. 20-21), an articulatory conflict between velarization of the consonant and articulation of the front vowel occurs, which makes these sequences marked and thus explains their low frequency. In contrast, hard CV sequences with other vowels, i.e. [a, ɨ, u, o], do not create an articulatory conflict between secondary articulation and the vowel tongue position, this is why such CV syllables are frequent in Russian (see table 3). Here it is worth mentioning that the combinations [ʐɛ, ʂɛ, tsɛ] are frequent in Russian and are thus unmarked. This fact suggests that there is no articulatory conflict in [ʐɛ, ʂɛ, tsɛ], which in its turn indicates that [ʐ, ʂ, ts] are not velarized in Russian.

To summarize, our hypothesis suggests that most Russian non-palatalized consonants, except for /ʐ, ʂ, ts/, are intrinsically velarized and that is why they do not generally occur with the front vowel [ɛ]. Based on frequency data of CV combinations with [ɛ] (Lyashevskaya & Sharov, 2009) and previous articulatory work, we make the following predictions:

1. Among the target sounds in this study:

   a) /f/ and /s/ are velarized in Russian;

   b) /l/ is also velarized (also based on previous articulatory work);

   c) /ʂ/ is not velarized;

   d) /x/'s primary gesture is in the same region as that of secondary velarization.

2. Secondary articulation of consonants is realized independently from vowels (based on our hypothesis that all Russian hard consonants are inherently velarized).

3.1.3 Syllables used (CV vs. VCV)

To test our hypothesis, we elicited CV syllables [fa, la, sa, ʂa, xa] and [fɛ, lɛ, sɛ, ʂɛ, xɛ] (see Appendix A). CV sequences were chosen for the lack of influence of the preceding vowel on the consonant. VCV́ sequences, where V is an identical vowel, were not studied due to stress-related reduction in Russian which would make it impossible to control for the vowels in two-syllable tokens. A number of phonetic studies on CV vs. VC coarticulatory effects more generally have shown that syllable-final consonants are more affected by coarticulation compared to syllable-initial (see Nittrouer et al. 1988, Krakow 1999, Modaressi et al. 2004 for literature review). Modaressi et al. (2004) mention the study by Kiritani & Sawashima (1987) who reported that syllable-final consonants undergo larger vowel dependent coarticulatory effects (tongue dorsum displacement) relative to syllable-initial consonants. This allows us to predict that the impact of vowels on secondary articulations of Russian consonants in VC syllables will differ from that in CV syllables, CV syllables showing less coarticulation. The relative influence of the preceding vs. following vowel on secondary velarization of Russian hard consonants should be examined in a separate follow-up study. For our purposes, CV syllables were chosen so as to minimize potential co-articulatory effects, since the goal was to investigate intrinsic velarization of consonants.

Participants were asked to read the stimuli at a comfortable rate 3 times. A total of 30 tokens were obtained per participant (3 repetitions × 5 consonants × 2 vowels).

3.2 Participants

Data came from 6 native Russian speakers, currently residing in Victoria, British Columbia, Canada. All of them were born on the territory of the former Union of Soviet Socialist Republics (USSR) and have lived in Canada for at most 2 years. One participant was born in the Russian Federation (S4), two participants come from the Republic of Belarus (S3 and S5) and three participants come from the Republic of Kazakhstan (S1, S2, S6). Belarus is a bilingual country where Russian and Belarusian (also an East Slavic language) are the official languages. Kazakhstan is also officially a bilingual country. In Kazakhstan, Kazakh, a Turkic language, is the state language, while Russian has the status of official language and is spoken by most Khazakhstanis. All the bilingual participants (S1, S2, S3, S5, S6) reported speaking Russian at home and in their social and work lives, and hardly using Belarusian or Kazakh at all outside of school. Two of the participants were male, four were female. The age of subjects ranged from 18 to 29.

3.3 Procedure

Participants were seated in a dental chair provided with a ‘two-cup’ headrest [12] to maximize head stability and ultrasound probe (or ‘transducer’) contact, in order to allow for comparisons across multiple repetitions of target sounds (see the experimental set-up in Figures 6(a) and 6(b) below). The ultrasound probe was attached to a spring-loaded mechanical arm and secured in a position where it was pressed up against the subject’s chin in such a way as to provide a consistent midsagittal (B-mode) image of the subject’s tongue from root to tip (see Figure 7). The subjects read stimuli from a computer monitor also mounted on the mechanical arm, one meter in front of participants. The stimuli were presented as separate power point slides on the screen. Audio recordings were made using a Sennheiser microphone directly in front of the subjects. Ultrasound data were collected via a portable GE Logiq E ultrasound machine with an 8C-RS 180-degree transducer. The tongue was imaged at 30 frames per second. The ultrasound video was converted via StarTech.com Professional VGA to HDMI video converter, then synchronized with the audio signal via Ultrastudio Mini Recorder and captured onto a hard drive of a Mac computer using Blackmagic Media Express.

[12] A two-cup head rest contacts the posterior part of the head at two points.

Figure 6(a). The experimental set-up: 1) portable GE Logiq E ultrasound machine; 2) ultrasound probe; 3) dental chair; 4) mechanical arm with spring-loaded probe holder; 5) microphone; 6) computer monitor mounted on the mechanical arm.

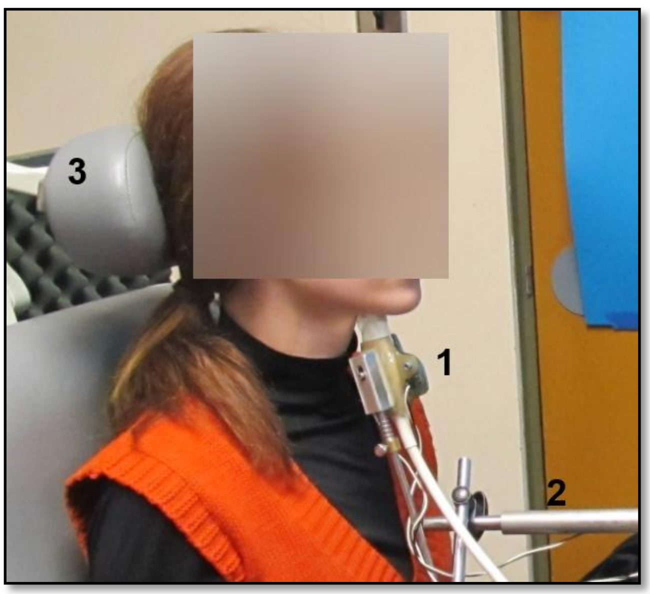


Figure 6(b). A subject with the probe under the chin: 1) ultrasound probe; 2) mechanical arm with spring-loaded probe holder; 3) a two-cup dental chair headrest.

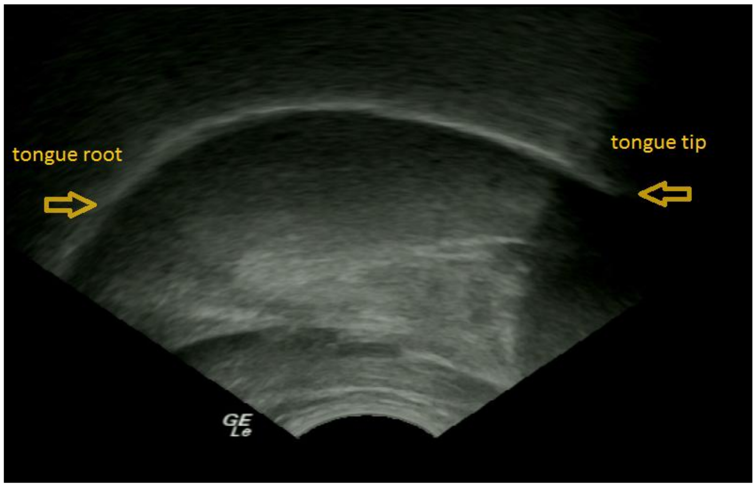


Figure 7. A mid-sagittal ultrasound image of the tongue during [f] in [fa] (S4), showing the location of the tongue tip and the root (tongue root on the left, tongue tip on the right).

3.4 Analysis

The data were analyzed by extracting tongue contours of the consonants from ultrasound images at the temporal midpoint of the consonant in each CV sequence. In 2012, Zharkova et al. conducted an ultrasound study of lingual coarticulation in /sV/ syllables produced by adults and typically developing children. The authors mentioned in the article that there are two ways to measure coarticulation effects: either to measure the onset time of an effect or to choose a certain time-point within the period of frication (when speaking about fricatives) and examine the size of any co-articulatory effect at that point (Zharkova et al. 2012:194). They adopted the second approach, motivating their choice by an attempt to ensure that the object of measurement was indeed 'coarticulation' as opposed to being part of the 'transition' from the consonant to the vowel (Zharkova et al. 2012:194). Indeed, there is a difference between 'coarticulation' and 'transition' from consonant to vowel, though according to Zharkova et al. (2012:194), this distinction is much easier to make conceptually than it is to identify in practice[13]. In our study,

[13] See Flemming's (2001) work unifying the two types of effects.

we adopted Zharkova et al.'s (2012) method of examining coarticulation. One of our primary research questions was to determine whether the following vowel induces any coarticulatory effects on the immediately preceding consonant, namely on its secondary articulation. As mentioned above, this effect might be stronger in VC sequences. The midpoint of consonants was chosen to avoid transitional (as opposed to co-articulatory) effects of the following vowel. The presence or absence of a vowel effect on the consonant was determined by examining differences between the consonant tongue contours in two vowel environments ([a] vs. [ɛ]), as described in more detail below.

The present study was an initial exploration of Russian secondary articulations of hard consonants. For this reason we aimed at qualitative rather than quantitative analysis. Also, the primary research question was to determine the presence vs. absence of secondary articulatory gestures, rather than measure the size, or degree, of these gestures. Visual examination of superimposed tongue contours alone was sufficient to address this question. A further quantitative investigation of secondary articulations in Russian is needed to describe articulatory details of such gestures, as well as to allow for inter-speaker comparisons.

Three tokens (= repetitions) of each CV sequence were extracted from the lingual ultrasound video for each speaker in VirtualDub 1.10.4. The CV token with the best image quality was chosen for analysis for each sequence. We initially planned on using the point of maximal tongue body stricture for each consonant for analysis, however determining it in the ultrasound data yielded a fair amount of difficulty, especially for labials due to their high mobility in terms of their change from frame to frame, therefore this idea was discarded. The midpoint frames of the consonants were instead determined with the help of a waveform in Sony Vegas Pro 12.0: the midpoint was first determined on the acoustic signal, and then the corresponding 2-3 frames were located on the ultrasound video. These frames were extracted from the ultrasound video with VirtualDub 1.10.4 and then loaded into Edgetrak (Li et al. 2005) to trace tongue contours (see Figure 8). This program tracks the tongue contours in the ultrasound images and extracts them as a series of XY coordinate points which are saved in a text file. In our study, we used 30 XY points as suggested in the manual by Gick & Namato (2012, not published). The data in the text file were then exported into Microsoft Office Excel 2007 as a set of 30 XY coordinates. The coordinates of the first of two or the middle of three midpoint frames were then used to build tongue contours and superimpose them onto each other (see Figure 9 below).

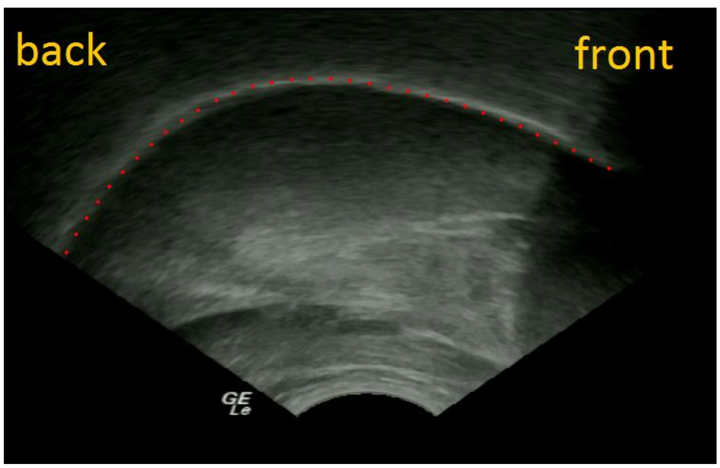


Figure 8. A semi-automated tongue contour of [f] in [fa] (S4) presented in Edgetrak (Li et al. 2005).

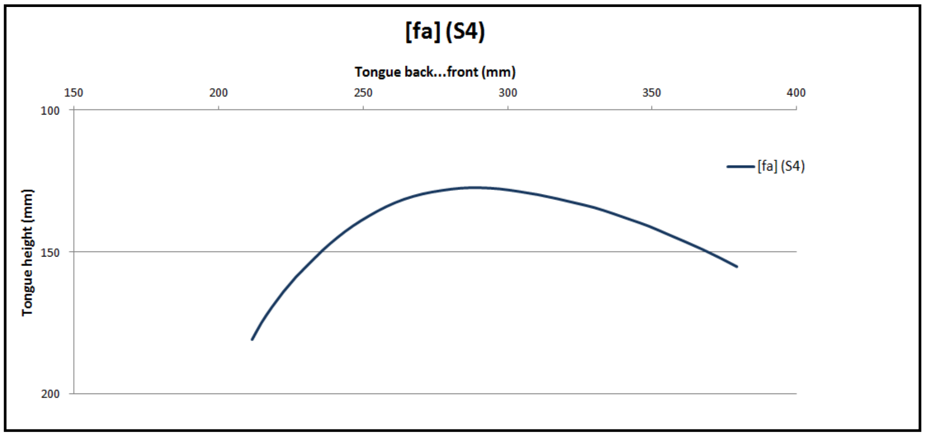


Figure 9. The tongue contour of [f] in [fa] (S4), built in Excel 2007.

To determine velarization on extracted tongue contours, the most curved, concave region of the tongue body was chosen. It was assumed that its highest point corresponded to the point of maximal dorsal stricture. Stricture points, and tongue contours more generally, were then compared to two ‘baseline’ contours: [x] and rest position. The maximum stricture points in sequences [xa] and [xɛ] were considered an articulatory landmark for *velarization*: [xa] and [xɛ] were expected to show the location of tongue back *raising* during articulation of [f, l, s, ʂ], if any. Absolute tongue rest position was chosen as the second reference point for determining secondary articulations. Specifically it was used to make inferences about *uvularization* and *pharyngealization* of the consonants. We assumed that a strong backward movement of the tongue root relative to the absolute rest position would point to either *uvularization* or *pharyngealization* of the segment (see the discussion in section 2.6.1). As mentioned above, it is impossible to image pharyngealization using lingual ultrasound because it does not image the larynx. To tease apart these possibilities, a *laryngeal* ultrasound investigation of the production of Russian consonants by one subject was conducted. This allowed for a transparent analysis of the results obtained in the *lingual* ultrasound study (see section 3.5).

It is worth mentioning here that the literature distinguishes between inter-speech posture, or speech rest position, and absolute tongue rest position (Gick et al. 2004, Gick et al. 2006, Wilson 2006, etc.). Speech rest position is the position the vocal tract acquires between utterances, when the person is still in speech mode (Wilson 2006). Absolute rest position is the one when an individual is not engaged in speech activity and which is used simply for respiration (Wilson 2006). Gick et al. (2004) proposed that the inter-speech position is the most representative configuration at which to measure the position of articulators in order to make inferences about a language's articulatory setting[14], or voice quality. According to Honikman (1964), the Russian articulatory setting is characterized by close jaws, spread lips and a fronted (palatalized) tongue position. Esling (1983) elaborated on this description by adding a "faucal constriction" feature – tightening of the upper pharynx. Taking into account these observations, we assumed that the absolute tongue rest position would be a more neutral tongue position than the inter-speech rest position, and thus a better baseline for evaluating the location and size of tongue body retraction during Russian non-palatalized consonants.

Our analysis of *lingual* ultrasound data involved several steps. First, the tongue contours of each consonant in their combinations with the vowel [a] and [ɛ] were superimposed onto each other and onto the tongue contours of [xa], [xɛ] and tongue rest position (see an example in Figure 10). This view 1) shows the location of the maximal **tongue body** stricture, 2) shows the location and size of the **tongue root** backing gesture, 3) allows for comparison of the tongue body and tongue root gestures of each consonant in two vowel contexts, and therefore 4) demonstrates whether the following vowel affects the location of the maximal tongue body

[14] According to Honikman (1964), articulatory setting is 'the overall arrangement and manoeuvring of the speech organs necessary for the facile accomplishment of natural utterance'.

stricture and the backing gesture of the tongue root of individual consonants. In other words, it shows whether vowels induce any effects on secondary articulation of consonants.

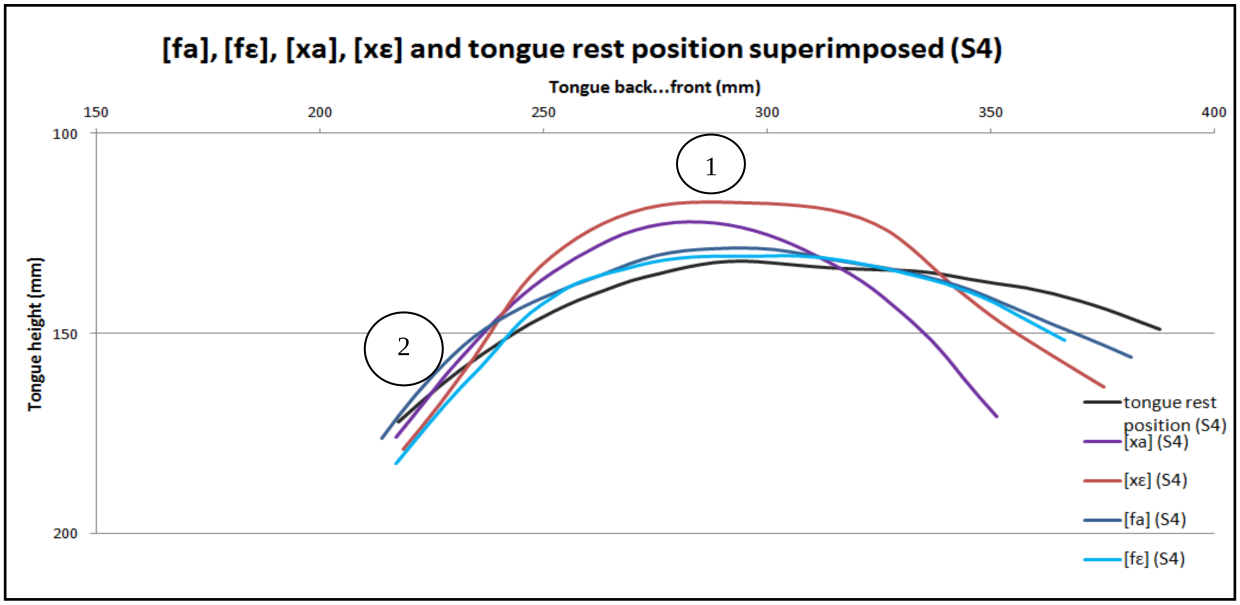


Figure 10. Superimposed contours of the tongue at the midpoint of consonants in [fa], [fɛ], [xa], [xɛ] and the shape of the tongue at rest (S4) (in mm): 1 – shows the location of the maximal tongue body stricture, 2 - shows the location and size of the horizontal backing of the tongue root.

Second, the tongue contours of all consonants before [a] (see Figure 11a) and [ɛ] (see Figure 11b) for each speaker were superimposed onto each other. These views allowed us 1) to judge the location of tongue body stricture and the tongue root backward gesture across consonants, 2) to make general inferences about the influence of the following vowel on the production of the preceding consonant. All superimposed tongue contours are presented in Appendix B.

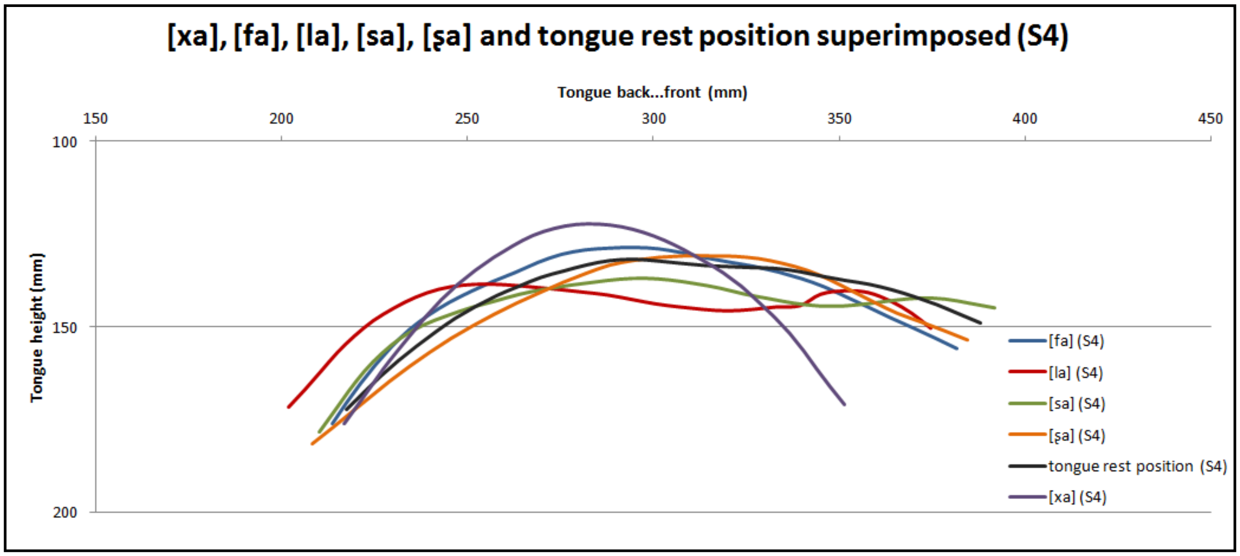


Figure 11a. Superimposed contours of the tongue at the midpoint of consonants in [xa], [fa], [la], [sa], [ʂa] and the shape of the tongue at rest (S4) (in mm).

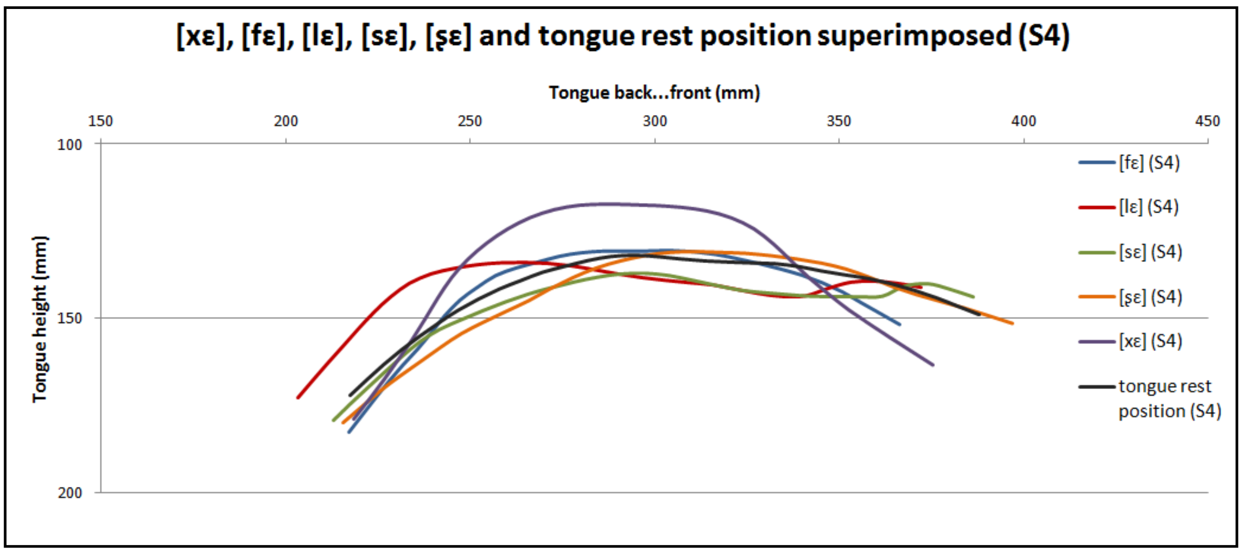


Figure 11b. Superimposed contours of the tongue at the midpoint of consonants in [xɛ], [fɛ], [lɛ], [sɛ], [ʂɛ] and the shape of the tongue at rest (S4) (in mm).

Here it should be noted that tongue root activity observed on superimposed tongue contours is not reliable enough to draw robust conclusions about the exact size of the backward gesture of the tongue. The root of the tongue is not always clearly imaged by ultrasound due to the ‘acoustic shadow’ cast by the hyoid bone (see Stone’s (2005:463) discussion of ultrasound image quality and interpretation of anatomical features as seen on the image). This fact should be taken into account when examining the extracted tongue contours in the results section and in Appendix B, as some deviations from the actual tongue root activity are possible in our data.

As discussed in section 2.6.1, *raising* of the tongue body during the production of a non-palatalized consonant could attest to either secondary *velarization* or *uvularization* of this consonant. *Velarization* and *uvularization*, however, differ in the size of the backward articulatory gesture, as well as in the stricture target of raising. In secondary velarization, the tongue is raised against the ‘anterior’ part of the soft palate, whereas in uvularization the tongue is pulled further back in the mouth resulting in a raising gesture against the ‘posterior’ part of the soft palate, namely in the uvular region. Delineation of the two regions is unfortunately not straightforward on ultrasound images. Lingual ultrasound does not image the soft and the hard palate because of their low *echogenicity*. *Echogenicity* refers to the ability of tissues to transmit or reflect ultrasound waves. When there is an interface of structures with different echogenicities, a visible difference in contrast will be seen on the screen (Ihnatenka & Boezzaart 2010). When using lingual ultrasound to observe the tongue movements, the probe is placed under the chin. According to Stone (2005), in this case, the sound wave travels upward from the probe through the tongue body and reflects back from the upper surface of the tongue, which is bounded by air or the hard palate. Both the air and the hard palate have very different densities, or echogenicity, from the tongue, which results in a strong echo and consequently in a good image of the tongue but a poor image of the soft and hard palates.

The tracing of the hard palate can be used as the reference for location of the soft palate on ultrasound images. The program Edgetrak (Li et al. 2005) is able to trace the hard palate from a swallow. In our study, however, the hard palate was not traced. We assumed that the location of the tongue body stricture during the production of the *velar* consonant /x/ can be used as a benchmark for determining the anterior part of the soft palate, and thus distinguishing the velar from the uvular region. However, we then realized that such an approach has a drawback. According to Ladefoged (1996:33), velars are variable in terms of the location of the tongue body stricture which is greatly affected by the vowel environment. This implies that velars can be fronted before a front vowel or, vice versa, drawn back before a retracted, i.e. pharyngealized, vowel. This makes velar consonants not a fully reliable reference for delineation of the velar and uvular regions on ultrasound images in general and on extracted tongue contours in particular.

Figures 12 and 13 below provide an additional reference for determining the regions of the roof of the mouth in ultrasound view. Figure 12 illustrates the parts of the tongue together with an approximate division of the soft palate as viewed on ultrasound images (retrieved from McDowell 2004:29). McDowell employs Gick's et al. (2002) division of the vocal tract into upper and lower pharyngeal, uvular, and oral regions. McDowell elaborates on this classification by dividing the uvular region into an upper and lower area in order to distinguish the Montana Salish pharyngeal-uvular, i.e. posterior uvular, production from what she calls "true" uvulars.

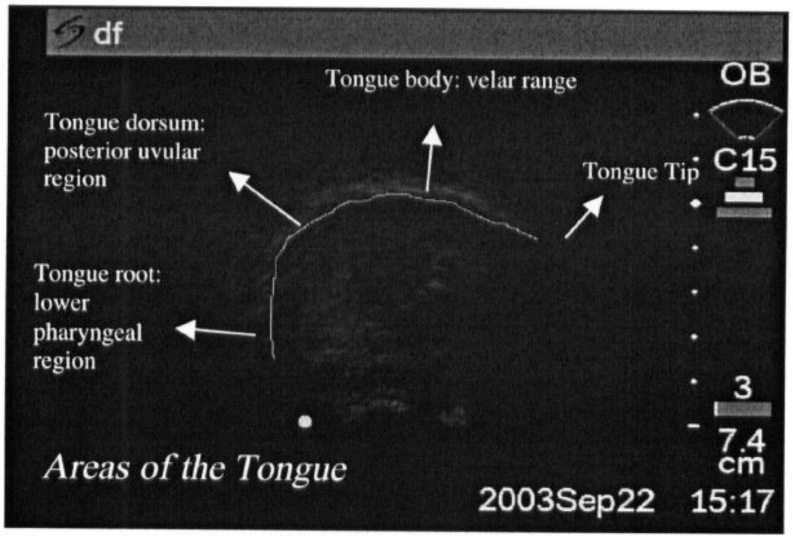


Figure 12. Regions of the tongue together with the division of the soft palate into the velar and uvular regions as seen on ultrasound. Retrieved from '*Retraction in Montana Salish lateral consonants'* (master's thesis), p.29, by R. McDowell, 2004. University of British Columbia, Vancouver BC.

Figure 13 demonstrates the differences in the contact location between the St'át'imcets uvular stop /q/ [q] and velar stop /k/ [k] traced on ultrasound images (retrieved from Namdaran 2006:47). The interspeech rest position (ISP) is also traced on the image.

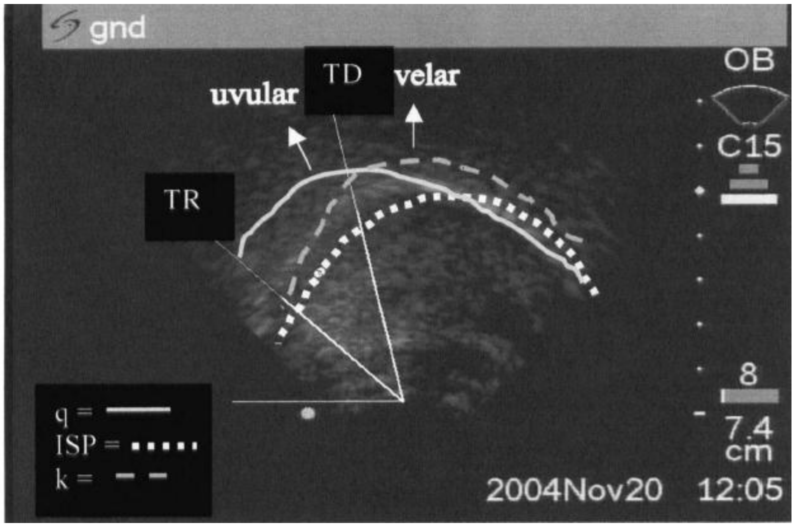


Figure 13. Tracings of uvular stop /q/, velar stop /k/ and interspeech rest position in St'át'imcets. Retrieved from '*Retraction in St'át'imcets: an ultrasonic investigation'* (master's thesis), p.47, by N. Namdaran, 2006. University of British Columbia, Vancouver BC.

As we can see on Figure 13, the velar stop /k/ exhibits tongue body raising almost perpendicular to the horisontal orientation of the tongue. In comparison, the tongue body of the uvular stop /q/ is drawn further backwards resulting in raising in a more posteror region of the the mouth and in a more flattened and stretched tongue front.

Thus we can conclude that the location of the stricture in the upper-pharynx together with the shape of the tongue can be used to distinguish *velarized* segments from *uvularized* segments on ultrasound images. In the present study, the combination of tongue body raising further back than /x/, horizontal backing of the tongue body relative to tongue rest position and a stretched or flattened tongue front were considered an indication of *uvularization* of non-palatalized consonants. Whereas, tongue body raising in the region of /x/, approximately in the center of the extracted tongue contour (see Figure 12), together with a slight or no backing of the tongue body relative to tongue rest position were used to infer about *secondary velarization*.

3.5 Laryngeal ultrasound: methodology

The goal of the *laryngeal* ultrasound investigation was to determine whether Russian non-palatalized consonants [f, l, s, ʂ, x] exhibit raising of the larynx, which would provide strong evidence for *pharyngealization* of these consonants. Larynx raising, aryepiglottic sphinctering and tongue root retraction are the primary components of pharyngeal articulations (see details in section 2.3). The images of the larynx, however, obtained using laryngeal ultrasound, do not lend themselves to an easy *visual* interpretation. Generally laryngeal ultrasound images are noisy. An additional level of complexity is added by the sophisticated structure of the larynx featuring a lot of air cavities, various tissue interfaces and many changes in direction of laryngeal structures during speech production, which are ‘continually moving into and out of the ultrasound beam’s imaging plane’ (Moisik et al. 2014:30). An ‘acoustic shadow’ is cast by the hyoid bone which obscures the action of the epiglottis and aryepiglotic folds, and, in general, makes the activity of *upper* laryngeal structures indistinguishable. According to Stone (2005), ultrasound produces the best images of structures which are perpendicular to the sound beam emitted by the ultrasound probe. The larynx however shows various space orientations of its structures. All these factors reduce image clarity.

To overcome the limitations of the *laryngeal* ultrasound, Moisik et al. (2014) implemented an *Optical Flow Analysis* of the video data. According to the authors, this technique allows for recording movement in a sequence of video frames and quantifying it as a discrete vector (or velocity) field (see the details in Moisik et al. 2014). The optical flow analysis is a complex procedure based on the use of sophisticated algorithms, which requires a lot of time. The primary focus of the present study, however, was oral articulations. Therefore we decided to conduct a *pilot visual* examination of the larynx state during the production of Russian non-palatalized consonants. Because the vocal cords can be easily located on laryngeal ultrasound video under the right angle of the probe, they were used as the reference for the raising gesture of adjacent laryngeal tissues and muscles, if any. Our goal was to observe the activity of the larynx without establishing the anatomy of the structures involved.

3.5.1 Stimuli

The stimuli used in the laryngeal ultrasound experiment are presented in Table 5 below. They include minimal contrastive pairs of Russian non-palatalized and palatalized *consonant-vowel* sequences, i.e. CV vs. C^jV, where C is a non-palatalized consonant, C^j is a palatalized consonant, and V is the vowel /a/.

Table 5. Stimuli used for laryngeal ultrasound.

Stimuli (laryngeal ultrasound)	
CV	**C^jV**
[fa]	[fʲæ]
[la]	[lʲæ]
[sa]	[sʲæ]
[s̨a]	[s̨ʲæ]
[xa]	[xʲæ]

As discussed in section 2.4, the phoneme /a/ corresponds to the vowel [a] when used after Russian hard consonants, and to [æ] when used after soft consonants. [a] is an inherently pharyngealized vowel, which suggests that [a] should exhibit raising of the larynx on laryngeal ultrasound view. We assumed that if the non-palatalized consonants are *not pharyngealized*, they should be articulated with a relatively low larynx (compared to /a/), and we should be able to observe larynx raising into the following /a/. On the other hand, if the non-palatalized consonants are *pharyngealized*, both the consonant and the vowel should exhibit larynx raising, which means that little movement should be observed between the consonant and the following vowel.

As an additional baseline for comparison of the larynx height, C^{j}V syllables featuring palatalized counterparts of non-palatalized consonants, i.e. [f^{j}, l^{j}, s^{j}, ʂ^{j}, x^{j}], were elicited. We assumed that the identical patterns of vertical larynx activity in both CV and C^{j}V sequences would attest to the absence of pharyngealization of Russian hard consonants, whereas different patterns would suggest its presence. This speculation was based on the assumption that Russian palatalized consonants are not pharyngealized. Pharyngealization would significantly alter the quality of palatalized segments due to the constriction of the larynx and would therefore be clearly audible, which is however not observed in Russian.

The stimuli were repeated three times. Before eliciting tokens, the vowel [i] was produced at a normal pitch to locate the vocal folds in ultrasound view. In total, 30 tokens of syllables were obtained: 10 consonants (5 palatalized and 5 non-palatalized) x 3 repetitions.

3.5.2 Participant

One subject (S5), the author of this work, participated in the laryngeal ultrasound investigation.

3.5.3 Procedure

The participant was seated in a chair holding the probe. The use of manual probe placement was justified for the pilot investigation of larynx height during the production of Russian non-palatalized consonants, based on Moisik et al. (2014). According to Moisik et al. (2014:26), ‘a fixed probe apparatus would require greater effort and time to readjust and fixing the participant’s head in place’. These measures were considered unnecessary due to the exploratory character of the experiment: the analysis of the data obtained using laryngeal ultrasound involved qualitative rather than quantitative examination. Because the participant's head and the probe were not stabilized, minor changes in probe position could have occurred between tokens. This fact, however, does not affect the credibility of the results obtained in this study for several reasons. First, our goal was simply to establish whether or not the larynx is raised rather than to quantify this gesture. Once the vocal folds were located on ultrasound images, they provided a good reference for any changes in the tissues of the lower larynx. Second, we made sure that the probe was stable within any given token. In this experiment we only used tokens showing the best probe contact, displaying the clearest ultrasound image of the larynx. The change in the probe position within a token would result in the loss of a good ultrasound image.

A Sennheiser microphone was placed on the desk near the ultrasound machine to obtain the audio signal. The audio signal was synchronized with the converted ultrasound video via Ultrastudio Mini Recorder and captured onto the hard drive of a Mac computer using Blackmagic Media Express (see the set up in section 3.3). An 8C-RS transducer/probe was pressed manually against the participant's right thyroid lamina near the laryngeal prominence so as to provide a consistent coronal, or rather semi-coronal/oblique view of the larynx due to the curvilinear shape of the probe (replicated from Moisik et al. 2014). The curved image of the anatomical structures obtained using this probe, in reality, are straight. The probe was positioned longitudinally. Figure 14 below demonstrates the approximate placement of ultrasound probe on the neck during the experiment.

a) b)

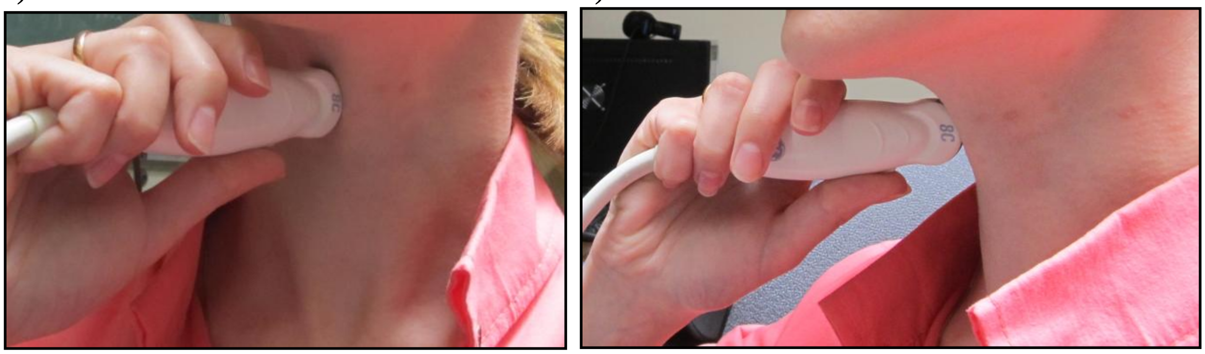


Figure 14. Illustrations of ultrasound probe placement: a) frontal view; b) lateral view.

Figure 15 elucidates the location of laryngeal structures when imaged using the set up described above (retrieved from Moisik et al. 2014:28).

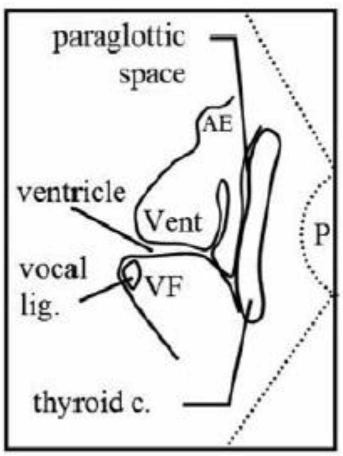


Figure 15. A diagram showing the structure of the larynx as viewed with the probe placement illustrated in Figure 14: VF – vocal fold, Vent – ventricular fold, AE – arypeiglottic fold, P – shows the position of a probe pressed against a thyroid lamina. Retrieved from 'A study of laryngeal gestures in mandarin citation tones using simultaneous laryngoscopy and laryngeal ultrasound (SLLUS)' by S.R. Moisik, H. Lin & J.H. Esling, 2014, *Journal of the International Phonetic Association*, *44*(1), p. 28.

3.5.4 Analysis

Three tokens of each CV and C^jV sequence were segmented from the ultrasound video using Virtual Dub 1.10.4. The palatalized consonants turned out to be difficult to interpret, therefore they were not included in the analysis. The token with the clearest view was used for qualitative analysis of each sequence. To compare the laryngeal activity in a non-palatalized consonant with that of the vowel [a] in a CV sequence, five to eight frames were extracted from the ultrasound video showing the production of the consonant and the vowel.

To facilitate comparison between the frames obtained during the production of the Russian non-palatalized consonants [f, l, s, ʂ, x] vs. the vowel [a], two lines were drawn in Paint.NET 3.5.11 through the upper point of the semi-oval formed by an ultrasound probe (see Figure 16 in Chapter 4). These lines were used to make inferences about the size of the displacement of laryngeal tissues in the consonants and the vowel, if any (see Chapter 4 – in particular Figure 19 – for further details).

Chapter 4

Results

As mentioned in section 3, our analysis included two stages: the analysis of *lingua*l ultrasound data followed by examination of *laryngeal* ultrasound data. *Lingual* ultrasound analysis included examination of two articulatory gestures: the location of the tongue body stricture in [f, l, s, ʂ] relative to the tongue body stricture of the velar [x] and the tongue root activity relative to the tongue rest position. *Laryngeal* ultrasound data analysis involved the observation of the larynx height in a non-palatalized consonant vs. [a] in a CV sequence, as well as in non-palatalized CV syllables vs. palatalized C^jV syllables. To contribute to the clarity of the results obtained using *lingual* ultrasound, the analysis of the *laryngeal* ultrasound data is presented first. The results are presented in sections 4.1 – 4.6. Each section provides illustrative figures of the articulation of consonants in question and summarizes the findings in tables 5-8.

4.1 Laryngeal ultrasound

The analysis of the results obtained using *laryngeal* ultrasound suggests that Russian non-palatalized consonants are not pharyngealized. Figure 16 below provides a sequence of eight frames obtained during the articulation of [a] in [la]. The upper pharynx is located at the top of the image, the lower larynx at the bottom of the image. Together, the frames show vertical movement of the larynx.

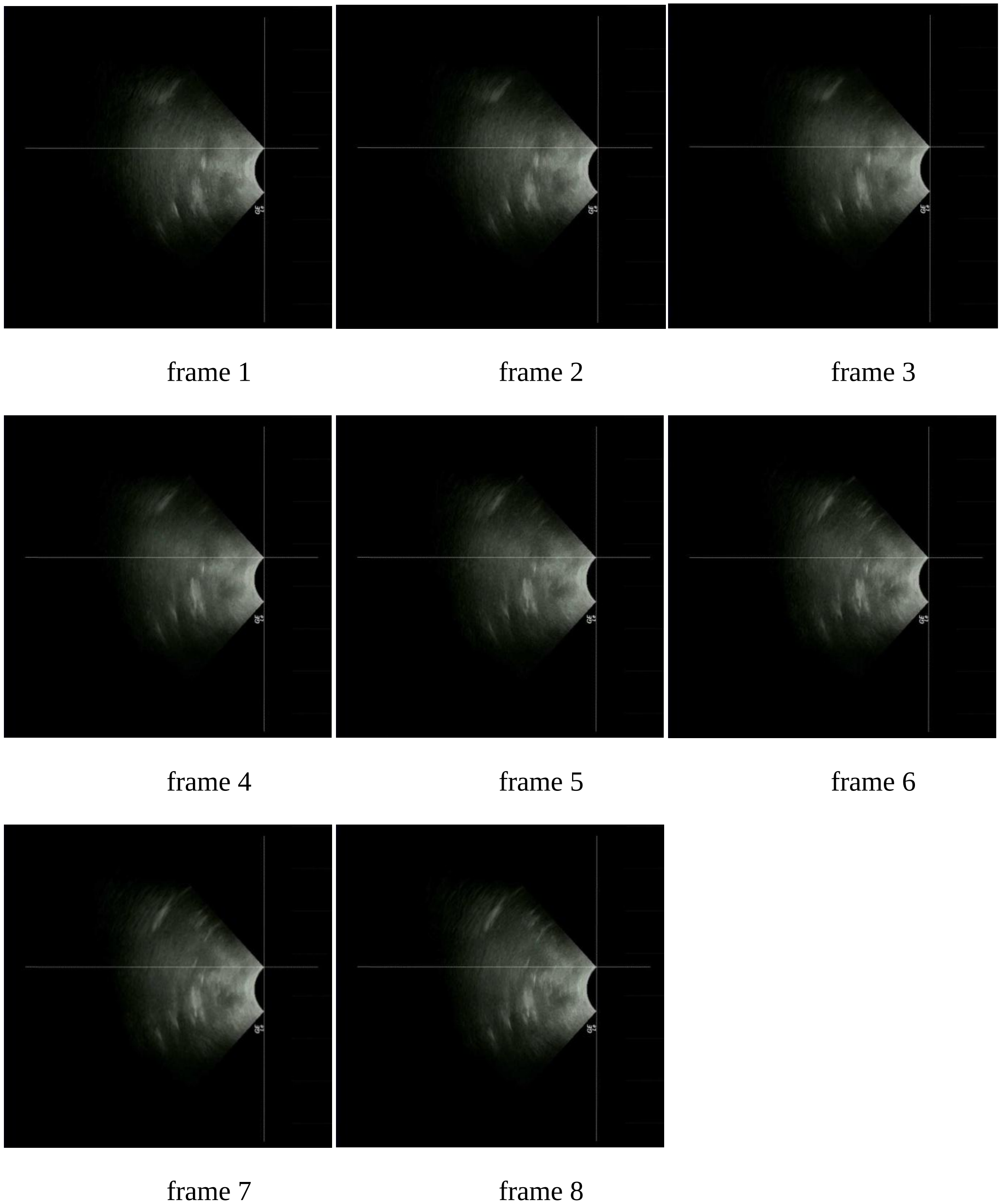


Figure 16. A sequence of eight frames demonstrating the activity of the laryngeal structures during the production of the vowel [a] in [la]. The top of the picture is *upper larynx*, the bottom of the picture is *lower larynx*.

Figure 17 compares only the first and the last frame of [a] from Figure 16. The white rectangle delineates the region which exhibits the upward movement of laryngeal structures. The change of the larynx height in [a] can be inferred from the displacement of the structure pointed to by the white arrow relative to the horizontal dashed line. The dashed line was superimposed on the images through upper point of the semi-oval produced by the probe to visualize the changes in the larynx activity. We can see that this structure is raised in frame 8 in comparison to frame 1, which proves that [a] is pharyngealized.

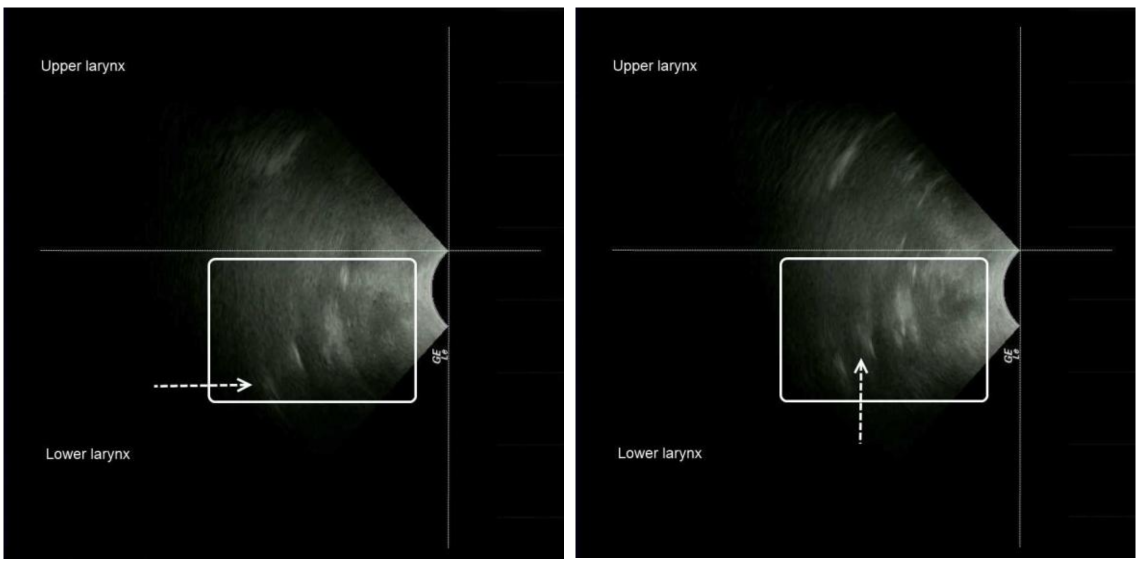
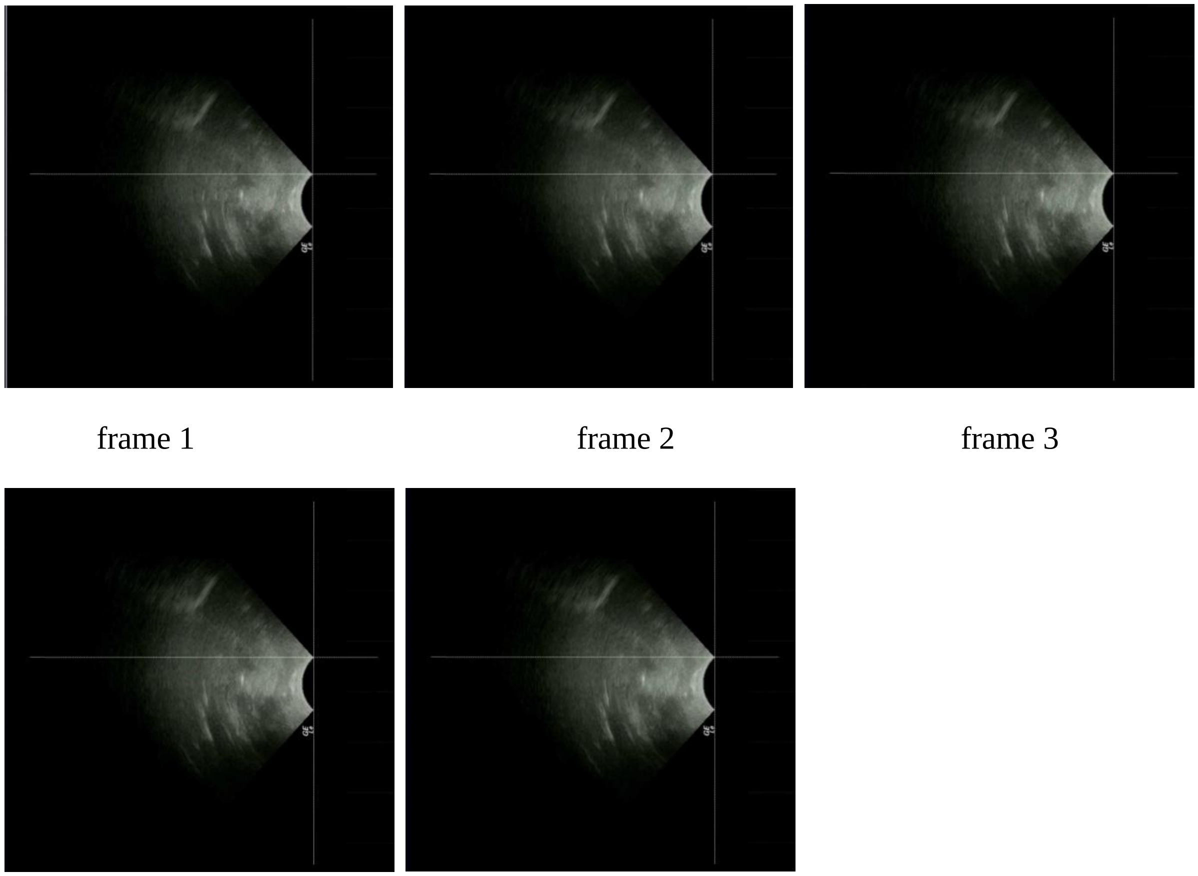


Figure 17. The comparison of the larynx height in frame 1 and frame 8 of Figure 16. The white rectangular highlights the region of special interest in the present study.

Figures 18 and 19 demonstrate a different articulatory pattern in comparison to [a]. Figure 18 below provides a sequence of five frames showing the laryngeal activity in a non-palatalized consonant [l] in the syllable [la]. We can see that there are no obvious changes in the movements of the laryngeal tissues. This implies that the larynx remains low.

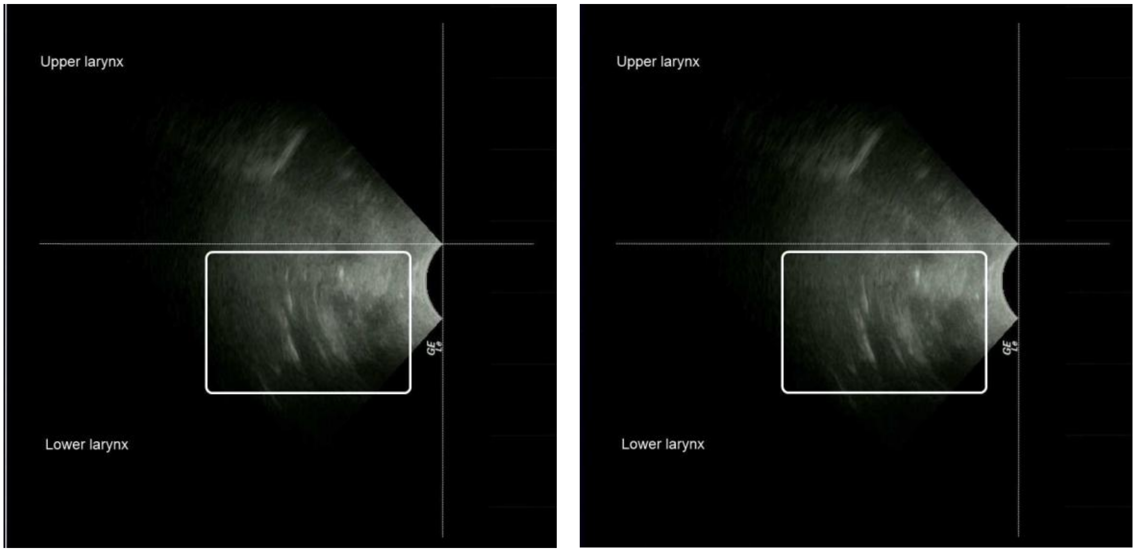


frame 1 frame 2 frame 3

frame 4 frame 5

Figure 18. A sequence of five frames demonstrating the activity of the laryngeal structures during the production of [l] in [la]. The top of the picture is *upper larynx*, the bottom of the picture is *lower larynx*.

Figure 19 allows for closer comparison of the first frame with the last frame of [l] in Figure 18. The dashed line was superimposed on the images through the upper point of the semi-oval produced by the probe. The white rectangle delineates the region that does not show any changes in the laryngeal structures during the production of the lateral [l] but which exhibits alternation in the larynx height during the production of the vowel [a] (see Figures 16 and 17 above).



Frame 1 Frame 5

Figure 19. The comparison of the larynx height in frame 1 and frame 5 of Figure 18. The dashed line is drawn through the upper point of the semi-oval produced by the probe. The white rectangular highlights the region of special interest in the present study.

The absence of changes in the larynx height in [l] and raising of the larynx in [a] suggest that Russian [l] is not pharyngealized. The same results were obtained for [f, s, ʂ, x]. This implies that Russian non-palatalized consonants are not pharyngealized.

Thus, our pilot laryngeal ultrasound investigation suggests that the production of Russian non-palatalized consonants does not involve pharyngeal constriction, as no larynx raising was observed (Esling 1999, 2005). This, in its turn, implies that hard consonants are not pharyngealized in Russian, contrary to Bolla's (1981) views. The results of the laryngeal ultrasound experiment predetermined our further analysis of the *lingual* ultrasound data presented in sections 4.2 – 4.6. Specifically, tongue root backing evident from the tongue contours was taken to reflect uvularization rather than pharyngealization.

4.2 Lingual ultrasound: /l/

Our analysis showed that [l] of all participants was characterized by simultaneous raising and horizontal backing of the tongue. The point of maximal raising of the tongue body was further back than that of [x] for 5 speakers, all except S1. Our data also showed a significant backward movement of the tongue body relative to the absolute tongue rest position for 5 speakers, all except S6. Figures 20 and 21 provide two illustrative sets of tongue contours from two separate individuals (S4 and S5). Dots mark the points of maximal tongue body stricture. These points should not be considered as rigid reference points because they were determined visually. They should rather be looked upon as landmarks of a certain region of articulation. In both figures we can see that dots are further back than for velar [x]. The tongue is stretched back, resulting in the configuration similar to that of the St’át’imcets uvular stop /q/ in Figure 13 (from Namdaran 2006). This implies that Russian [l] is *uvularized*.

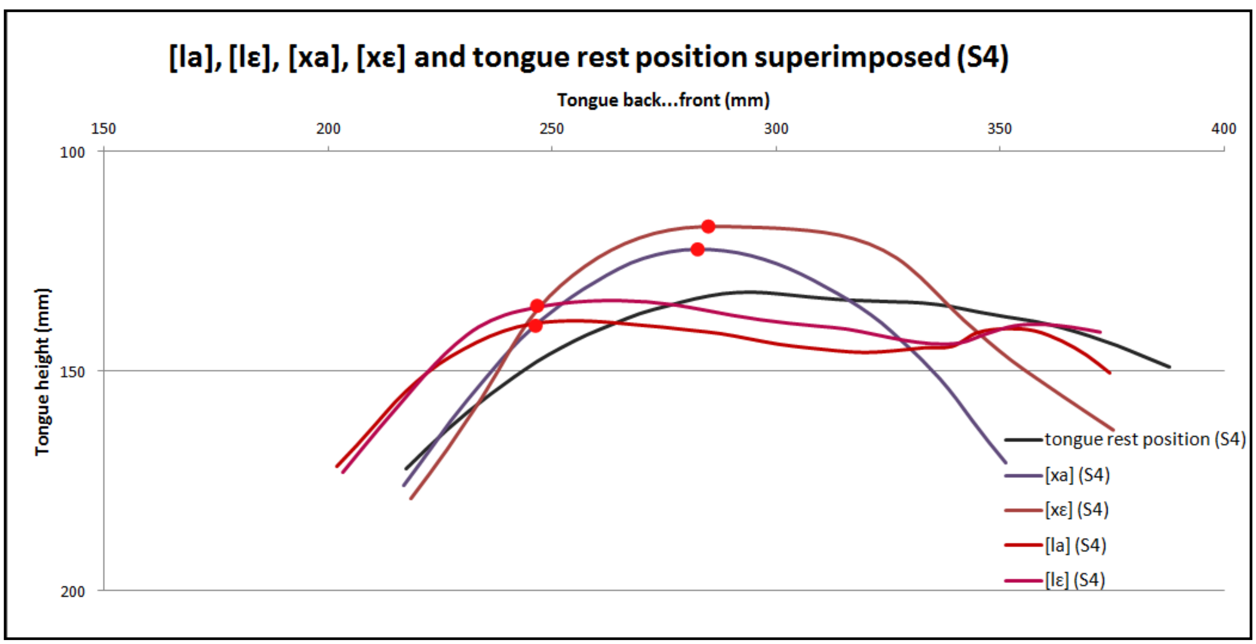


Figure 20. Superimposed tongue contours of [la], [lɛ], [xa], [xɛ] and tongue rest position of S4; the dots are the points of maximal tongue body stricture.

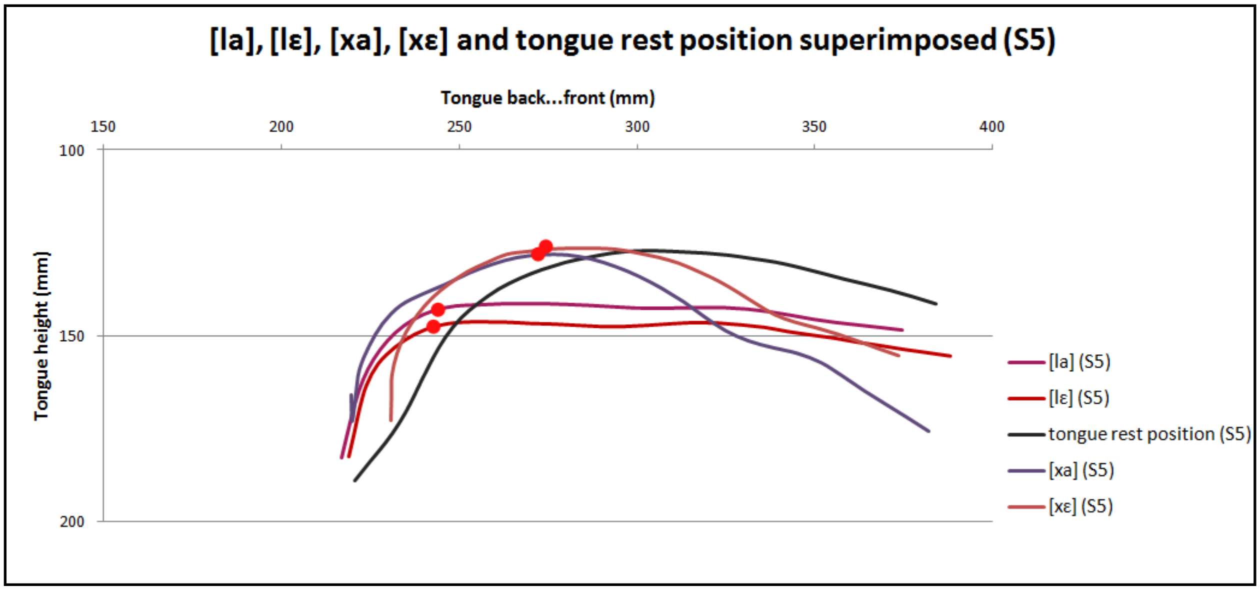


Figure 21. Superimposed tongue contours of [la], [lɛ], [xa], [xɛ] and tongue rest position of S5; the dots are the points of maximal tongue body stricture.

Table 6 summarizes our observations with respect to the location of the maximal tongue body stricture and the tongue root activity in [la] and [lɛ] across 6 speakers. It demonstrates that the location of the point of maximal tongue body stricture does not depend on the vowel context. This can also be inferred from Figures 20 and 21 above which illustrate that for both speakers, the contours of [la] and [lɛ] are very similar and the dots are roughly in the same region. These facts suggest that Russian /l/ is *inherently* uvularized.

Table 6. The location of the maximal tongue body (TB) stricture and tongue root (TR) activity of [la] and [lɛ] across speakers:

TB: ‘=’ – equal to [xa]/[xɛ], ‘>’ – **pulled further back** than [xa]/[xɛ];

TR: ‘=’ – equal to the tongue rest position; ‘>’ – **pulled further back** than the tongue rest position; shaded cells mark exceptions to the general pattern.

Speaker	**TB**		**TR**	
	[la]	[lɛ]	[la]	[lɛ]
S1	=	=	>	>
S2	>	>	>	>
S3	>	>	>	>
S4	>	>	>	>
S5	>	>	>	>
S6	>	>	=	=

4.3 /f/

The labial [f] showed raising of the back of the tongue across all 6 speakers. Figure 22 below illustrates the raising gesture of the back of the tongue in [fa] and [fɛ] of S1. We can see that the maximal tongue body stricture of [fa] and [fɛ], marked by dots, are in the region of [xa] and [xɛ]. The tongue is stretched back, resulting in the shape similar to that of the St’át’imcets uvular stop /q/ in Figure 13 (from Namdaran 2006).

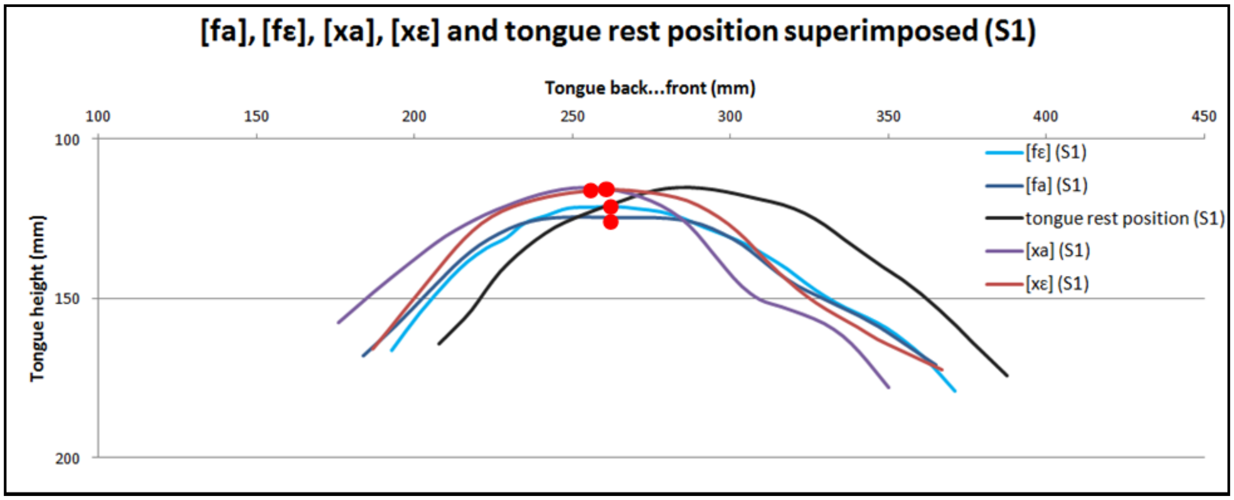


Figure 22. Superimposed tongue contours of [fa], [fɛ], [xa], [xɛ] and tongue rest position of S1; the dots are the points of maximal tongue body stricture.

The location of the point of maximal tongue body stricture relative to [x] varied across speakers. Some individual variation was also exhibited in the horizontal backing of the tongue relative to the tongue rest position across subjects. In Figure 22, we can see that the tongue root in [fa] and [fɛ] of S1 is pulled further back relative to tongue rest position. Table 7 summarizes variations observed in [fa] and [fɛ] with respect to the location of the tongue body raising and the location of tongue root across 6 participants.

Table 7. The location of the maximal tongue body (TB) stricture and tongue root (TR) activity of [fa] and [fɛ] across speakers:

TB: ‘=’ – equal to [xa]/[xɛ], ‘>’ – **pulled further back** than [xa]/[xɛ];

TR: ‘=’ – equal to the tongue rest position; ‘>’ – **pulled further back** than the tongue rest position; shaded cells mark exceptions to the general pattern

Speaker	**TB**		**TR**	
	[fa]	[fɛ]	[fa]	[fɛ]
S1	=	=	>	>
S2	>	>	>	>
S3	>	>	>	>
S4	=	=	=	=
S5	=	=	>	>
S6	>	=	>	=

As is clear from table 7, a tongue body stricture did occur for [f] either in the region of [x] or further back. The tongue root was generally drawn backwards relative to the tongue rest position, except for S4 and S6. The comparison of the extracted tongue contours of [fa] and [fɛ] of all six participants with the St’át’imcets uvular stop /q/ in Figure 13 (from Namdaran 2006) reveals similarities in the tongue configuration: the tongue back in /f/ is strongly pulled back as in /q/ resulting in a more or less stretched tongue front. The comparison of [fa] and [fɛ] with the Montana Salish uvular stop /q/ in Figure 12 (from McDowell 2004) also suggests a stronger tongue back displacement into the posterior part of the mouth than one would expect for *velarized* segments. All these facts suggest that Russian /f/ is *uvularized*. Here it is worth mentioning that [xa] and [xɛ] in Figure 22 also feature a stretched tongue front and a significant backward gesture of the tongue body relative to tongue rest position, which implies that /x/ of S1 is uvularized as well (see the discussion in section 5.1).

[fa] and [fɛ] showed identical patterns of location of the maximal tongue body stricture and tongue root activity across 5 speakers, except for S6 (see table 7). In other words, no vowel influence on consonants was observed except possibly for S6. This fact suggests again that secondary articulation, i.e. uvularization, is *inherent* to the consonant rather than dependent on the vowel.

4.4 /s/

Examination of superimposed tongue contours of [sa] and [sɛ] across 6 speakers yielded mixed results. Three participants (S1, S2 and S3) showed some raising of the tongue body in the region further back than the velar [x]. They also demonstrated some horizontal backing of the tongue root relative to tongue rest position. Figure 23 illustrates superimposed contours of [sa], [sɛ], [xa], [xɛ] and tongue rest position of S3. As we can see, the tongue back in [sa] and [sɛ] is obviously raised. The point of maximal tongue body stricture in [sa] and [sɛ] of S1 is further back than the region of [x]. The tongue root is pulled back relative to tongue rest position. The tongue shape is similar to the St'át'imcets uvular stop /q/ in Figure 13 (from Namdaran 2006). This suggests that [s] of S3 is a *uvularized* consonant.

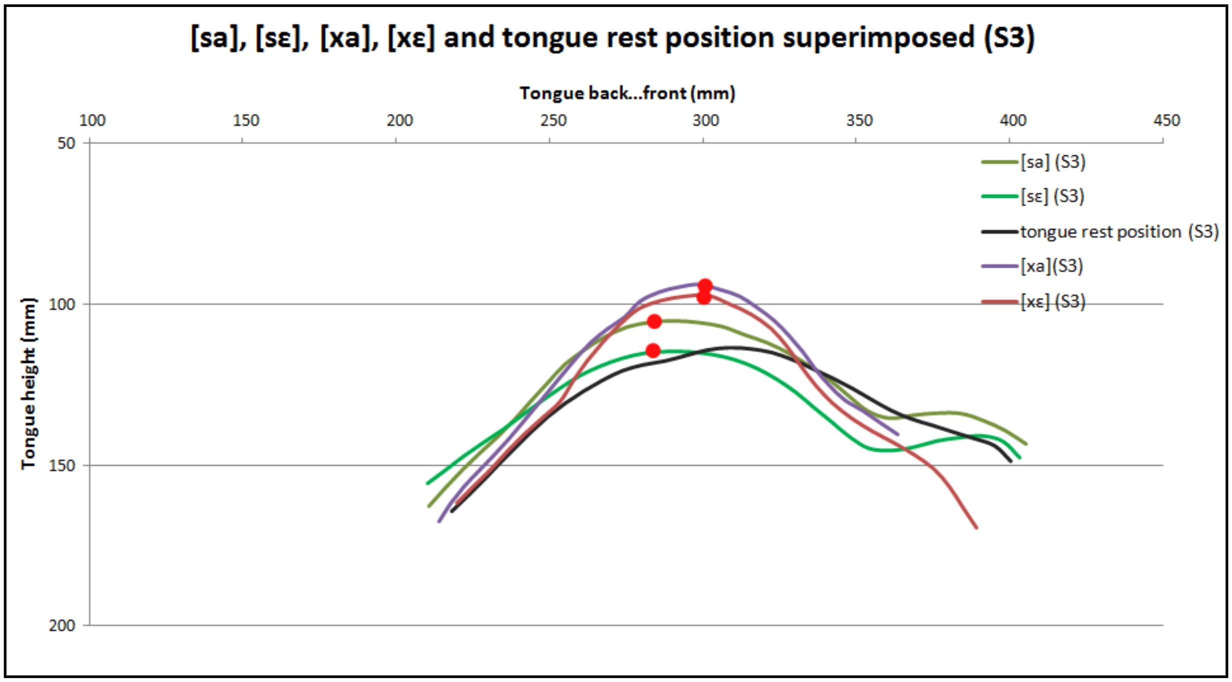


Figure 23. Superimposed tongue contours of [sa], [sɛ], [xa], [xɛ] and tongue rest position of S3; the dots are the points of maximal tongue body stricture.

However, the contours of S4, S5 and S6 showed a different articulatory pattern. Figure 24 below demonstrates superimposed tongue contours of [sa] and [sɛ] of S4. The dots mark the approximate points of maximal tongue body stricture. We can see that the tongue exhibits a slight curve in the posterior region. The points of maximal tongue body stricture in [sa] and [sɛ] are located a little further forward than those of [xa] and [xɛ], which excludes the involvement of the uvular region in the production of /s/ of S4. The question arises: is the location of maximal tongue body stricture of [sa] and [sɛ] still in the region of velar [xa] and [xɛ], which would mean velarization, or is it in the palatal region, which would mean no velarization? Ladefoged & Maddieson (1996:33) mention that the active articulator of velars is the body of the tongue itself which is also involved in the production of front/back contrasts in vowels. That is why neighbouring vowels can induce modification of the location of the stricture of velars. Thus

Ladefoged & Maddieson distinguish front, central and back velars. According to the authors, front velars may actually make contact on the hard palate. Figure 24 shows that [xɛ] of S4 shows a relatively large region of stricture, reflected in the relatively flat tongue contour around the point of maximal stricture. This constriction may actually occupy part of the palatal region, which would not be surprising in the context of [ɛ]. However, the comparison of Figure 24 with Figures 12 and 13 (from McDowell 2004 and Namdaran 2006 respectively) suggests that the raising of the tongue body in [sa] and [sɛ] of S4 still occurs in the velar region. This fact implies secondary *velarization* of [s] of S4. Here it is worth mentioning that the position of the probe was not controlled in the present study. Therefore, to compare the position of stricture in the extracted tongue contours with that in Figures 12 and 13, we located the approximate centre of the tongue on the tongue curve based on the approximate location of the tongue tip (lingual ultrasound does not image the tongue tip because of the acoustic shadow cast by the mandible bone). Basing on Figure 12 (from McDowell 2004), we assumed that the stricture formed by tongue body raising almost perpendicular to the tongue centre would demarcate the velar region and thus represent velarization. If the raising occurred in a more posterior region and the tongue front was stretched, this was considered to be the indication of uvularization.

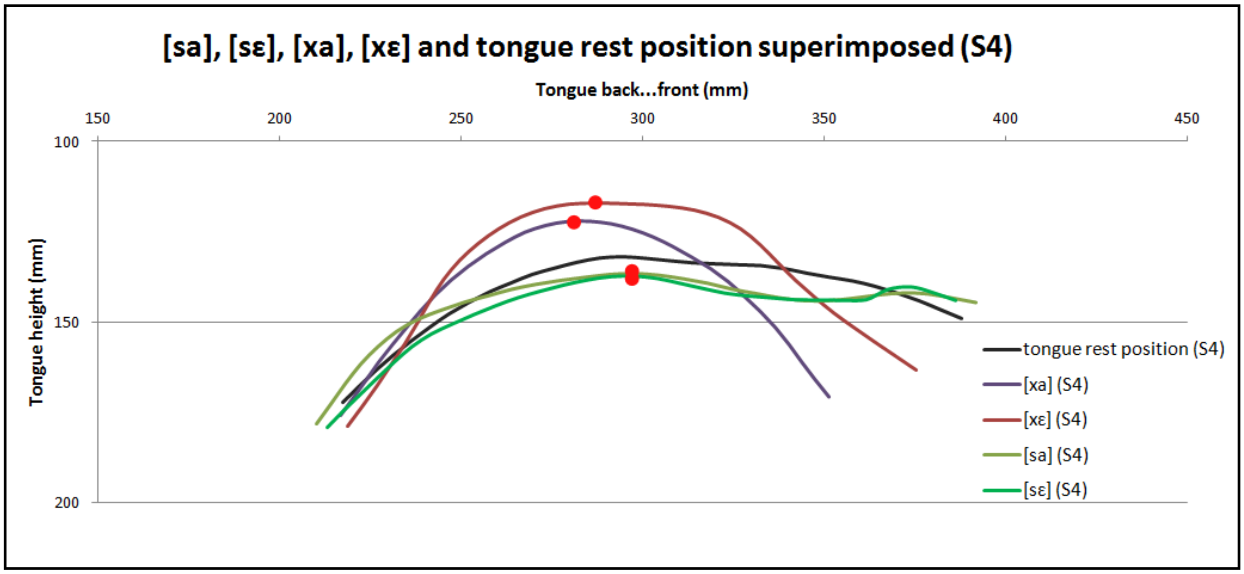


Figure 24. Superimposed tongue contours of [sa], [sɛ], [xa], [xɛ] and tongue rest position of S4; the dots are the points of maximal tongue body stricture.

Similar to S4, S5 and S6 showed a tongue body raising further front than [xa] and [xɛ], (see Appendix B for all the tongue contours). No significant backing of the tongue root was observed on superimposed tongue contours. This all suggests, that [s] of S5 and S6 is *velarized* as well. Table 8 below illustrates the variation found across participants in terms of the location of maximal tongue body stricture of [sa] and [sɛ] relative to [x], and in terms of tongue root activity in [sa] and [sɛ] relative to the absolute tongue rest position.

Table 8. The location of maximal tongue body (TB) stricture and tongue root (TR) activity of [sa] and [sɛ] across speakers:

TB: ‘=’ – equal to [xa]/[xɛ], ‘>’ – pulled further **back** than [xa]/[xɛ], ‘<’ – raised further **front** than [xa]/[xɛ]; *TR:* ‘=’ – equal to the tongue rest position; ‘>’ – **pulled further back** than the tongue rest position;shaded cells mark exceptions to the general pattern.

Speaker	**TB**		**TR**	
	[sa]	[sɛ]	[sa]	[sɛ]
S1	>	>	>	>
S2	>	>	>	>
S3	>	>	>	>
S4	<	<	=	=
S5	<	<	=	=
S6	<	<	=	=

Table 8 shows that when the tongue body stricture in [sa]/[sɛ] occurs further back than in [xa] and [xɛ], the tongue root is also drawn backwards. Whereas when the tongue body stricture is observed in the velar region, no backing of the tongue root occurs. These observations are consistent with the terminology used in the present research, specifically they conform to our distinction of ‘uvularization’ from ‘velarization’.

Table 8 also demonstrates that the location of the maximal tongue body stricture and tongue root activity in two vowel contexts are identical across 6 speakers, which suggests no influence of the following vowels on the presence/absence of the secondary articulations of [s].

4.5 /ʂ/

[ʂ] showed an overall raising of the tongue body across 6 subjects in comparison to other consonants. For all speakers except S4, raising of the tongue back was observed further back than the location of the tongue body strictures in [xa] and [xɛ]. The tongue root was either pulled back relative to tongue rest position, or remained intact. Figure 25 illustrates the tongue contours of [ʂ̡a] and [ʂ̡ɛ] superimposed on [xa] and [xɛ] (S2). As we can see, the approximate points of maximal tongue body stricture are further back than in [xa] and [xɛ].

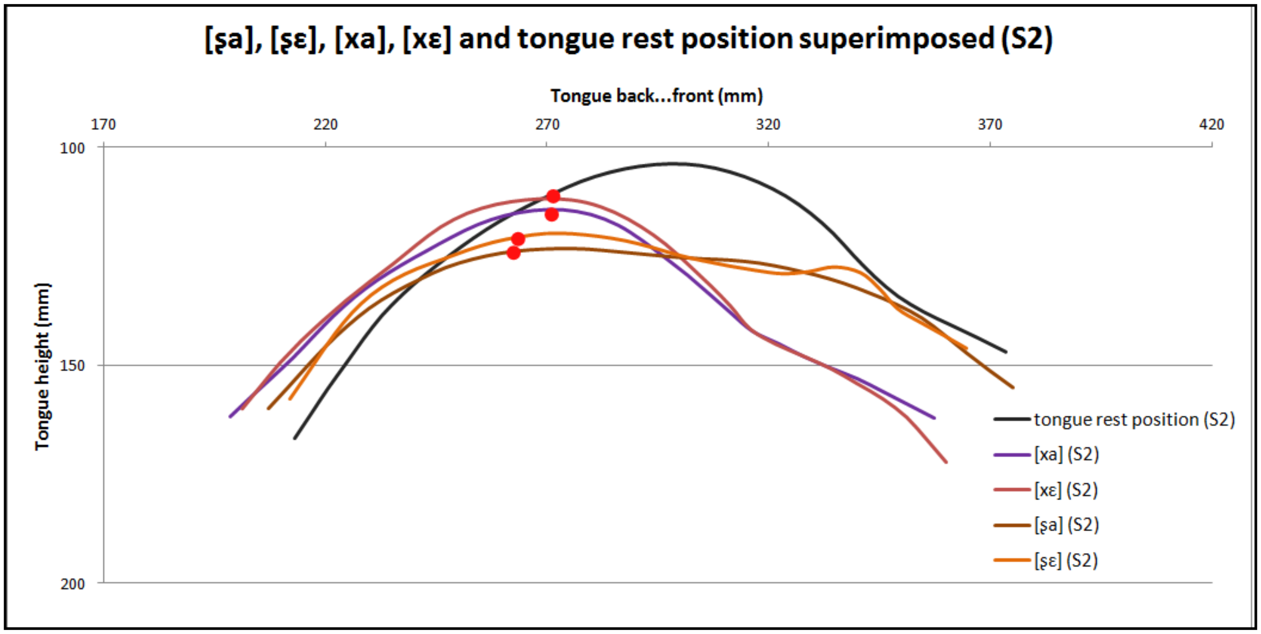


Figure 25. Superimposed tongue contours of [ʂ̡a], [ʂ̡ɛ], [xa], [xɛ] and tongue rest position of S2; the dots are the points of maximal tongue body stricture.

Figures 26 and 27 below illustrate the stricture of the tongue body in [ʂ̡a] and [ʂ̡ɛ] more back relative to [xa] and [xɛ] of S2 more clearly. They also show that the tongue body in [ʂ̡a] and [ʂ̡ɛ] is raised so high that the location of the tongue body stricture in [ʂ̡] is even higher than that for [l] and [s].

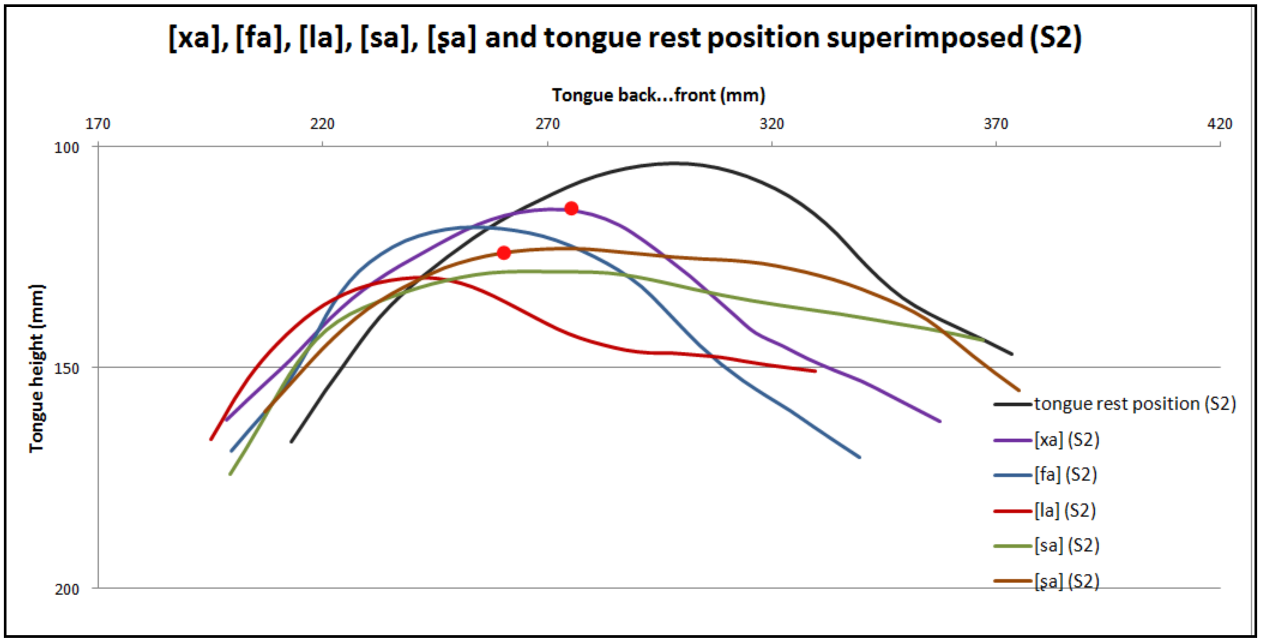


Figure 26. Superimposed tongue contours of [ʂa], [xa], [fa], [la], [sa] and tongue rest position of S2; the dots are the points of maximal tongue body stricture.

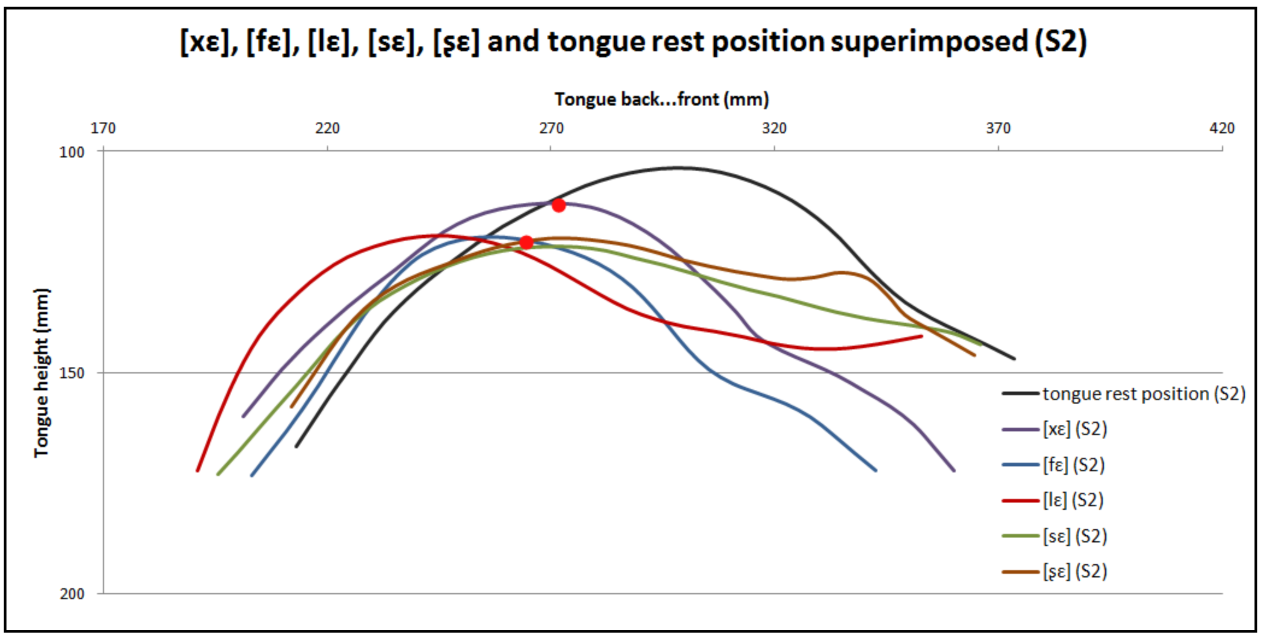


Figure 27. Superimposed tongue contours of [ʂɛ], [xɛ], [fɛ], [lɛ], [sɛ] and tongue rest position of S2; the dots are the points of maximal tongue body stricture.

Moreover, the tongue is stretched, or flattened in [ʂ] similar to the St'át'imcets uvular stop /q/ in Figure 13 (from Namdaran 2006). These observations suggest that [ʂ] of S2 is *uvularized*. Here it is worth mentioning that, according to Hamann (2002a, 2002b), a flattened tongue shape is a typical configuration of retroflex fricatives suggesting 'velarization' of these segments. The present study however shows that a flattened tongue should be better looked upon as a function of 'uvularization' (see section 5 for further discussion of retroflexion vs. uvularization).

S4 however showed a different articulatory pattern. The maximal tongue body stricture was further forward than [x] and no horizontal tongue backing relative to the tongue rest position was observed (see Figure 28). This suggests that [ʂ] of S4 is *velarized* rather than uvularized.

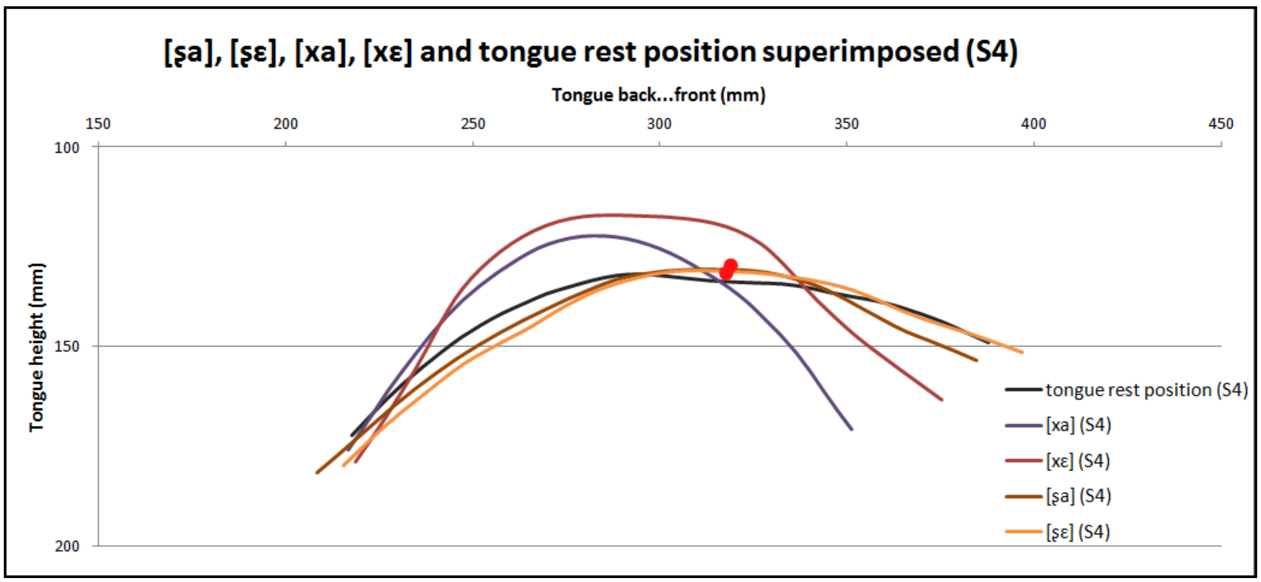


Figure 28. Superimposed tongue contours of [ʂa], [ʂɛ], [xa], [xɛ] and tongue rest position of S2; the dots are the points of maximal tongue body stricture.

Table 9 summarizes our observations with respect to the location of the maximal stricture of the tongue body and the tongue root activity in [ʂa] and [ʂɛ] across 6 speakers.

Table 9. The location of maximal tongue body (TB) stricture and tongue root (TR) activity of [ʂa] and [ʂɛ] across speakers:

TB: ‘=’ – equal to [xa]/[xɛ], ‘>’ – pulled further **back** than [xa]/[xɛ], ‘<’ – raised further **front** than [xa]/[xɛ]; *TR:* ‘=’ – equal to the tongue rest position; ‘>’ – **pulled further back** than the tongue rest position;shaded cells mark exceptions to the general pattern.

Speaker	**TB**		**TR**	
	[ʂa]	[ʂɛ]	[ʂa]	[ʂɛ]
S1	>	>	>	>
S2	>	>	>	>
S3	>	>	>	>
S4	<	<	=	=
S5	>	>	=	=
S6	>	>	=	=

As is clear from table 9, no differences were observed in the location of the maximal tongue body stricture in [a] vs. [ɛ] context and in tongue root activity in two vowel contexts. This again suggests no vowel effect on the realization of secondary articulations of /ʂ/, which in its turn means that Russian hard /ʂ/ is *intrinsically* uvularized and in some cases velarized (see discussion in section 5).

4.6 General results

To summarize, the analysis of the ultrasound data yielded the following main results for Russian non-palatalized fricatives and /l/:

1. /l/ is uvularized;
2. /f/ is uvularized;
3. /s/ can be either velarized or uvularized;
4. /ʂ/ can be either velarized or uvularized;

5. Secondary articulations of hard (non-palatalized) consonants are inherent, as the following vowel does not affect the location of the point of maximal tongue body stricture and the backing gesture of the tongue root.

Chapter 5

Discussion

Chapter 5 provides the discussion of results presented in Chapter 4. Section 5.1 summarizes our observations with respect to the details of articulation of Russian non-palatalized consonants [l, f, s, ʂ] obtained using *laryngeal* and *lingual* ultrasound and compares our conclusions to those of previous articulatory studies. Section 5.2 addresses our hypothesis, presented in section 3.1.2, about the intrinsic velarization of Russian non-palatalized consonants (except for [ʂ, ʐ, ts]) and discusses how the results obtained in this study fit into the predictions made in Chapter 2. Section 5.3, discusses the effects of the immediately following vowel on the realization of secondary articulations in Russian non-palatalized segments. Section 5.4 deals with the limitations of the current study and sets up the directions for future research of the production of Russian consonants.

5.1 Consonant effects and previous studies

As mentioned in section 2.6.1, the current study adopts the Laryngeal Articulator Model (LAM) which clearly delineates oral articulations from laryngeal articulations. Within this framework, secondary *velarization* and *uvularization* belong to oral articulations and are realized as a narrowing in the upper pharynx, while *pharyngealization* belongs to the articulations produced in the lower, i.e. laryngeal, vocal tract and involves a complex laryngeal mechanism of production (see the details in sections 2.3 and 2.6).

Our pilot investigation of the larynx height during the production of non-palatalized consonants [f, l, s, ʂ, x] by one native speaker of Russian showed that these consonants do not involve raising of the larynx, which implies that [f, l, s, ʂ, x] are not pharyngealized in Russian, in the sense of Esling (1996, 1999, 2005, etc.). Based on this fact, we assume that Russian does not feature pharyngealization in general, which does not comply with Bolla's (1981) conclusions who attested to pharyngealization of all Russian hard consonants, except for [x, γ] (see the details in section 2.3). The result of our *laryngeal* ultrasound study also allows us to argue against Kedrova et al.'s (2011) conclusion about simultaneous velarization and pharyngealization of [b] before the vowel [ɛ] in their MRI investigation of Russian hard bilabial consonants. As mentioned in section 2.3, Kedrova et al. (as well as Bolla) follow a 'linguo-centric' approach to distinguishing pharyngeal articulations, therefore the activity of the larynx is completely overlooked by the authors. This suggests that within the Laryngeal Articulator Model framework, Kedrova et al.'s (2011) inferences about pharyngealization of Russian [b] cannot be correct. In other words, the different conclusions drawn by Kedrova et al. (2011) and Bolla (1981) in comparison to those of the present study with respect to secondary articulations of Russian non-palatalized consonants reflect different uses of the term 'pharyngealization'.

Our *lingual* ultrasound study showed that *uvularization* is an inherent feature of Russian non-palatalized consonants [f, l, s, ʂ]. Thorough analysis of the results also suggested that in some cases *uvularization* can be substituted by *velarization* in Russian fricatives [s] and [ʂ]. To the best of our knowledge, this is the first phonetic study to date suggesting *uvularization* of Russian non-palatalized consonants. As mentioned in chapter 2, the main disagreements about the production of Russian consonants have to do with the degree of secondary velarization in different non-palatalized consonants (e.g. Bogoroditsky 1930, Skalozub 1963, Matusevich 1976, Ladefoged & Maddieson 1996, etc.) and with velarization vs. pharyngealization of Russian consonants (Skalozub 1963, Bolla 1981). The lack of mention of uvularization in the literature on Russian phonetics can be explained by the terminology employed by researchers. As suggested in chapter 2, researchers understand different things under the terms ‘velarization’ and ‘pharyngealization’.

In our study, we assume that velarization and uvularization are two distinct articulatory gestures, the former exhibiting the raising of the tongue body against the anterior part of the soft palate, the latter showing tongue body raising against the posterior part of the soft palate, i.e. the uvular region (see details about the differences in velarization and uvularization as seen in ultrasound view in McDowell (2004) and Namdaran (2006)). Despite the fact that velarization and uvularization have different stricture targets for raising, and thus articulatorily, i.e. phonetically, represent different gestures, our study suggests that *phonologically* velarization and uvularization perform a single function, namely the reinforcement of the contrast between non-palatalized consonants and their palatalized counterparts (also see Stevens & Keyser 1989 for the discussion of primary features and their enhancement in consonants). The production of Russian fricatives [s] and [ʂ] provide evidence for this claim. Our data show that these consonants can either be uvularized or velarized in Russian. Our analysis suggests that *uvularization* of the Russian retroflex [ʂ] is by far the most common articulation. However, velarization of [ʂ] is also possible. Our study features a clear case of articulation of [ʂ] in the velar region. Such an articulation is not a single exception to the overall pattern of the production of Russian retroflex fricatives. Skalozub (1963) reported that three of her subjects exhibited a convexity of the tongue at the boundary of the soft and the hard palates in the production of [ʂ]. The discussion above suggests that Russian /ʂ/ has two articulatory realizations, one showing uvularization, the other velarization. However, auditorily the two variants produce the same effect. This implies that phonologically *velarization* and *uvularization* perform the same function.

The Russian non-palatalized fricative [s] also exhibits variation in its production. In our study, half of the productions of [s] exhibited uvularization and half of them velarization. This fact suggests that, as in the case of /ʂ/, velarized and uvularized variants are equally acceptable productions, both fulfilling a single phonological function of discriminating non-palatalized from palatalized consonants. It is worth mentioning here that when Russian /s/ is velarized, the tongue body shows only a slight convexity of the tongue in the velar region. Similar observations are made by Bennett et al. (2012) about the production of /s/ in Irish, a language which has a palatalization contrast very much like in Russian (see also Ní Chiosáin & Padgett's (2012) study of Connemara Irish palatalization). In their ultrasound study of Connemara Irish palatalization and velarization, Bennett et al. conclude that coronal /s/ is weakly velarized. The authors mention that, impressionistically, [s] of their speakers varied from very velarized to not velarized at all. This 'weak' velarization of /s/ in Russian and Irish implies that coronal fricatives can pattern similarly across languages with the palatalization contrast.

Weak velarization of /s/ can be explained by certain aerodynamic conditions necessary for creating the turbulent airflow characteristic of this fricative. According to Ladefoged & Maddieson (1996), fricative consonants require a precisely shaped vocal tract so that a turbulent airstream can be produced. Shadle (n.d.) adds to this claim and states that fricatives are characterized by a pressure drop across the constriction to generate turbulence and therefore turbulent noise. Taking these facts into account, we can assume that weak velarization of /s/ causes lowering of the tongue body, which, in its turn, expands the volume of the oral cavity behind the constriction. Volume and pressure are inversely proportional, therefore the enlarged oral cavity in /s/ will result in a lower pressure. In other words, a large volume behind the constriction will allow a lot of air to build up, creating the necessarily aerodynamic conditions to get turbulence, i.e. large volume of air rushing though a narrow opening. If velarization was strong, it would reduce the size of the cavity (i.e. the volume) behind the constriction, which would allow less air to build up behind the constriction and thus would not provide the right aerodynamic conditions for turbulence. The other explanation is suggested by Bennett et al. (2012): the authors assume that the articulatory pattern observed in /s/ might be the result of **a coupling gesture** between the tongue body and blade/tip in coronals, which might inhibit full velarization. In any case, some articulatory conditions seem to suppress full velarization of /s/ but rather to favour its uvularization in Russian (see the superimposed contours in Appendix B). Uvularization of /s/ may be the result of the subject's effort to reinforce the perceptual distinction between the non-palatalized [s] and the palatalized [s^j]. Moreover, this secondary articulatory gesture can be explained by *hyperarticulation*, i.e. exaggerated articulation, induced by the nature of the task in the experiment (participants had to produce consonant-vowel sequences not embedded in real words or sentences), or the unnatural setting (the laboratory). This could lead to a subject's subconscious attempt to emphasize articulation.

Our data also suggest the possibility of uvularization of the velar [x]. As discussed in section 4.4, velar consonants can be affected by their environment. Figures 29a, 29b and 30a, 30b below demonstrate the extracted contours of velar [xa]/[xɛ] of S5 and S1 respectively. In figures 29a and 29b, we can see that the tongue back in [x] is pulled significantly backward, while the tongue front is stretched and flattened (compare with Figure 13 from Namdaran (2006)). The maximal tongue body strictures in [xa] and [xɛ] approximate the tongue body stricture of the uvularized consonant [l]. All these facts suggest that [x] of S5 is uvularized.

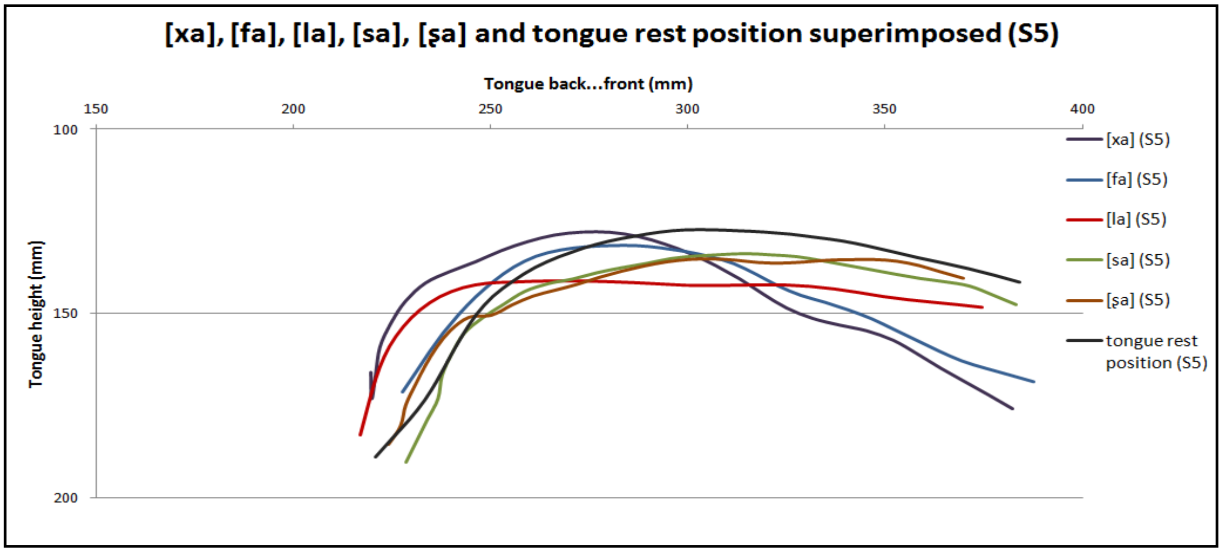


Figure 29a). Superimposed tongue contours of [fa, la, sa, ʂa, xa] and tongue rest position of S5.

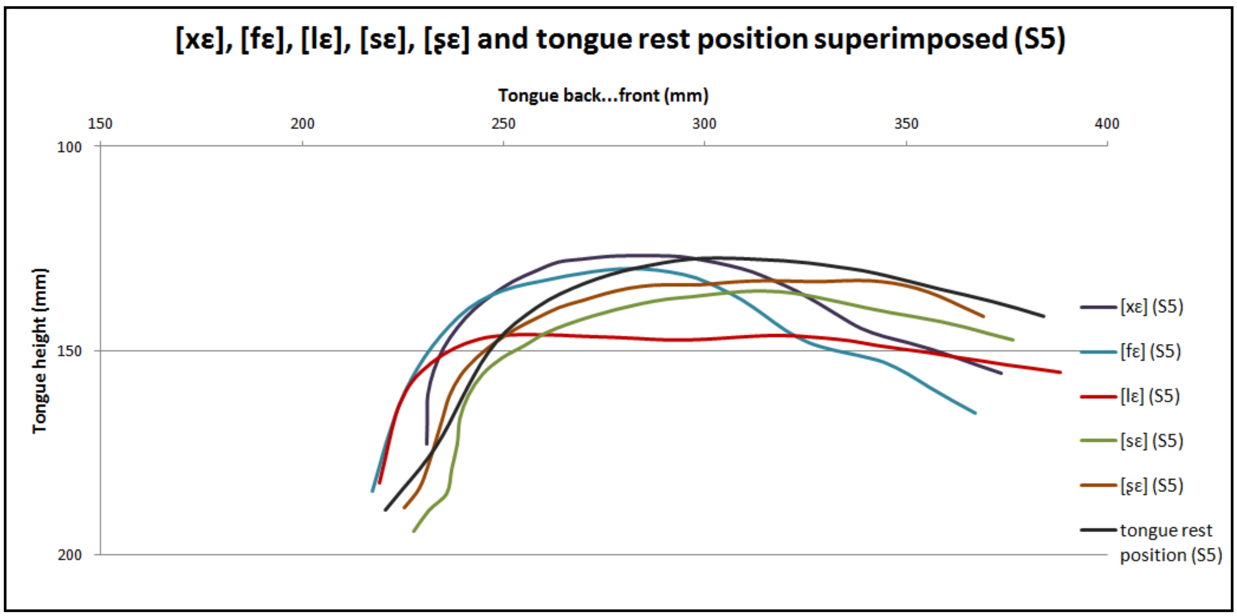


Figure 29b). Superimposed tongue contours of [fɛ, lɛ, sɛ, ʂɛ, xɛ] and tongue rest position of S5.

Figures 30a) and 30b) demonstrate uvularization of all consonants produced by S1, alluded to in section 4.3. We can see that the maximal tongue body stricture of the velar [x] occurs in the posterior region of the mouth, in the region of tongue body raising in [f, l, s, ʂ]. The tongue root exhibits a strong horizontal backing gesture relative to tongue rest position. The tongue back is strongly pulled back and is similar to the shape of the St’át’imcets uvular stop /q/

in Figure 13 (from Namdaran 2006). These facts allow us to conclude that /x/ in [xa] and [xɛ] of S1 is also uvularized, despite the fact that uvularization leads to differently shaped contours than those observed for S5.

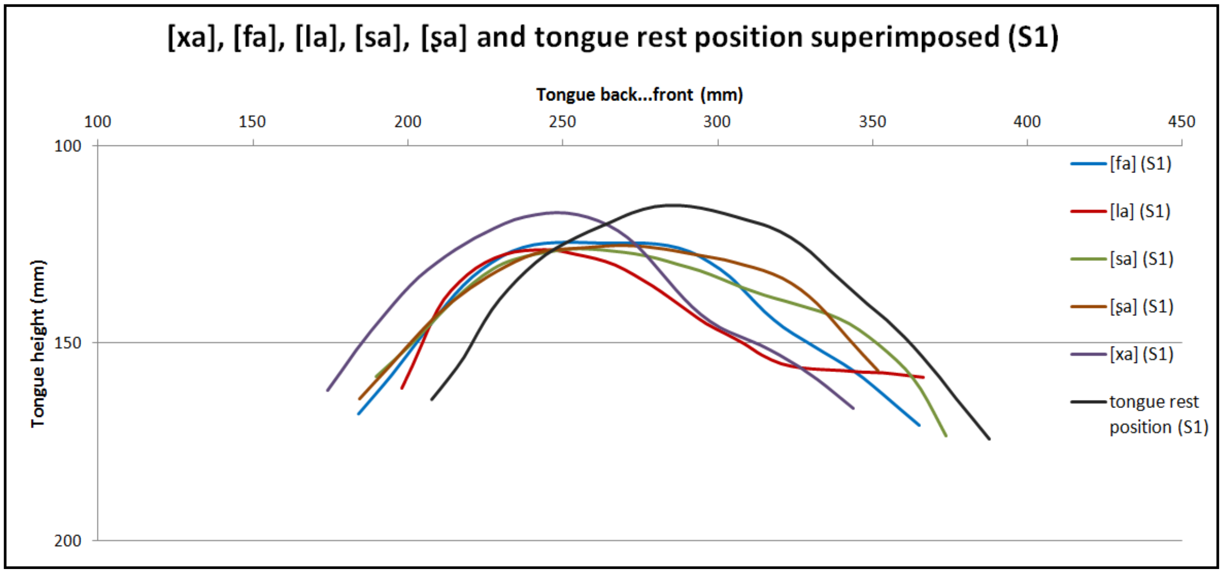


Figure 30a). Superimposed tongue contours of [fa, la, sa, ʂa, xa] and tongue rest position of S1.

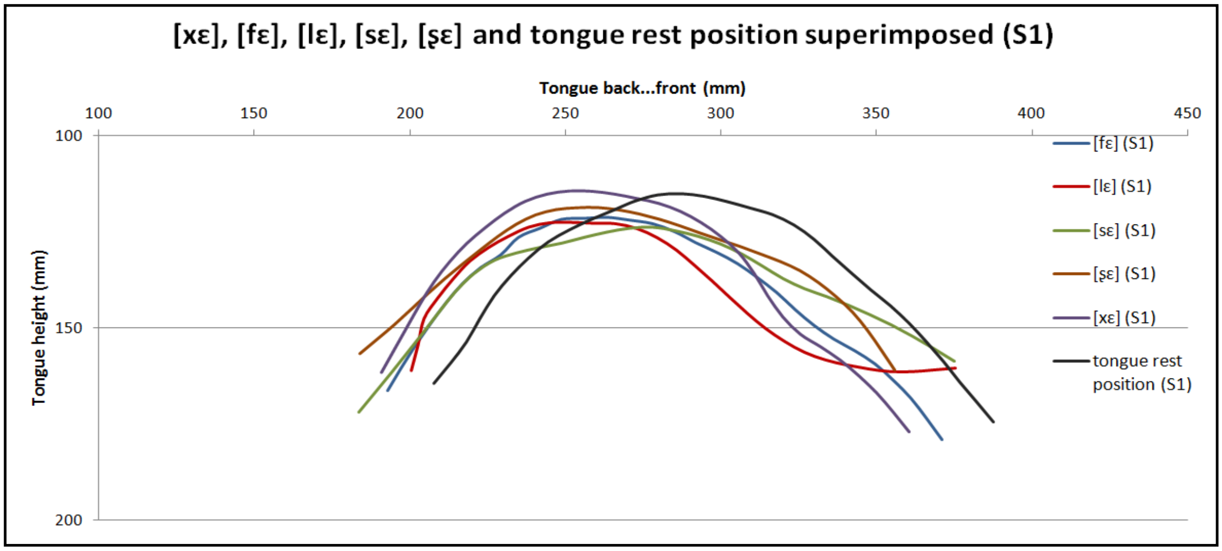


Figure 30b). Superimposed tongue contours of [fɛ, lɛ, sɛ, ʂɛ, xɛ] and tongue rest position of S1.

The possibility of uvularization of /x/ provides further support for our assumption that secondary uvularization is pervasive in Russian. The participants' background, however, can offer a further insight into uvularization of velars. As mentioned in chapter 3, S1 comes from Kazakhstan and therefore speaks two languages natively: Russian and Kazakh. The Kazakh phonological inventory features uvular consonants: the uvular stop /q/ and uvular trill /ʁ/. The transfer of the Kazakh phonology onto Russian could explain uvularization of /x/ in the production by S1. As is clear from Figures 29a), 29b) and 30a), 30b), the tongue shapes of [x] of S1 and S5 are different despite the fact that the tongue body in [x] is strongly pulled back in both cases. Thus, the influence of the Kazakh language could account for the tongue contour differences between S1 and S5.

To summarize, our study shows that Russian non-palatalized consonants [f, l, s, ʂ, x] are not pharyngealized. The Russian non-palatalized [f] and [l] exhibit secondary uvularization, while [s] and [ʂ] can display either uvularization or velarization as a function of individual variation. Both secondary uvularization and velarization, however, perform a single *phonological* function: differentiation of non-palatalized/hard consonants and their palatalized/soft counterparts.

5.2 Our hypothesis and the actual results

In section 3.1.2, we analyzed the frequency of distribution of *consonant-vowel* (CV) sequences in Russian which indicated that combinations of non-palatalized consonants with the vowel [ɛ], unlike with other vowels, are low-frequency in Russian. The exception was made by [ʂɛ, ʐɛ, tsɛ] which exhibited high frequency. We took these facts to suggest an articulatory conflict between velarization of non-palatalized consonants, except for [ʂ, ʐ, ts], and the front tongue position during the production of the front vowel [ɛ]. Thus we introduced a hypothesis that Russian non-palatalized consonants are intrinsically velarized, with the exception of /ʂ, ʐ, ts/.

The results obtained in the present study, however, indicate that the hypothesis was not entirely correct. We rightly predicted secondary articulation of Russian /f/, /l/ and /s/. However, we incorrectly assumed that the Russian retroflex fricative /ʂ/ would show the absence of velarization/uvularization. The results of our study indicated that /ʂ/ can equally be uvularized or velarized in Russian.

The unexpected results for [ʂɛ] are best explained by the retroflex nature of [ʂ]. More specifically, we assume that the retroflex consonant [ʂ] causes [ɛ] to assimilate to the place of articulation of the retroflex. The ability of retroflexes to induce 'backing' of front vowels was suggested by Flemming (2003). Flemming (2003) explains that a retroflex cannot assimilate to the tongue body position of a front vowel because this would result in the loss of retroflexion. Therefore it is a vowel that assimilates to the tongue position of a retroflex consonant, not vice versa. This claim finds support in Jones & Ward (1969:41), who mention that some writers on Russian phonetics consider the vowel [ɛ] is lowered and slightly pulled back from the fully front position after the consonants [ʂ, ʐ, ts] (see the discussion of Russian vowel inventory in section 2.4).

Flemming (2003:10) however, assumes that retroflexes generally affect *preceding* front vowels in VC sequences, rather than *following* vowels in CV sequences. He notices that retroflexes are phonetically dynamic, involving three main stages in their production: first, the tongue tip is most fully pulled back at the formation of the constriction, then the tongue tip moves forward during the consonant constriction, and then the constriction is released at or just behind the alveolar ridge (Flemming 2003:10). Thus Flemming suggests that retroflexes exhibit 'full' retroflexion at the onset of constriction, therefore only the vowel preceding the retroflex is affected. We assume that Flemming's assumption cannot be entirely correct, at least with respect to fricative consonants. As is clear from the discussion above, Flemming (2003) investigates the behaviour of retroflex stops, rather than retroflex fricatives. We assume that fricatives sustain retroflexion throughout the whole consonant due to the stable nature of fricatives: because, unlike stops, fricatives involve a single stage of production (ensuring turbulence throughout the consonant), they can equally affect preceding or following vowels. Here it is worth mentioning that according to Hamann (2002a, 2002b, 2004), retroflex fricatives can be of two varieties: involving curling of the tongue tip or exhibiting a 'flattened' tongue. The researcher mentions that the second variety is by far the most common.

Thus the results of the present study suggest that all Russian non-palatalized consonants exhibit secondary articulation. We also assume that retroflex fricatives induce backing on adjacent front vowels, resulting in the loss of articulatory conflict between the back gesture of the tongue in hard consonants and the front tongue gesture in the only front vowel [ɛ] used with hard consonants in Russian. A further articulatory study is needed to verify these assumptions.

5.3 Vowel effects

One of the research questions of the current study was to determine whether secondary articulation(s) of Russian non-palatalized consonants, i.e velarization, uvularization or pharyngealization, is inherent, or whether it is rather the result of coarticulation with the following vowel. Our data did not show any vowel influence on the presence of secondary articulations in Russian: the consonants [f, l, s, ʂ] of 6 participants exhibited similar articulatory patters in both vowel contexts, i.e. adjacent to the vowels [a] and [ɛ]. This fact attests to the *intrinsic* nature of secondary articulations of Russian hard consonants, i.e. uvularization (and velarization).

This claim is corroborated by the results obtained in an ultrasound study of Connemara Irish palatalization and velarization by Bennett et al. (2012). The researchers examined target consonants in a CV(C) syllable, where C is a non-palatalized or a palatalized consonant, and V is the vowel /i:/ and /u:/, which represent the most extreme degrees of frontness/backness. Bennett et al. focus primarily on examination of secondary articulations at the consonantal onset of Irish consonants, however they still present the results of a limited study of articulatory properties of the consonantal onset vs. offset (see the justification for the choice of temporal points in Bennett et al. 2012:9). Their ultrasound study showed very little effect of the vowel context on tongue position for Irish consonants at the consonantal onset. The examination of the articulatory properties of the consonantal onset vs. the consonantal offset also did not exhibit any vowel influence (see the details in Bennett et al. 2012:23). Thus, our investigation of secondary articulations of Russian non-palatalized consonants yielded the same results as those presented by Bennett et al. (2012) for Irish consonants. This suggests that the absence of vowel impact on secondary articulations of preceding consonants finds cross-linguistic support. A further examination of the vowel influence on secondary articulation in other world languages is needed to establish how common this effect is.

As predicted in section 3.1.3, our study has provided evidence that consonants in CV syllables are not significantly affected by coarticulation with the following vowel. Hard consonants in CV sequences in Russian resist coarticulation with the following vowels which can be explained by the fact that co-articulation would decrease the distinctiveness of palatalized vs. non-palatalized Cs and would impede perception (c.f. Manuel 1987, 1990 on V-to-V coarticulation). A further follow-up study is needed to examine the relative influence of the preceding vs. following vowel on secondary articulations of Russian hard consonants, i.e.

examination of CV vs. VC sequences. We expect greater co-articulatory effects in VC syllables suggested by the literature review on CV vs. VC coarticulatory effects presented in Nittrouer et al. (1988), Krakow (1999), Modaressi et al. (2004), as well as by the study by Kiritani & Sawashima (1987).

5.4 Limitations & future studies

The current study has definite limitations. First and foremost, the present study represents qualitative rather than quantitative work. The position of the ultrasound probe used for *lingual* ultrasound was not controlled, which precluded any concrete measurements, statistic analysis and inter-speaker comparisons. Second, the hard palate was not traced on ultrasound images, although it could have been employed as the reference for the front edge of the soft palate, and could have thus suggested a clearer delineation of the velar and uvular regions. Third, the stimuli were presented as separate CV (in lingual and laryngeal ultrasound studies) and C^jV (laryngeal ultrasound study) syllables not embedded in real words or in a carrier phrase, which could have resulted in hyperarticulation (see the details in section 5.1). Fourth, the pool of participants was not controlled for in terms of their origin and the variety of Russian they were speaking. Ideally, the subjects for such an experiment should come from the Russian Federation speaking a Standard variety of the Russian language, i.e. the Moscow or St. Petersburg variety, and possibly being monolingual. Fifth, even though the set of consonants used in the present study was relatively big in comparison with previous investigations, there is still a necessity to examine all Russian non-palatalized consonants, plosives and fricatives. Contemporary ultrasound techniques can increase the ultrasound video frame rate to as high as 50-60 frames per second which allows capturing the rapid articulations of stop consonants (see, for example, Miller & Finch 2011). Finally, the next laryngeal ultrasound investigation should be a full-fledged phonetic study, involving a bigger number of participants and a more sophisticated analysis of larynx height, for example, using Optical Flow techniques.

To sum up, a further lingual and laryngeal ultrasound investigation of Russian non-palatalized consonants is needed that could address the limitations of the present research outlined above.

Chapter 6

Conclusion

The present study is an attempt to elucidate the actual production of Russian non-palatalized consonants. Previous literature is generally inconsistent in how the term ‘velarization’ is used and in what articulatory gestures the term ‘velarization’ describes. In the current research, we adopt the Laryngeal Articulator Model (Esling 1999, 2005, etc.), which clearly delineates oral from laryngeal articulations. Within this framework, secondary velarization and uvularization belong to the oral vocal tract, while pharyngealization belongs to the laryngeal vocal tract, being the result of laryngeal constriction. In this research, we conducted the first *laryngeal* ultrasound investigation of larynx height in Russian, and one of the first laryngeal ultrasound studies in general after Moisik et al. (2014), which allowed us to conclude that Russian non-palatalized consonants do not feature pharyngealization. We also used *lingual* ultrasound to examine a relatively large set of Russian non-palatalized consonants across *different vowel contexts*. As far as we know, this is the first study after Skalozub (1963) and Bolla (1981), which aimed at a systematic investigation of Russian consonants. Moreover, most previous studies examined consonants adjacent to one vowel, namely the pharyngealized vowel [a]. Our study used two vowels, namely [a] and [ɛ], in order to tease apart intrinsic consonant backing from backing related to the adjacent vowel. The choice of the vowels (specifically [ɛ]) was based on an analysis of phonotactics in Russian.

The results of the lingual ultrasound study showed that Russian non-palatalized consonants /l/ and /f/ are uvularized, while /s/ and /ʂ/ can feature either uvularization or velarization. The consonants examined represent all consonantal places of articulation: labials, coronals, dorsals, retroflexes. These results suggest that all Russian non-palatalized consonants exhibit secondary articulation and are likely uvularized or velarized. This study also shows that all the observed secondary articulations of Russian hard consonants are *intrinsic*, featuring the absence of vowel impact on the manifestation of uvularization and velarization.

This study refines our knowledge of the articulation of Russian consonants and will be beneficial to phoneticians, teachers and learners of the Russian language interested in the articulatory details of non-palatalized consonants.

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Appendix A

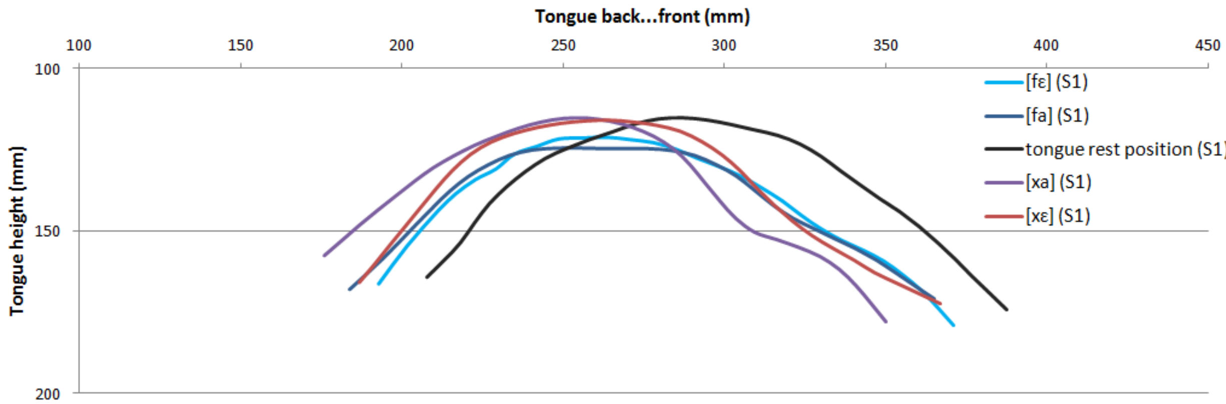
Stimuli (lingual ultrasound)

C-[a]	**C-[ɛ]**
fa	fɛ
la	lɛ
sa	sɛ
ʂa	ʂɛ
xa	xɛ

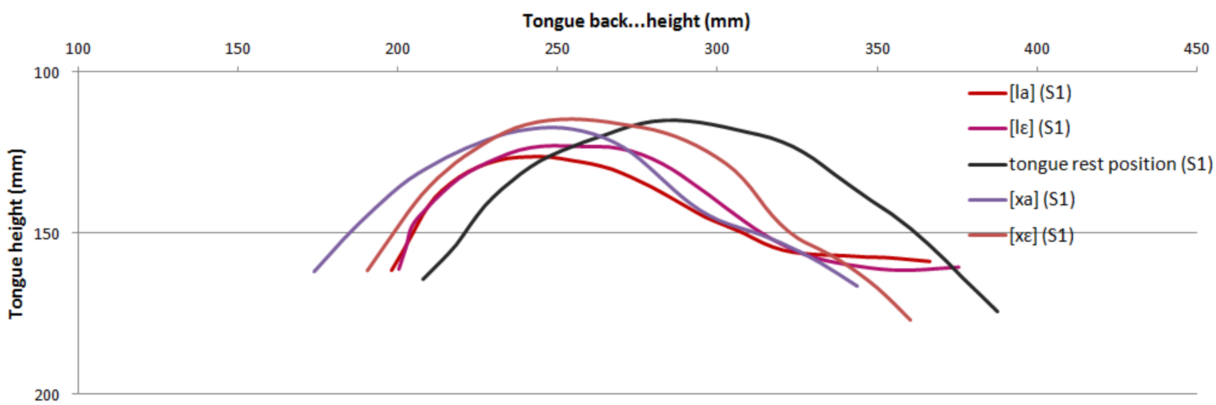
Appendix B

S1

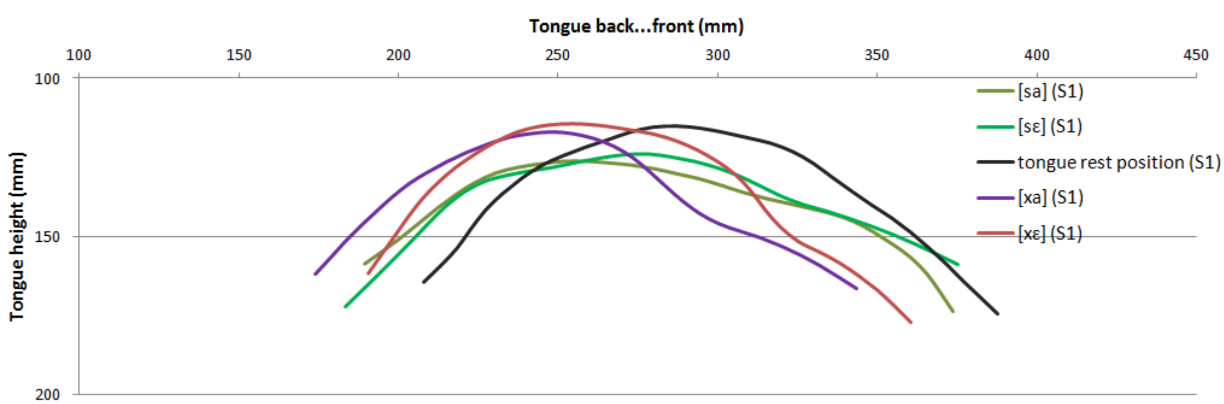
[fa], [fɛ], [xa], [xɛ] and tongue rest position superimposed (S1)

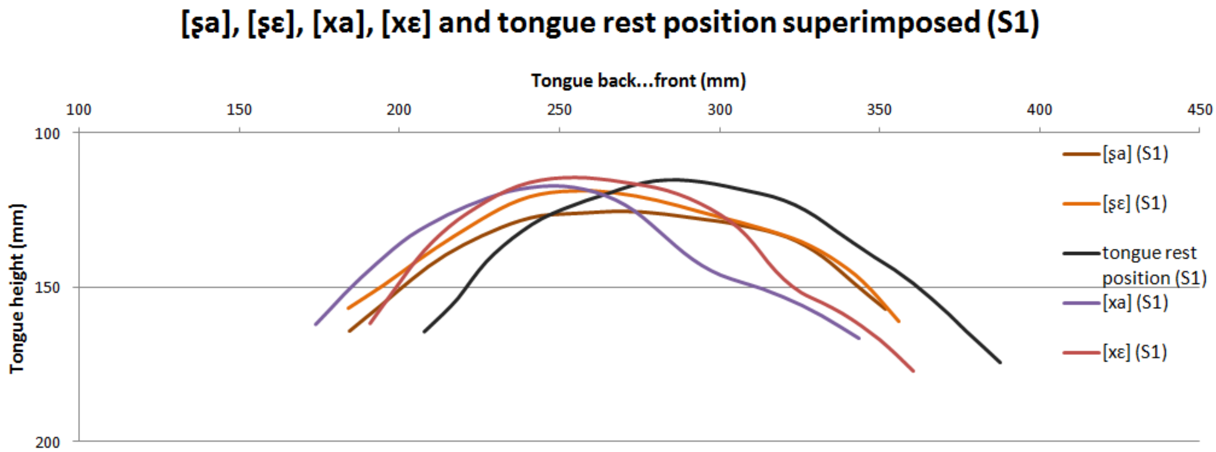


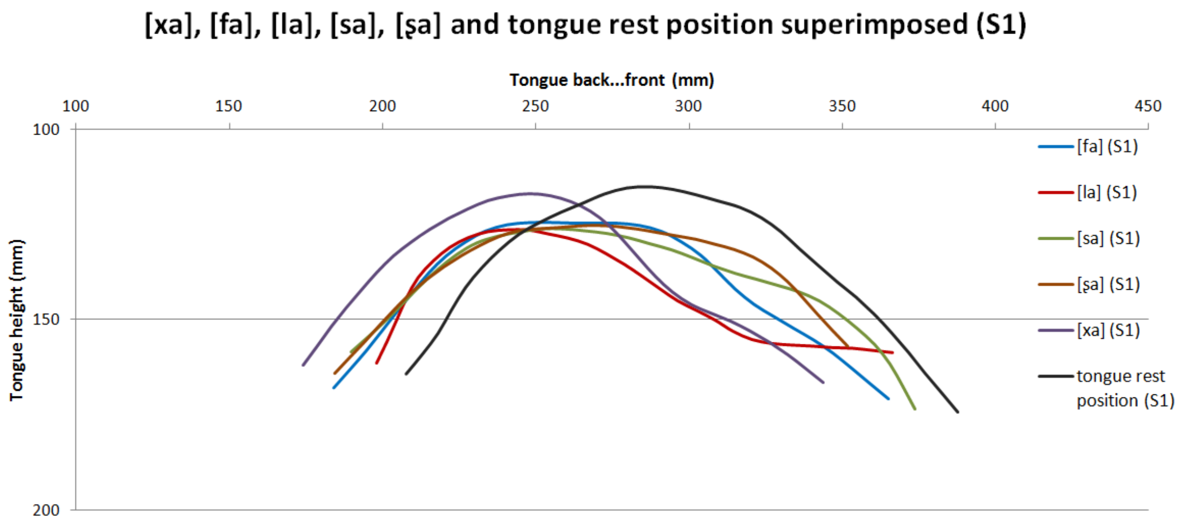
[la], [lɛ], [xa], [xɛ] and tongue rest position superimposed (S1)

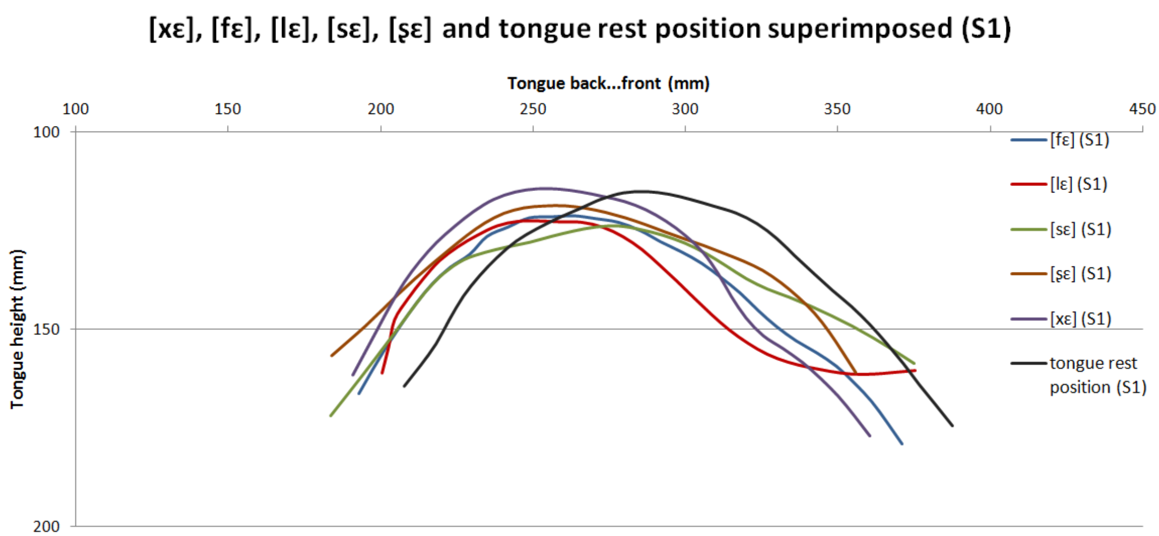


[sa], [sɛ], [xa], [xɛ] and tongue rest position superimposed (S1)

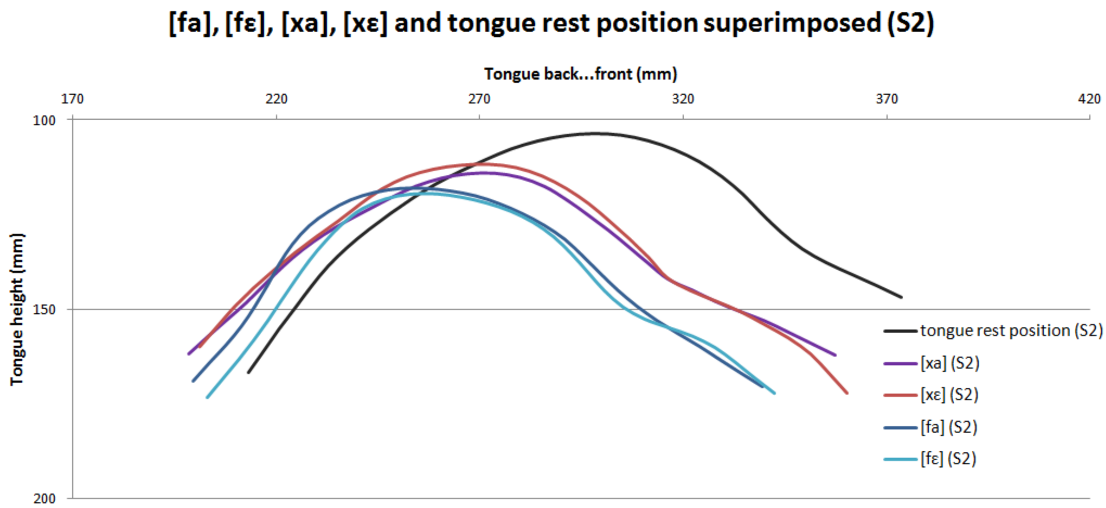


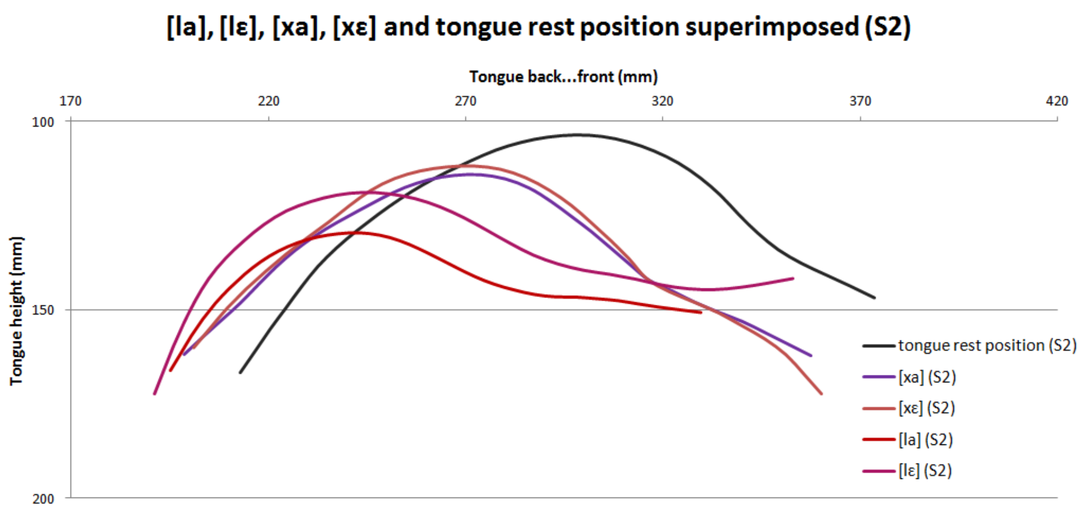

[ʂa], [ʂɛ], [xa], [xɛ] and tongue rest position superimposed (S1)
Tongue back...front (mm)
Tongue height (mm)
100
150
200
250
300
350
400
450
[ʂa] (S1)
[ʂɛ] (S1)
tongue rest position (S1)
[xa] (S1)
[xɛ] (S1)

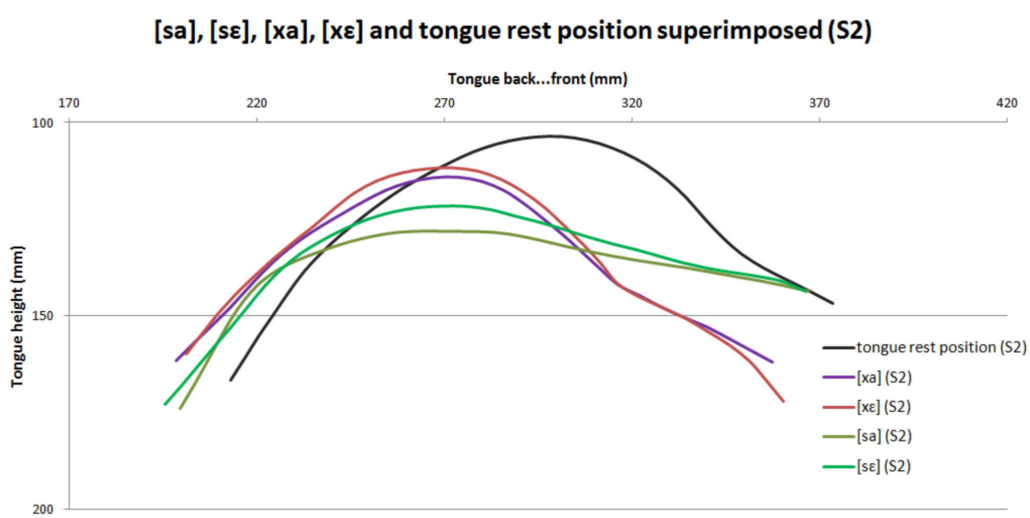

[xa], [fa], [la], [sa], [ʂa] and tongue rest position superimposed (S1)
Tongue back...front (mm)
Tongue height (mm)
100
150
200
250
300
350
400
450
[fa] (S1)
[la] (S1)
[sa] (S1)
[ʂa] (S1)
[xa] (S1)
tongue rest position (S1)

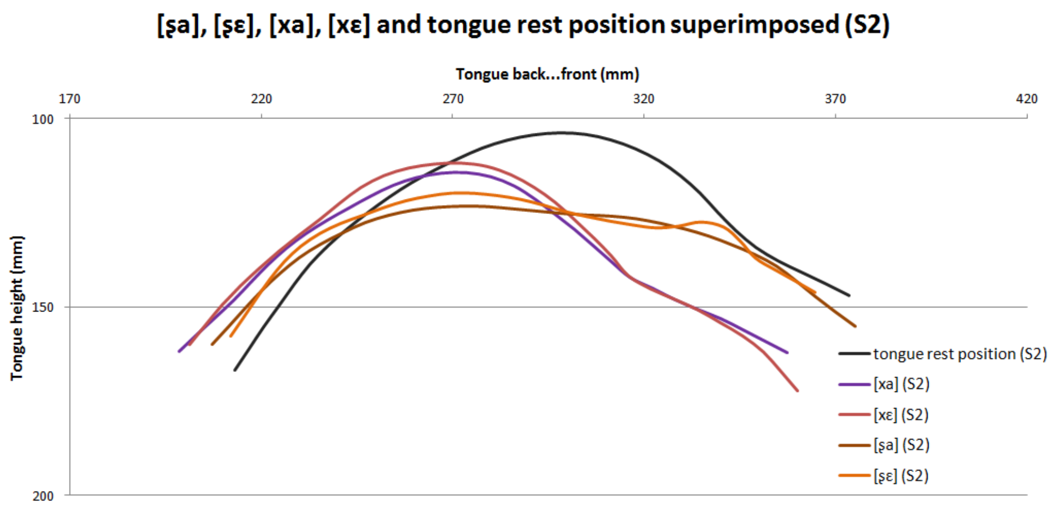

[xɛ], [fɛ], [lɛ], [sɛ], [ʂɛ] and tongue rest position superimposed (S1)
Tongue back...front (mm)
Tongue height (mm)
100
150
200
250
300
350
400
450
[fɛ] (S1)
[lɛ] (S1)
[sɛ] (S1)
[ʂɛ] (S1)
[xɛ] (S1)
tongue rest position (S1)

S2


[fa], [fɛ], [xa], [xɛ] and tongue rest position superimposed (S2)
Tongue back...front (mm)
170
220
270
320
370
420
100
150
200
Tongue height (mm)
tongue rest position (S2)
[xa] (S2)
[xɛ] (S2)
[fa] (S2)
[fɛ] (S2)


[la], [lɛ], [xa], [xɛ] and tongue rest position superimposed (S2)
Tongue back...front (mm)
170
220
270
320
370
420
100
150
200
Tongue height (mm)
tongue rest position (S2)
[xa] (S2)
[xɛ] (S2)
[la] (S2)
[lɛ] (S2)


[sa], [sɛ], [xa], [xɛ] and tongue rest position superimposed (S2)
Tongue back...front (mm)
170
220
270
320
370
420
100
150
200
Tongue height (mm)
tongue rest position (S2)
[xa] (S2)
[xɛ] (S2)
[sa] (S2)
[sɛ] (S2)


[ʂa], [ʂɛ], [xa], [xɛ] and tongue rest position superimposed (S2)
Tongue back...front (mm)
170
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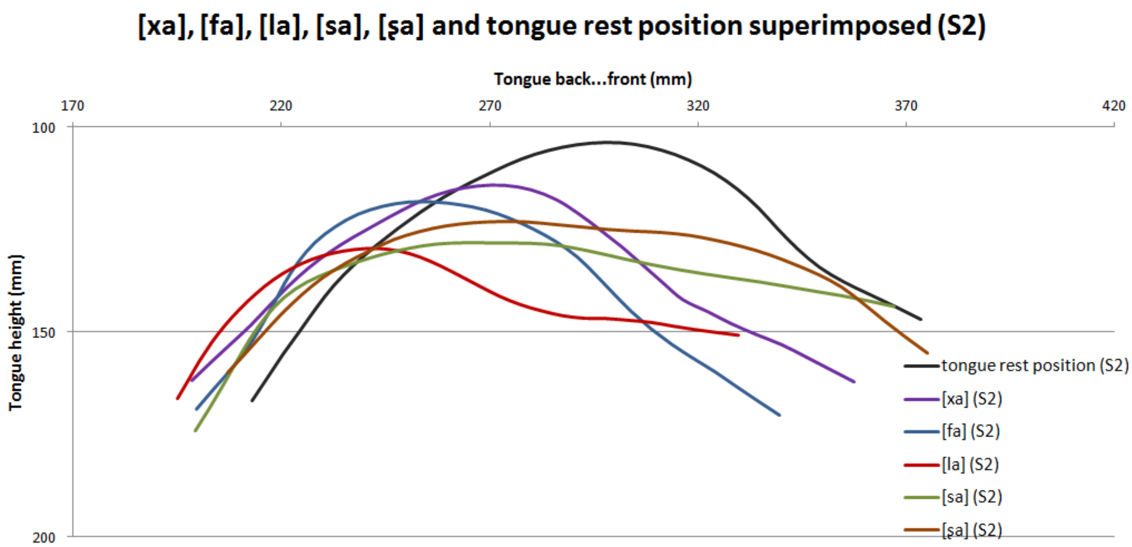
Tongue height (mm)
tongue rest position (S2)
[xa] (S2)
[xɛ] (S2)
[ʂa] (S2)
[ʂɛ] (S2)


[xa], [fa], [la], [sa], [ʂa] and tongue rest position superimposed (S2)
Tongue back...front (mm)
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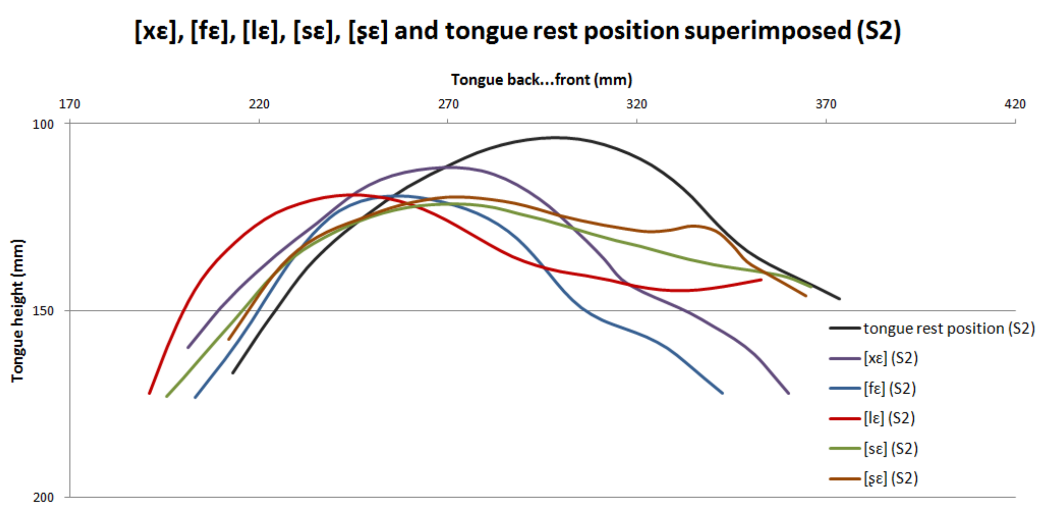
Tongue height (mm)
tongue rest position (S2)
[xa] (S2)
[fa] (S2)
[la] (S2)
[sa] (S2)
[ʂa] (S2)


[xɛ], [fɛ], [lɛ], [sɛ], [ʂɛ] and tongue rest position superimposed (S2)
Tongue back...front (mm)
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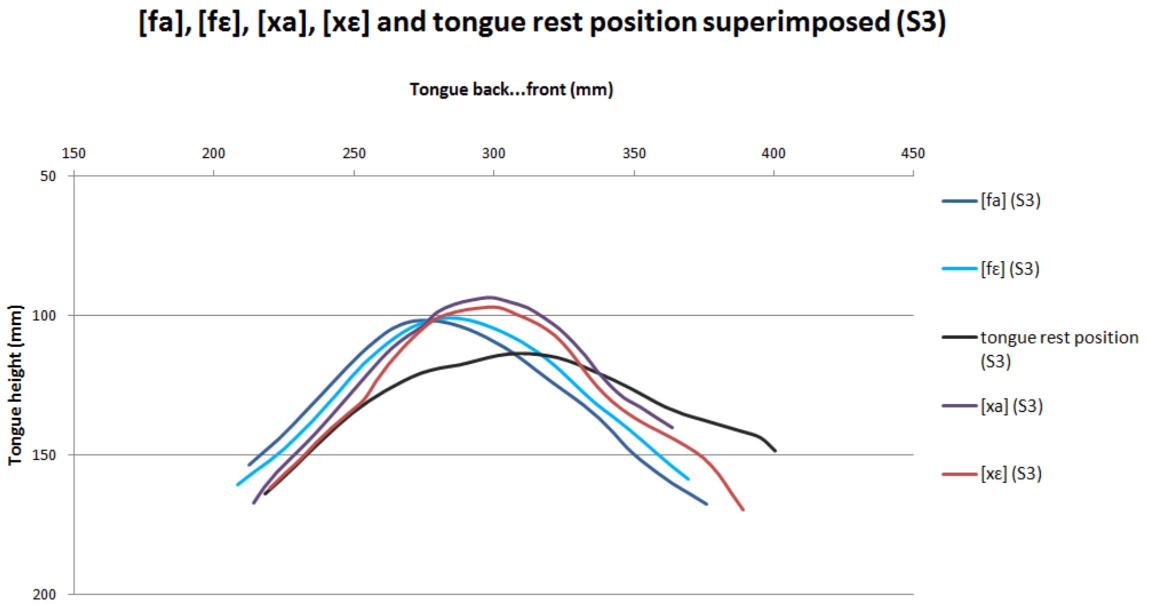
Tongue height (mm)
tongue rest position (S2)
[xɛ] (S2)
[fɛ] (S2)
[lɛ] (S2)
[sɛ] (S2)
[ʂɛ] (S2)

S3


[fa], [fɛ], [xa], [xɛ] and tongue rest position superimposed (S3)
Tongue back...front (mm)
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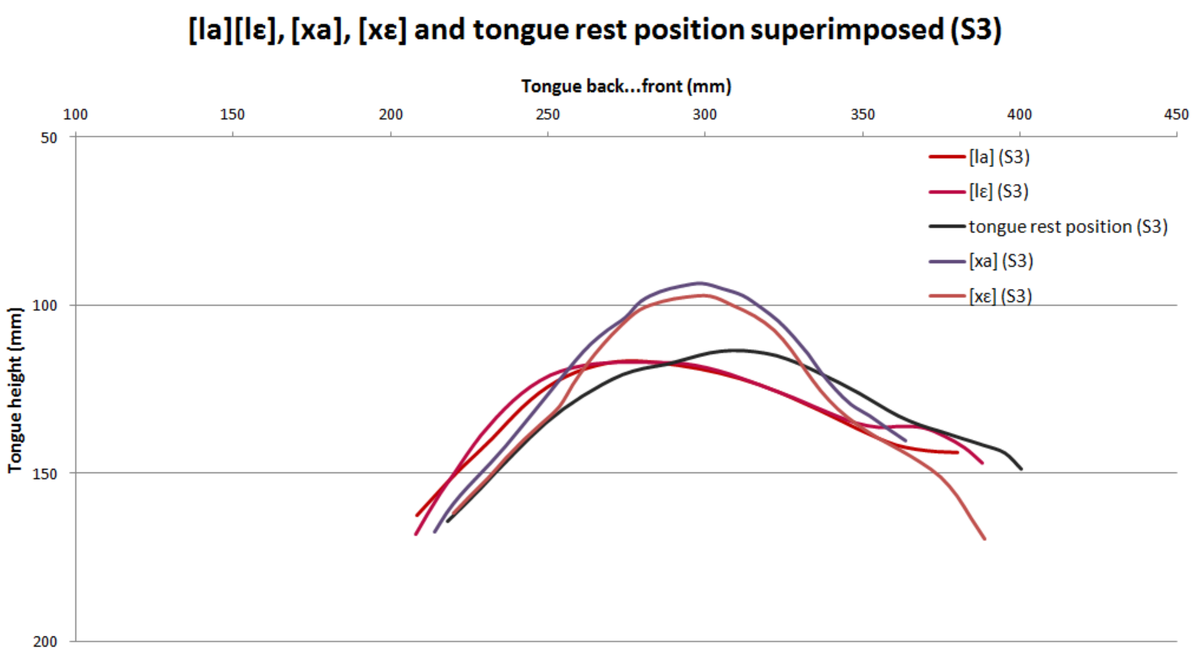
Tongue height (mm)
[fa] (S3)
[fɛ] (S3)
tongue rest position (S3)
[xa] (S3)
[xɛ] (S3)


[la][lɛ], [xa], [xɛ] and tongue rest position superimposed (S3)
Tongue back...front (mm)
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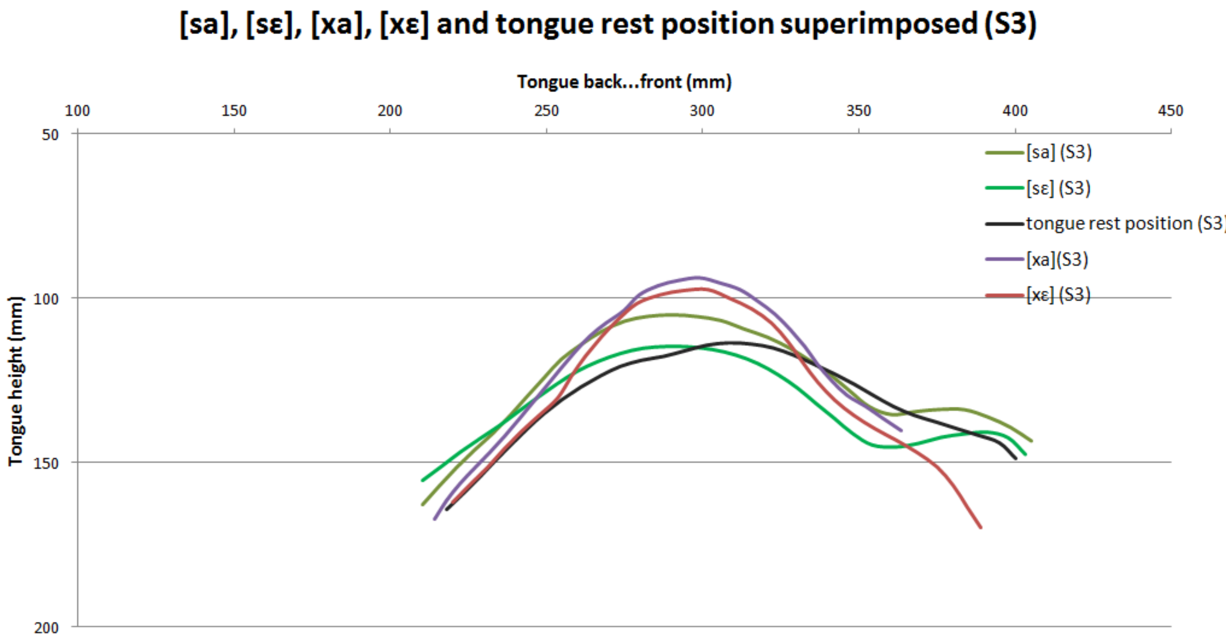
Tongue height (mm)
[la] (S3)
[lɛ] (S3)
tongue rest position (S3)
[xa] (S3)
[xɛ] (S3)


[sa], [sɛ], [xa], [xɛ] and tongue rest position superimposed (S3)
Tongue back...front (mm)
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Tongue height (mm)
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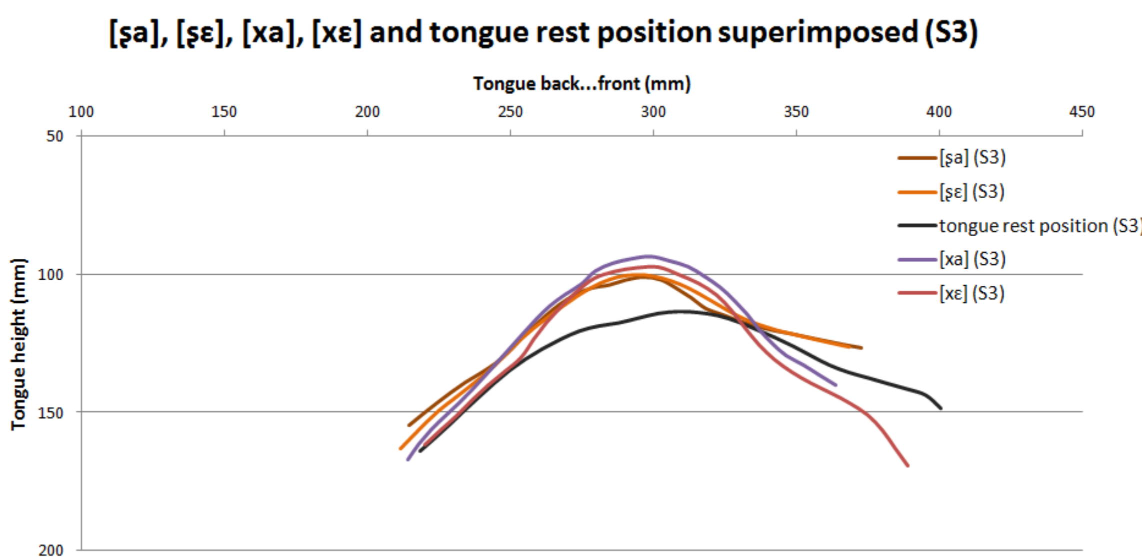
tongue rest position (S3)
[xa](S3)
[xɛ] (S3)


[ʂa], [ʂɛ], [xa], [xɛ] and tongue rest position superimposed (S3)
Tongue back...front (mm)
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Tongue height (mm)
[ʂa] (S3)
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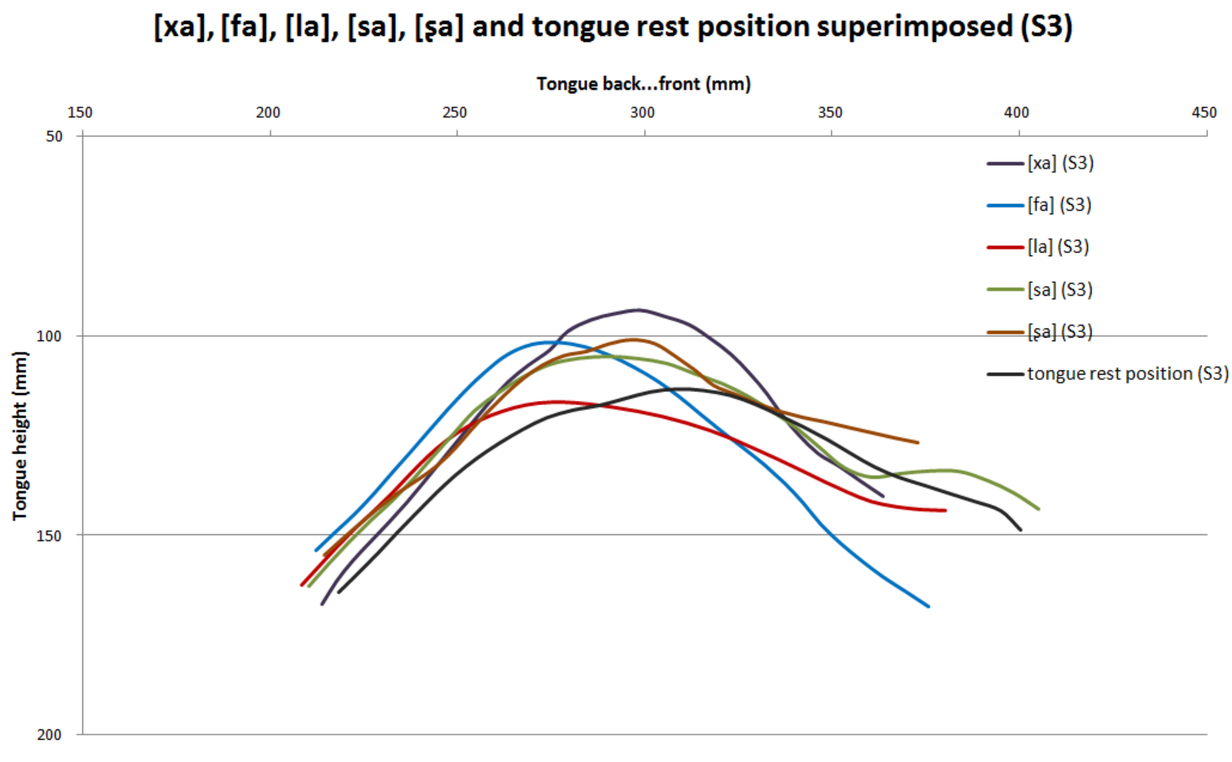
tongue rest position (S3)
[xa] (S3)
[xɛ] (S3)


[xa], [fa], [la], [sa], [ʂa] and tongue rest position superimposed (S3)
Tongue back...front (mm)
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Tongue height (mm)
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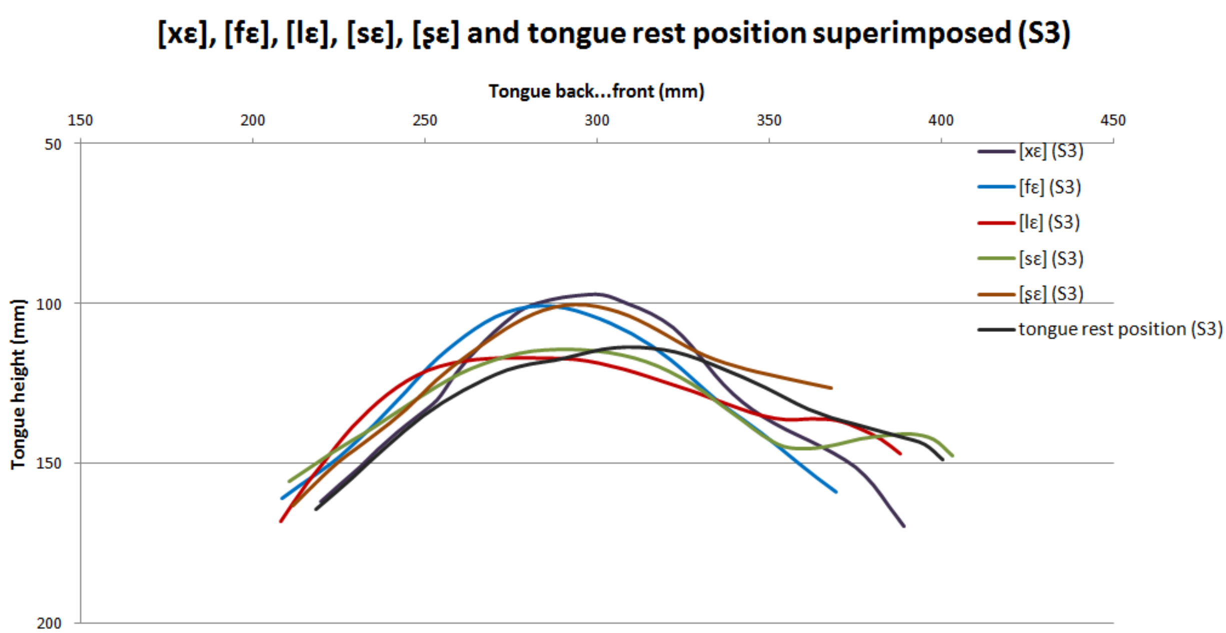
[fa] (S3)
[la] (S3)
[sa] (S3)
[ʂa] (S3)
tongue rest position (S3)


[xɛ], [fɛ], [lɛ], [sɛ], [ʂɛ] and tongue rest position superimposed (S3)
Tongue back...front (mm)
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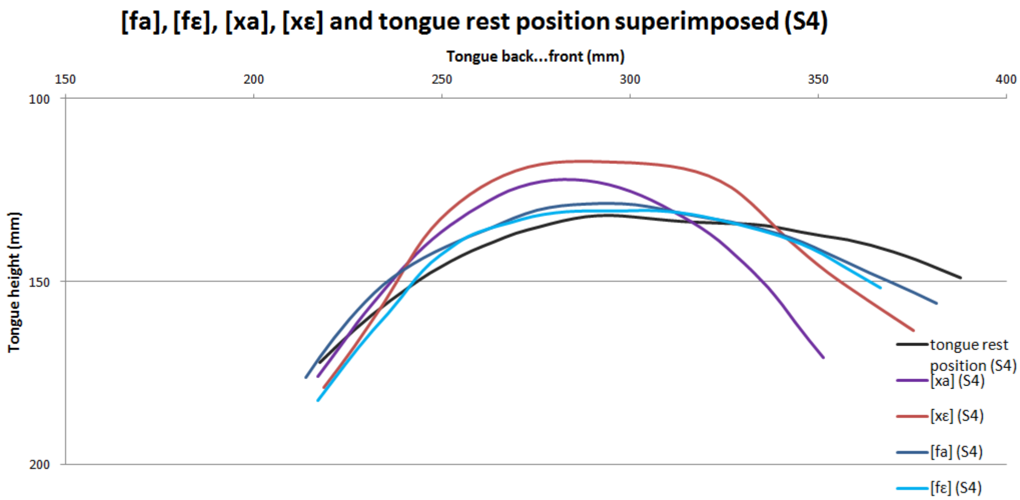
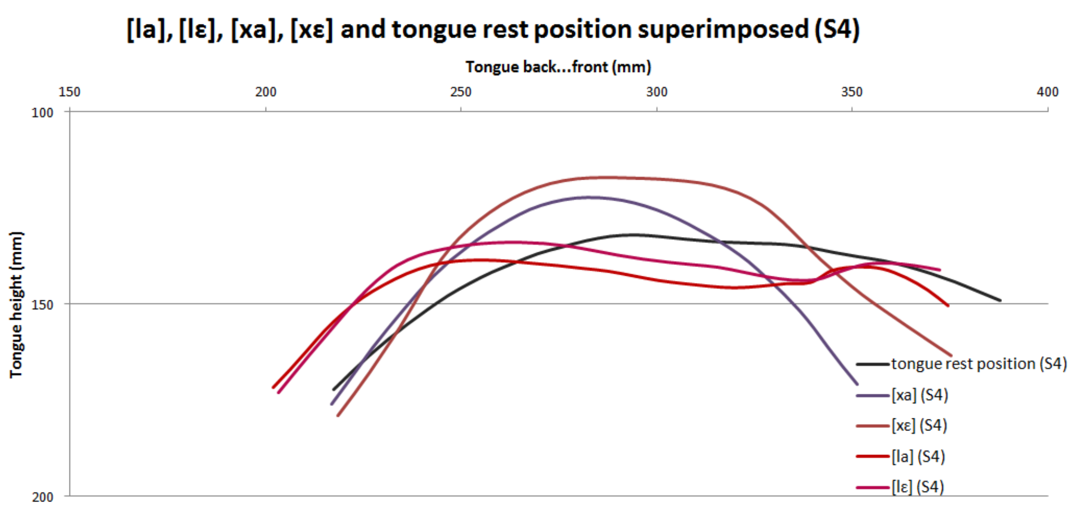
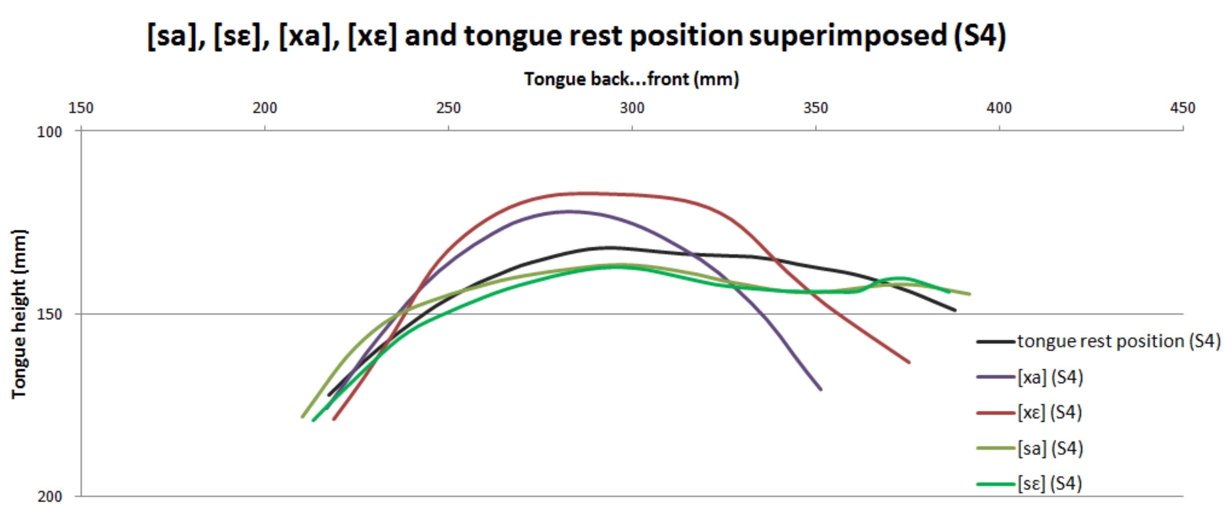
Tongue height (mm)
[xɛ] (S3)
[fɛ] (S3)
[lɛ] (S3)
[sɛ] (S3)
[ʂɛ] (S3)
tongue rest position (S3)

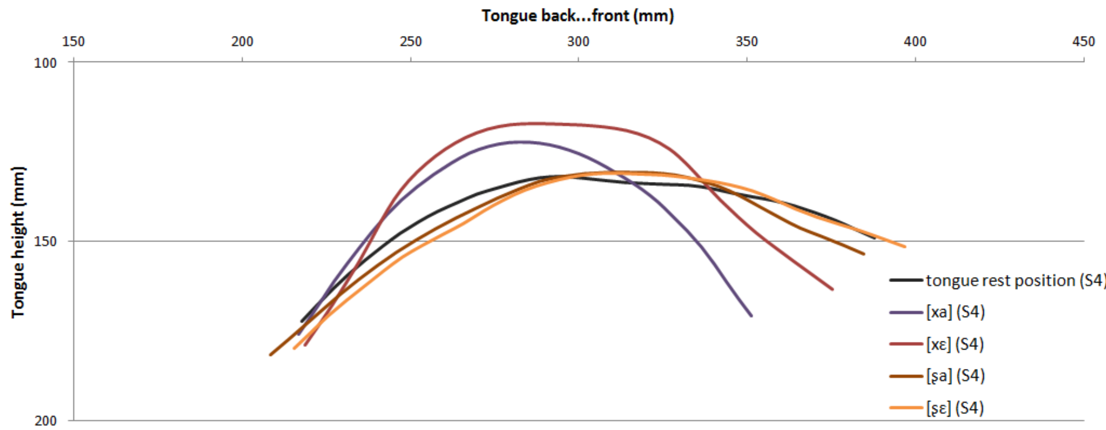
S4


[fa], [fɛ], [xa], [xɛ] and tongue rest position superimposed (S4)
Tongue back...front (mm)
150
200
250
300
350
400
100
150
200
Tongue height (mm)
tongue rest position (S4)
[xa] (S4)
[xɛ] (S4)
[fa] (S4)
[fɛ] (S4)

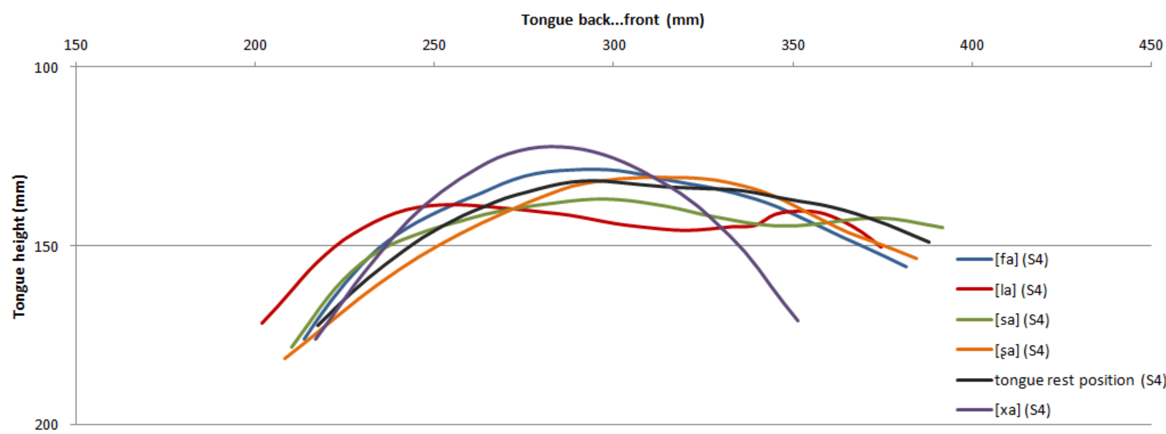

[la], [lɛ], [xa], [xɛ] and tongue rest position superimposed (S4)
Tongue back...front (mm)
150
200
250
300
350
400
100
150
200
Tongue height (mm)
tongue rest position (S4)
[xa] (S4)
[xɛ] (S4)
[la] (S4)
[lɛ] (S4)


[sa], [sɛ], [xa], [xɛ] and tongue rest position superimposed (S4)
Tongue back...front (mm)
150
200
250
300
350
400
450
100
150
200
Tongue height (mm)
tongue rest position (S4)
[xa] (S4)
[xɛ] (S4)
[sa] (S4)
[sɛ] (S4)

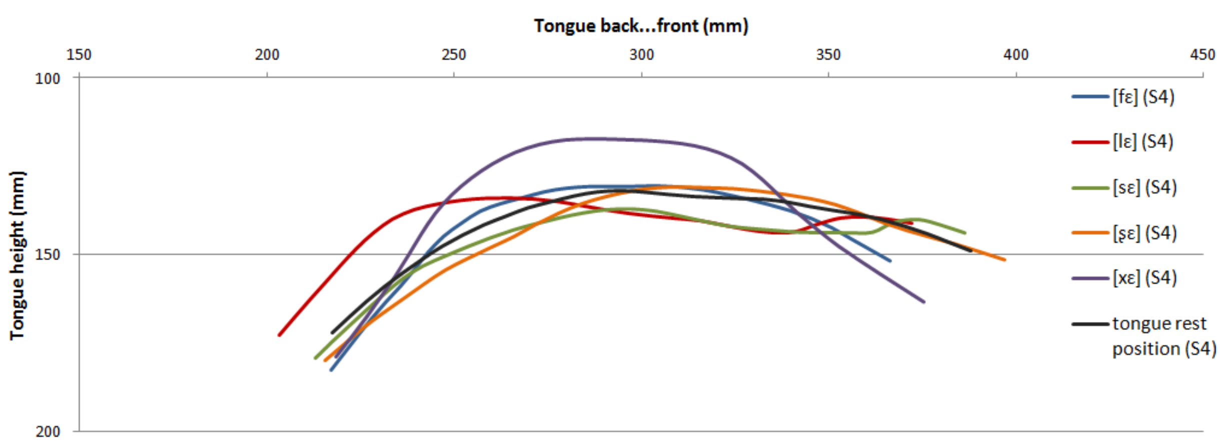
[ṣa], [ṣɛ], [xa], [xɛ] and tongue rest position superimposed (S4)



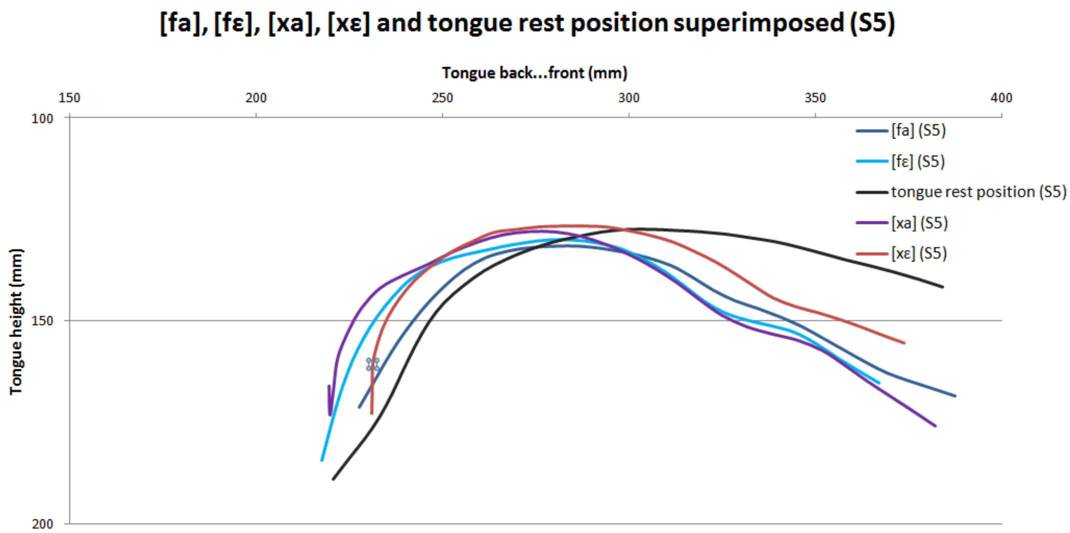
[xa], [fa], [la], [sa], [ṣa] and tongue rest position superimposed (S4)

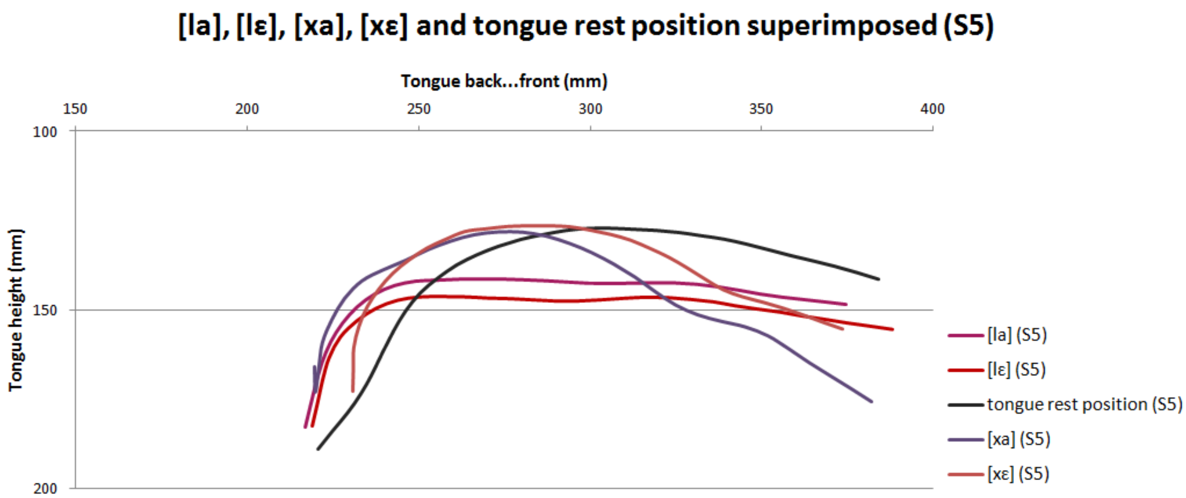


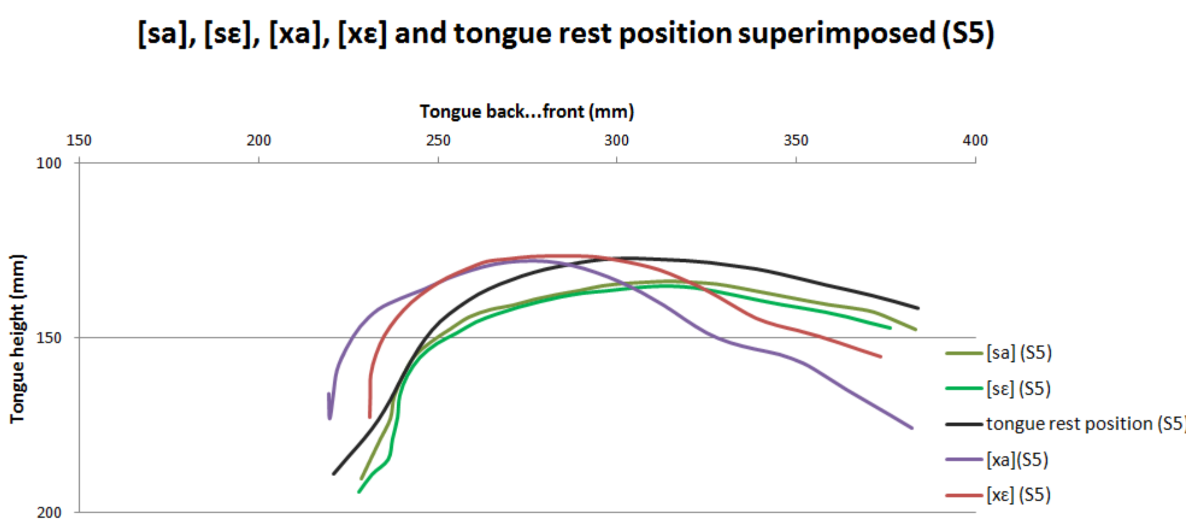
[xɛ], [fɛ], [lɛ], [sɛ], [ṣɛ] and tongue rest position superimposed (S4)

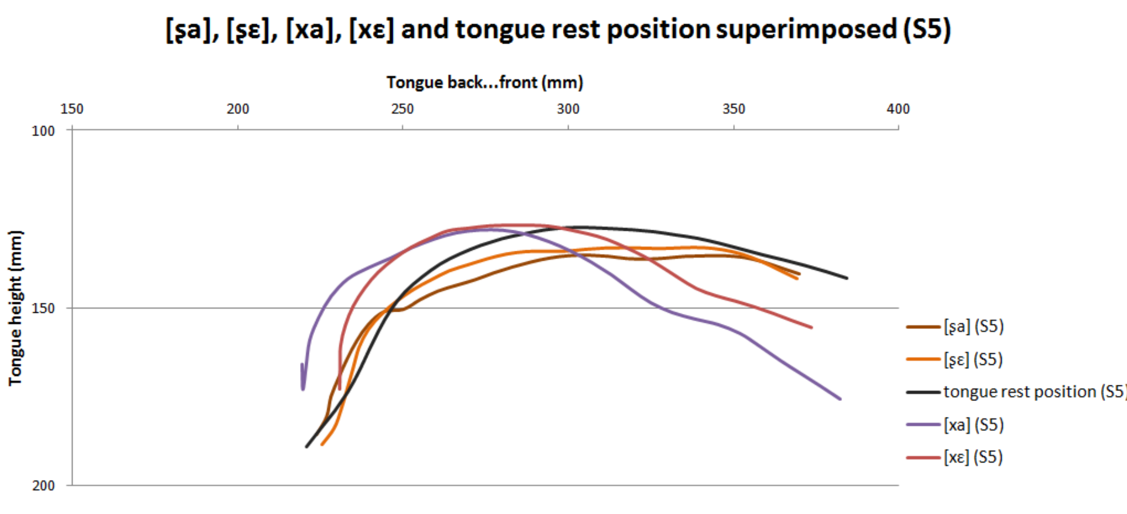


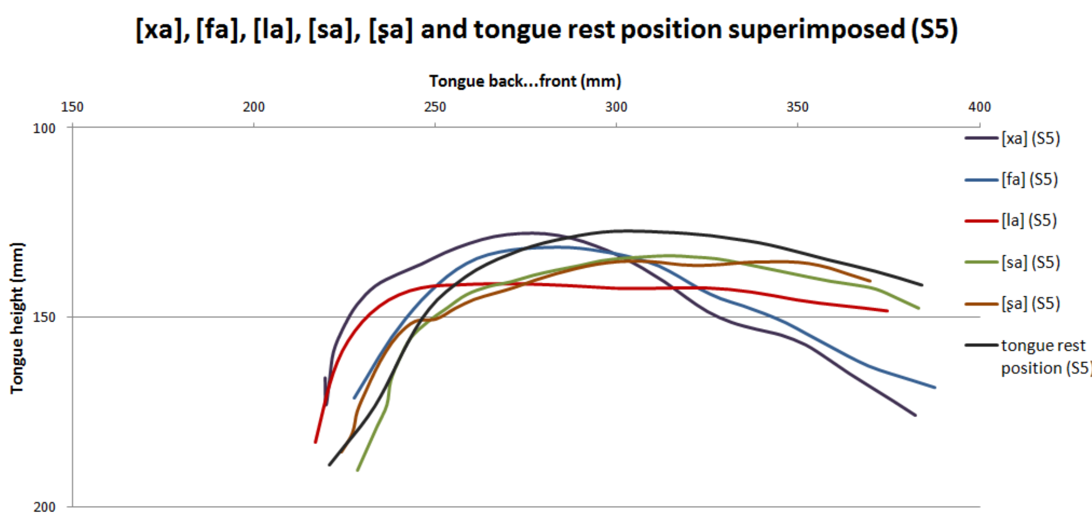
S5

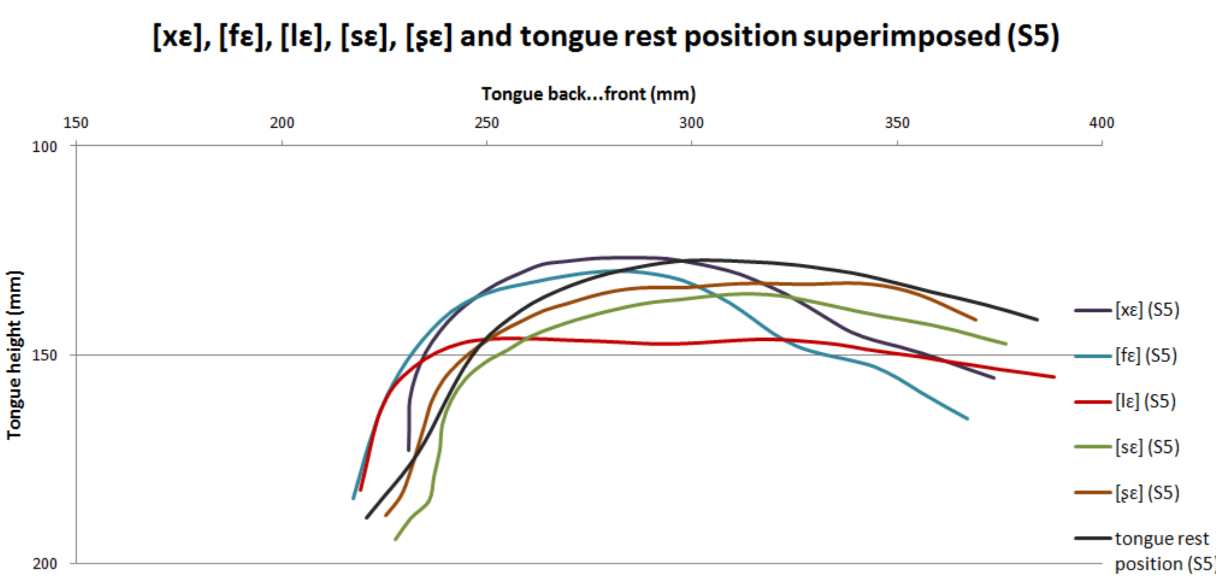

[fa], [fɛ], [xa], [xɛ] and tongue rest position superimposed (S5)
Tongue back...front (mm)
150
200
250
300
350
400
100
150
200
Tongue height (mm)
[fa] (S5)
[fɛ] (S5)
tongue rest position (S5)
[xa] (S5)
[xɛ] (S5)


[la], [lɛ], [xa], [xɛ] and tongue rest position superimposed (S5)
Tongue back...front (mm)
150
200
250
300
350
400
100
150
200
Tongue height (mm)
[la] (S5)
[lɛ] (S5)
tongue rest position (S5)
[xa] (S5)
[xɛ] (S5)


[sa], [sɛ], [xa], [xɛ] and tongue rest position superimposed (S5)
Tongue back...front (mm)
150
200
250
300
350
400
100
150
200
Tongue height (mm)
[sa] (S5)
[sɛ] (S5)
tongue rest position (S5)
[xa](S5)
[xɛ] (S5)

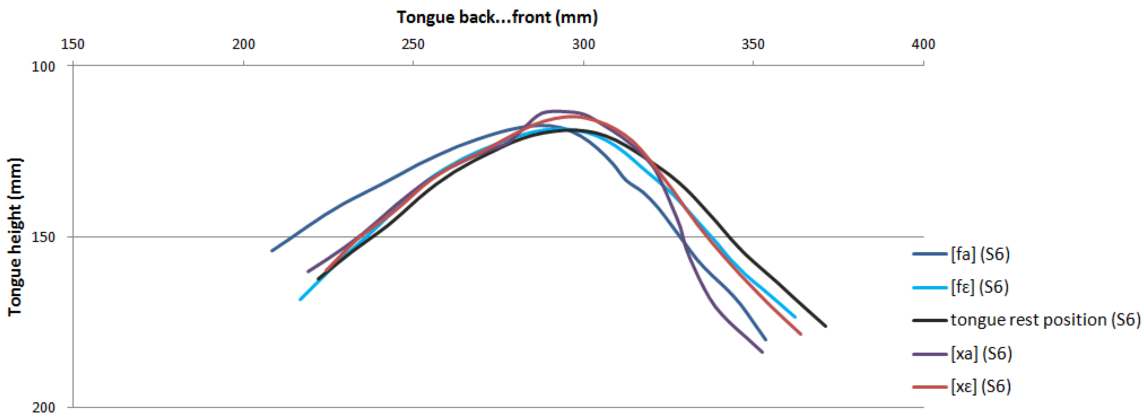

[şa], [şɛ], [xa], [xɛ] and tongue rest position superimposed (S5)
Tongue back...front (mm)
150
200
250
300
350
400
Tongue height (mm)
100
150
200
[şa] (S5)
[şɛ] (S5)
tongue rest position (S5)
[xa] (S5)
[xɛ] (S5)


[xa], [fa], [la], [sa], [şa] and tongue rest position superimposed (S5)
Tongue back...front (mm)
150
200
250
300
350
400
Tongue height (mm)
100
150
200
[xa] (S5)
[fa] (S5)
[la] (S5)
[sa] (S5)
[şa] (S5)
tongue rest position (S5)

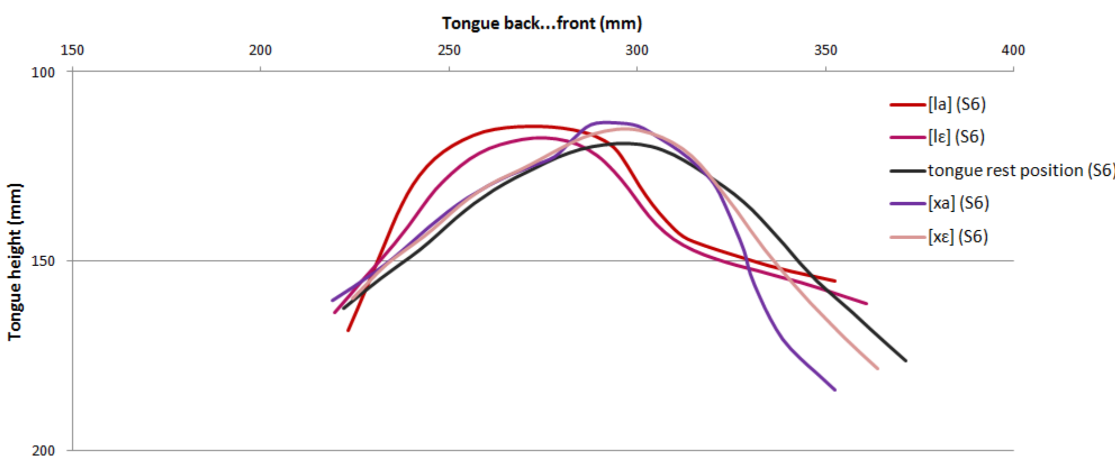

[xɛ], [fɛ], [lɛ], [sɛ], [şɛ] and tongue rest position superimposed (S5)
Tongue back...front (mm)
150
200
250
300
350
400
Tongue height (mm)
100
150
200
[xɛ] (S5)
[fɛ] (S5)
[lɛ] (S5)
[sɛ] (S5)
[şɛ] (S5)
tongue rest position (S5)

S6

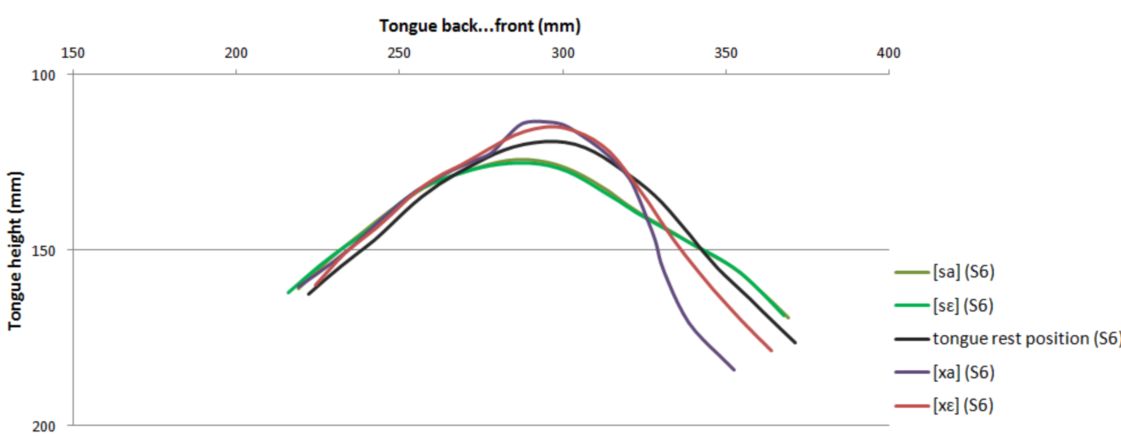
[fa], [fɛ], [xa], [xɛ] and tongue rest position superimposed (S6)



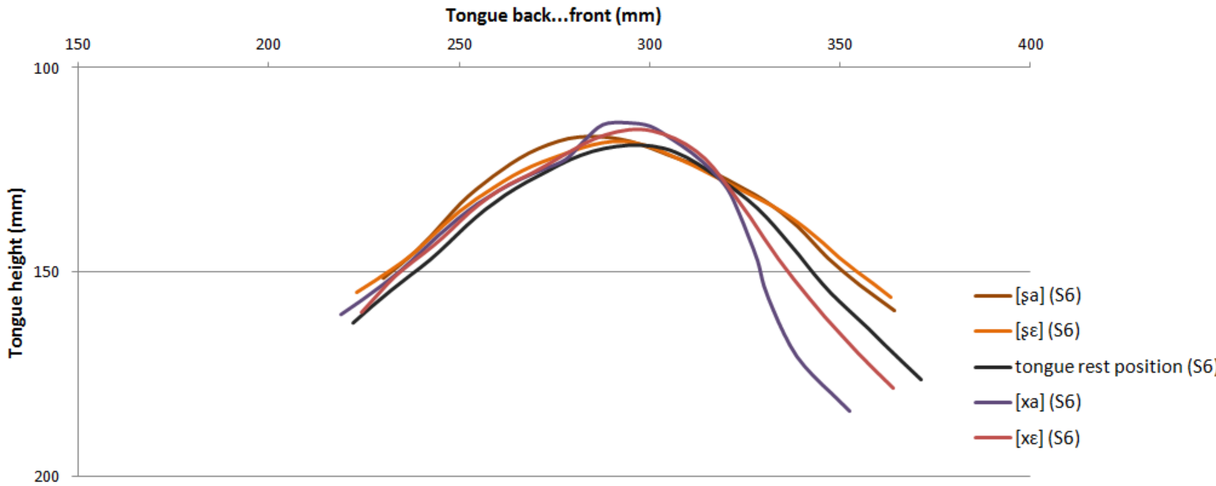
[la], [lɛ], [xa], [xɛ] and tongue rest position superimposed (S6)



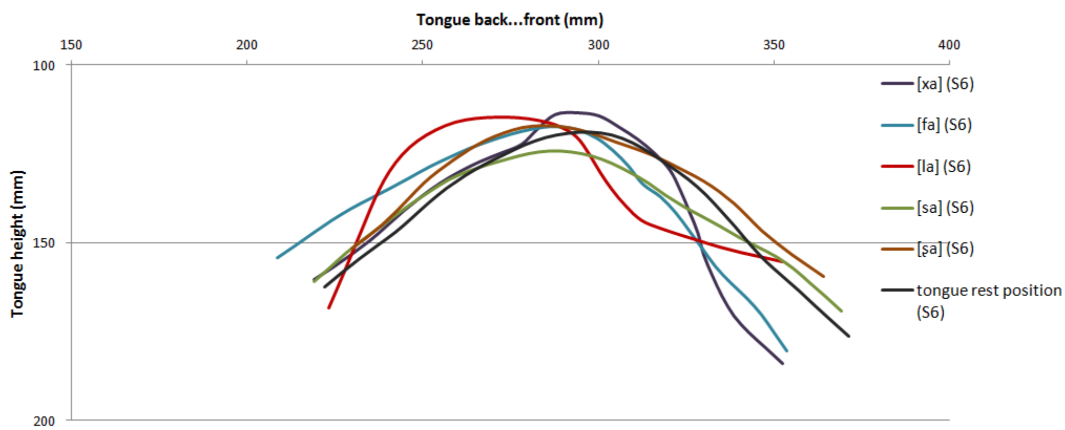
[sa], [sɛ], [xa], [xɛ] and tongue rest position superimposed (S6)



[ʂa], [ʂɛ], [xa], [xɛ] and tongue rest position superimposed (S6)



[xa], [fa], [la], [sa], [ʂa] and tongue rest position superimposed (S6)



[xɛ], [fɛ], [lɛ], [sɛ], [ʂɛ] and tongue rest position superimposed (S6)