# Russian palatalization is a matter of the tongue body

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## 1 Introduction

Russian is well known for having a secondary palatalization contrast that pervades its consonant inventory. Table 1 shows the contrast word-initially (top) and finally (bottom), adjacent to the vowels [u] and [i]. (Non-palatalized consonants are marked as velarized; see below for discussion.)[1,2]

| | | | | | |
|---|---|---|---|---|---|
| бюст | bʲustˠ | 'bosom' | бит | bʲitˠ | 'beaten' |
| будто | bˠuttˠə | 'as if' | быт | bˠitˠ | 'life' |
| | | | | | |
| дуть | dˠutʲ | 'to blow' | бить | bʲitʲ | 'to beat' |
| тут | tˠutˠ | 'here' | бит | bʲitˠ | 'beaten' |

Table 1: Russian palatalization contrast word-initially (top) and word-finally (bottom)

Though this contrast is well known, relatively few languages in the world have such a contrast, and both the phonetics and phonology of palatalization contrasts remain incompletely understood. For example, though the contrast is often understood to involve the tongue body as its active articulator, some have argued that the contrast is primarily one of pharyngealization or [advanced tongue root] (ATR). This is a view that must be taken seriously, since a palatalization contrast does involve changes in tongue root position and pharyngeal cavity size. However, we argue here that the only features active in the Russian palatalization contrast are tongue body features, specifically [back] and [high], based on i) results of an ultrasound study, ii) consonant-vowel interactions in Russian, and iii) what we know about the typology of ATR systems.

## 2 Preliminaries: on the status of 'ы'

Following Padgett (2001, 2003); Operstein (2010), we understand Russian 'ы' (often transliterated as *y*) to be [ˠi], that is, velarization of a preceding consonant plus the

[1]The term 'secondary palatalization' refers to palatalization as a secondary articulation, akin to [j], superimposed on a primary place of articulation, giving [bʲ], [sʲ], [nʲ], etc.

[2]In the case of consonant clusters, here and elsewhere we indicate a secondary articulation only on the final consonant. Assimilation of secondary articulations in Russian clusters (or lack of it) is a complex topic that we don't address here, see for example Avanesov (1972); Timberlake (2004).

vowel [i]. As shown in Table 1, for example, we transcribe the Russian word *быт* 'life' as [b$^{ɣ}$it$^{ɣ}$]. Since our ultrasound study involves consonants preceding the high vowels /i,u/, it is important that we make clear our assumptions about the nature of the /i/ context.

It is more common to analyze 'ы' as a [+back] allophone of /i/ after non-palatalized consonants (e.g. Halle, 1959; Trubetzkoy, 1969). Under this analysis, Russian has five vowel phonemes /i,e,a,o,u/, and a rule spreads [+back] from a preceding non-palatalized consonant to [i], producing [ɨ]. Such an analysis necessarily assumes that the preceding consonant is [+back], since this is the hypothesized source of the [+back] specification on [ɨ]. We agree that Russian 'ы' is not a phoneme and that non-palatalized consonants are [+back], but we do not agree that this [+back] specification spreads to the vowel 'ы' or that this vowel is [ɨ]. Rather, the vowel itself is simply [i].

Figure 1 shows plots of the five Russian vowel phonemes according to their first and second formant values (converted to equivalent rectangular bandwidth (ERB) scale to better convey perceptual distances, and measured at 75% of vowel duration; see e.g. Clopper 2009 and many others). On the left are vowels after palatalized consonants (indicated by 'ji' etc., though the data represent only the vowel), and on the right vowels after non-palatalized consonants. As can be seen, the vowel /i/ after a non-palatalized consonant–that is, 'ы'–is at least as front as [e] in this context.[3]

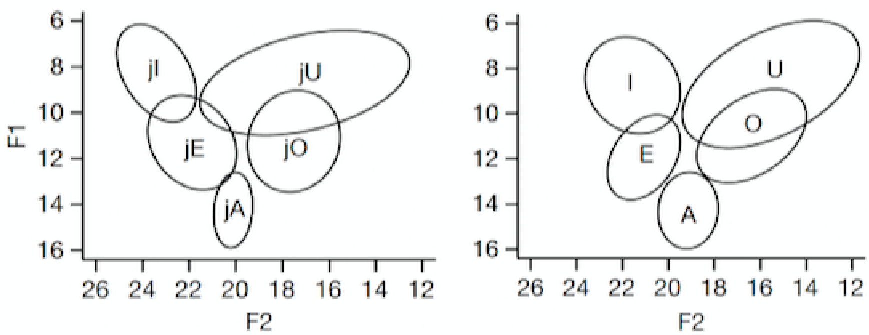


Figure 1: Russian vowel formant plots showing stressed vowels after palatalized (left) and non-palatalized (right) consonants, for 8 female speakers combined. Units are equivalent rectangular bandwidth (ERB) to better convey perceptual distances. Measured at 75% of vowel duration. From Padgett & Tabain (2005).

One reason why 'ы' is often mistakenly treated as [+back] is that it occurs only immediately following a [+back] consonant and is heavily colored by coarticulation with that consonant, just as /a,o,u/ are heavily colored by coarticulation with a palatalized consonant (see section 5.1). The plots above are based on measurements of the vowel at 75% of its duration in order to minimize this coarticulation. When 'ы' is held for any time at all, as when singing, its front character is unmistakable, as Reformatskii (2021) observes.[4] Indeed, the analysis of 'ы' as [$^{ɣ}$i], that is, [i] preceded by velarization of a

[3]The vowels in this study mostly follow labial consonants, see Padgett & Tabain (2005) for details. Other phonetic studies showing that 'ы' is [-back] are Holden & Nearey (1986), Padgett (2001), and Cavar & Lulich (2021).

[4]Interested readers can hear this at 3:36 in this video of vocal coach Ol'ga Kulagina, where she pro-

consonant, makes sense of the typical diphthongized pronunciation of 'ы' when stressed (e.g. Meillet, 1951; Jones & Ward, 1969; Bondarko, 1977). Velarized consonants cause similar 'diphthongal' effects on vowels in Irish and Marshallese (see Operstein, 2010; Choi, 1992, respectively). In those languages, as in Russian, these effects are simply the unremarkable result of transitioning between consonants, which bear their own vocalic secondary articulations, and vowels. This can be seen by comparing the spectrograms of *бы* [bˠi] and *би* [bʲi] in the right panels of Figure 2. The vowel's second formant is indicated by the higher of the two traced lines in the figure; a low second formant indicates a relatively backed and/or rounded vowel. This formant begins much lower for [bˠi] than for *би*, due to the high, backed tongue position of a velarized consonant. Yet by the end of the vowel the formants are of similar height. This is not the profile of a vowel [ɨ], and it makes clear why research on Russian cannot collectively agree whether this "vowel" is [+back] or [-back]. The sequence [ˠi] is in fact [+back] (velarization of the preceding consonant) followed by [-back] (the vowel [i]).

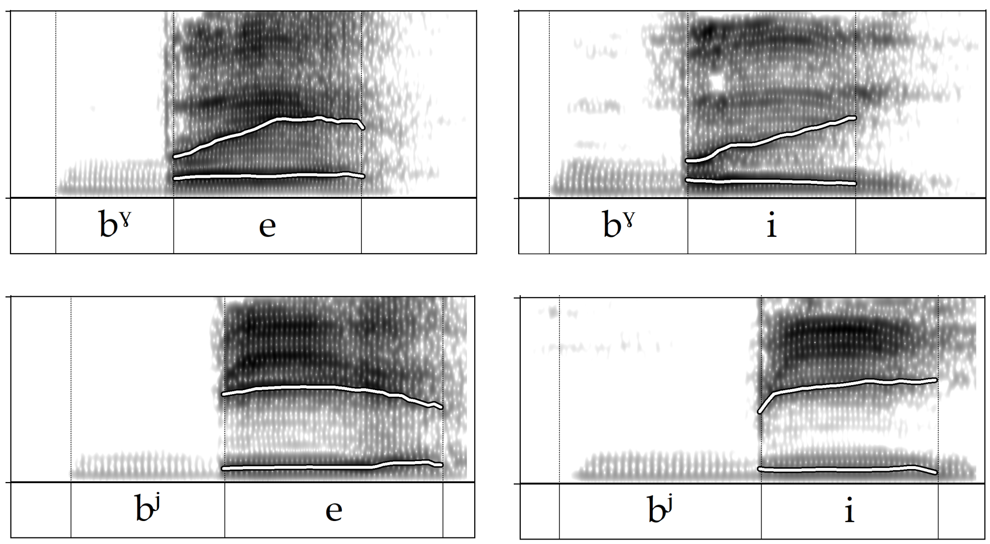


Figure 2: F1/F2 transitions for Russian *бэ, бы* [bˠe, bˠi] and *бе, би* [bʲe, bʲi]. Y-axis scale for spectrogram is [0,5000] Hz. Recordings from `http://www.russianforeveryone.com/Rufe/Lessons/Course1/Introduction/IntrUnit6/IntrEx6_1.htm`, used by permission of Dr. Julia Rochtchina.

Once we acknowledge that Russian 'ы' is [ˠi] and not [ɨ], a number of benefits immediately ensue. First, this analysis is descriptively more accurate, as discussed above. Second, it explains the distribution of 'ы' *for free*. After all, the status of non-palatalized consonants as [+back] is already presupposed by the allophonic analysis /i/ → [ɨ] / [C, +back] ___, and independently motivated for Russian (as discussed below). The allophonic rule itself is simply incorrect and unnecessary. Finally, our analysis captures the parallelism between the facts of /i/ and /e/. After non-palatalized consonants, /e/ is also 'diphthongized' (left panels of Figure 2), and for the same reason that /i/ is: the pre-

longs *ты* 'you' in *ты камень а я бриллиант* 'you're a stone and I'm a diamond': `https://youtu.be/xfHXKgpbxxo`.

ceding consonant is velarized, giving [Cˠe], e.g. в этом кафе [ˈvˠetˠəmˠ kˠɐˈfˠe] 'in this cafe'. In the face of the phonetic parallel, the fact that scholars of Russian posit a vowel [ɨ] but nothing similar for [e] misses a simple and obvious generalization. The parallel goes beyond the simple presence or absence of apparent velarization. Scholars have long noted that the diphthongal character of 'ы' is more pronounced after labial consonants like [p,b,m] than coronal ones like [t,d,n] (Boyanus, 1955; Jones & Ward, 1969; Meillet, 1951). But the same is true of /e/. Under an analysis featuring [ɨ], this fact, and in fact the pervasive appearance of velarization more generally in Russian, is a remarkable coincidence.

# 3 Velarization or pharyngealization?

Scholars of Russian have long observed that non-palatalized consonants in Russian are generally velarized–having a tongue body that is raised and backed (Evans-Romaine, 1998; Öhman, 1966; Purcell, 1979; Reformatskii, 1958; Trubetzkoy, 1969). Recent articulatory studies have shown the same (Kochetov, 2002; Kedrova et al., 2008, 2009; Proctor, 2009; Litvin, 2014; Roon & Whalen, 2019; Biteeva, 2021).[5] The work cited shows that the degree of velarization (and sometimes the perceptibility of velarization) can depend on factors like the place of articulation of the consonant or the context. For example, labials are generally more strongly velarized than coronals. And velarization is more strongly perceived in the context of front vowels, especially when the vowel follows, since this creates a large transition in formant values between the consonant and the vowel, extending well into the vowel, as discussed in the preceding section for /e/ and /i/ ('ы').

However, for decades scholars have also suggested that non-palatalized consonants in Russian are *pharyngealized* (Halle, 1959; Fant, 1960; Bolla, 1981), or in a related proposal involve a retracted tongue root ([-advanced tongue root] or [-ATR]) in contrast to the [+ATR] specification of palatalized consonants (Cavar & Lulich, 2021). And it is indeed clear that the palatalization contrast involves large displacements in the position of the tongue root and consequently the size of the pharyngeal cavity, something Matsui & Kochetov (2018) demonstrate and explicitly discuss. Hence this sort of proposal is to be taken seriously.

The problem that arises in addressing this issue is that the tongue body and tongue root are physiologically dependent on each other: tongue body raising and fronting is known to cause tongue root advancement–and vice versa. Likewise, tongue body lowering and backing causes tongue root retraction–and vice versa. (See for example Ladefoged et al. (1972); MacKay (1976); Roon & Whalen (2019), as well as Archangeli & Pulleyblank (1994); Calabrese (1995) for application of these generalizations to phonological systems.) Therefore, if a palatalization contrast involves active displacement of the tongue dorsum, then displacement of the tongue root (or pharyngealization) would be an expected side effect; and again, vice versa. How do we determine whether the tongue body, the tongue root, or both are actively involved in a palatalization contrast?

The Irish language has a palatalization/velarization contrast that is very similar to that of Russian (e.g. Ní Chiosáin, 1991; Ní Chasaide, 1995). Bennett et al. (2018) carried

[5] Some studies suggest that non-palatalized consonants can be more uvularized than velarized. We discuss this in section 4.

out an ultrasound study of the Irish consonants /p(b),t,k,f,s,x/ in onset position before stressed /i:,u:/. Ultrasound allows for imaging of the tongue surface during speech. The tongue body contour during a given consonant or vowel can then be traced from still frames of an ultrasound video using software like EdgeTrak (Li et al., 2005). Sample tongue contour tracings from the study described in Bennett et al. (2018) are provided in Fig. 3; note that the front of the mouth is on the right in this figure, as is common in ultrasound studies.

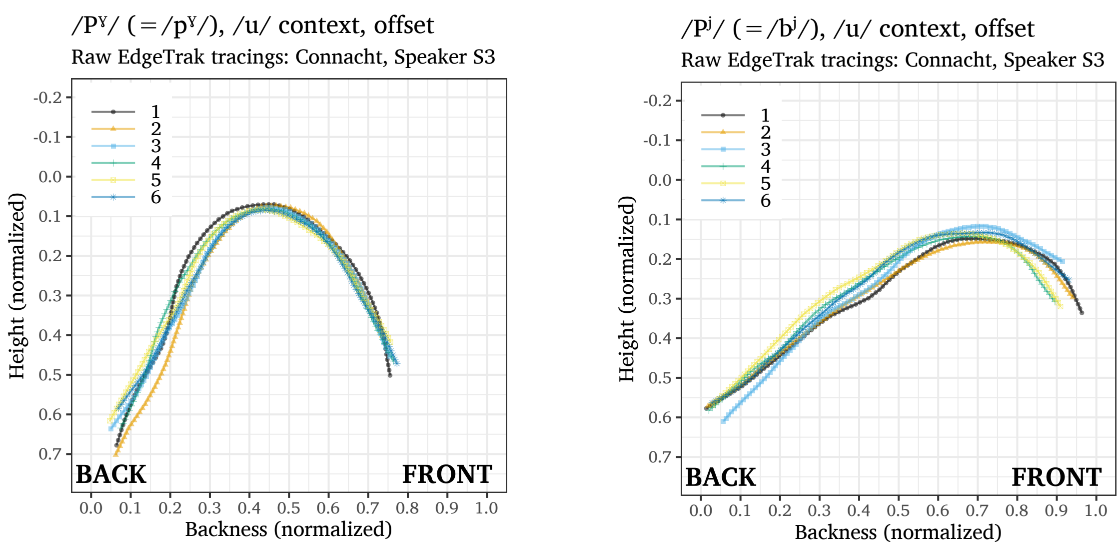


Figure 3: Velarized [pˠ] (left) and palatalized [bʲ] (right) at consonantal offset before [u:] in Irish, Bennett et al. (2018), Speaker 3.

Bennett et al. (2018) analyzed raw tracings like those in Fig. 3 using principal component analysis (PCA). PCA can reduce the dimensionality of tongue shape/position data, typically to a few independent components capturing variability–informally, 'ways the tongue moves'–that are guaranteed to be independent of each other (see e.g. Johnson, 2008). Essentially, PCA allows the analyst to explore how tongue contour tracings tend to differ from each other across tokens: each principal component produced by PCA corresponds to an important pattern of movement or change observed across the set of pooled tracings in the raw data.

Figure 4 shows the first two principal components derived from the raw tracings collected by Bennett et al. (2018). The solid line in these images represents the average tongue position over all of the data; dashed lines in each panel indicate how the tongue contour changes along the dimensions defined by each principal component.

Bennett et al. (2018) interpret the first principal component (PC1), which accounts for about 40% of the variability in the data, as involving movement of the tongue body forwards and backwards in connection with the palatalization/velarization contrast. (Indeed, secondary palatalization/velarization had the largest effect on PC1 values in the statistical model presented by Bennett et al. 2018.) Notice how the tongue root advances and retracts at the same time; based on the discussion above, it is not clear whether PC1 really represents an active tongue body, an active tongue root, or both. However, Bennett et al. (2018) interpret PC2, representing 30% of the variability in the Irish data, as suggesting an active tongue root or pharyngeal component to the Irish palatalization contrast, independent of PC1.

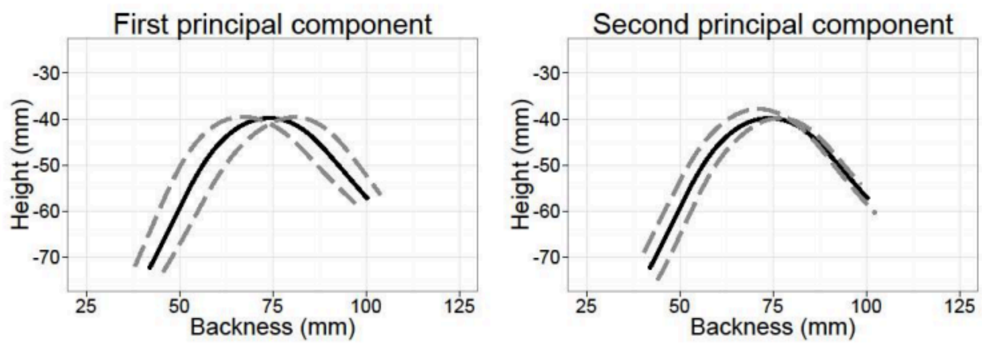


Figure 4: First two principal components derived from Irish ultrasound data. Front of tongue is to the right. From Bennett et al. (2018).

Bennett et al.'s PC2 likely indicates tongue root *advancement* for palatalized consonants rather than tongue root *retraction* (or pharyngealization) for non-palatalized consonants. Why? As noted above, tongue root retraction is associated with tongue body lowering as well as backing. According to Esling's 2005 Laryngeal Articulator Model, there are three main directions of lingual movement by which vowel quality (and by extension, the quality of secondary articulations) is determined, each associated with an extrinsic lingual muscle group: a fronting mechanism associated with the genioglossus, a backing and raising mechanism associated with the styloglossus, and a backing and lowering (or 'retraction') mechanism associated with the hyoglossus. Research adopting this framework (e.g. Moisik, 2013; Al-Tamimi, 2017) argues that true tongue root retraction, and pharyngealization, engages a laryngeal (or aryepiglottic) constrictor mechanism, which pulls the tongue root–and tongue body–toward the larynx. In other words, pharyngealization and tongue root retraction are not consistent with a high tongue body.[6] And yet Bennett et al. (2018) find that, at least for Irish non-palatalized sounds that are labial and velar, the tongue body is indeed high, often as high as it is for palatalized consonants (as in Fig. 3 above). As we will see in the following section, the same is true of Russian.

# 4 Ultrasound study

## 4.1 Methods

The methods for this study were mostly identical to those of Bennett et al. (2018), the main difference being the language of the speakers and materials (Russian instead of Irish). We recorded three female speakers, students participating in a summer linguistics program housed at St. Petersburg University, who self-identified as speakers of Standard

[6]See Alwabari (2020) for an ultrasound study of coarticulation in Eastern Peninsular Arabic demonstrating antagonism between pharyngealization and a high tongue body even in [χ].

Russian. These participants were 19, 21, and 26 years old and came from St. Petersburg, Moscow, and Novosibirsk.

Ultrasound data was collected using a Terason T3000 ultrasound system with a model 8MC3 probe. The ultrasound machine recorded video at a frame rate of 58-60 frames per second, giving a temporal error of 8.3-8.6 ms. The probe was mounted in an Articulate Instruments Ultrasound Stabilization Headset Wrench (2008), which was worn by the speakers throughout the experiment. The speakers recorded five repetitions each of the consonants /p(b),t,k,f,s,x/ in the onset of (mostly) monosyllabic words before the vowels /i,u/; the target words are shown in Table 2. The words were recorded within the carrier phrase [ɐˈnˠa skˠɐˈzˠalˠə __ kˠakˠ ˈnˠadˠə] (*Она сказала __ как надо*) 'she said ___ as she should'. This choice of phrase placed the target words in a context of central vowels and velarized (rather than palatalized) consonants.

The forms without glosses in the table (nine out of 24 forms) are nonce words. We included nonce words in order to allow for close control of the phonetic environment, and to match the phonological form of the Irish materials analyzed by Bennett et al. (2018). Of the nine nonce forms, four are clear cases of accidental gaps in the Russian lexicon, respecting Russian phonotactics ([tˠisˠ], [tʲusˠ], [sʲutˠ], [kʲutˠ]).[7] (At issue mainly is whether the onset and the following vowel are a licit combination.) Of the remaining five nonce forms, [fˠitˠ] and [fʲutˠ] involve very uncommon CV sequences, in part because /f/ is historically foreign, but *фыркнуть* ([ˈfˠirknˠutʲ]) 'snort' and *фюзеляж* ([fʲuzʲiˈlʲaʂ] 'fuselage' are familiar words. The CV sequences in [xʲutˠ], [xˠitˠ] and [kˠitˠ], in contrast, are virtually unattested within words in Russian. The sequence [xʲu] might be expected to cause little problem because of parallelism with [kʲu]. In addition, the car brand Hyundai is sometimes incorrectly rendered in Russian as *Хюндай* [ˈxʲundaj]; the standard spelling and pronunciation *Хёндэ* [ˈxʲondˠe] also places [xʲ] before a back vowel. Though the sequences [kˠi] and [xˠi] do not occur within words in Russian, they routinely occur at the phrasal level. This fact is usually attributed to application of the purported allophonic rule discussed in section 2; in our terms, it is simply what happens when a word-final non-palatalized (velarized) consonant precedes a word-initial /i/, e.g. [sˠokˠ iˈrʲinˠi] 'Irina's juice', [pˠuxˠ iˈvˠanˠə] 'Ivan's fluff'. When the preposition *к* 'to/toward' combines with any /i/-initial word, the result is a prosodic word such as [ˈkˠirʲi] 'to Ira', effectively a minimal pair with [ˈkʲirʲi] 'Kira (dat.sg.)'. Perhaps the most important point to make, however, is that none of our subjects found any of the materials puzzling or difficult, and they made no mistakes in pronouncing any of the forms.

For further details on the experimental methods, including alignment of ultrasound video with audio, data capture, creation of tongue shape images, and principal component analysis, we refer the reader to Bennett et al. (2018). We make clear below where our methods differ from that work.

Our experiment contributes to the literature on the articulation of the Russian palatalization contrast in several ways. Like several recent studies, including Litvin (2014); Matsui & Kochetov (2018); Proctor (2009); Roon & Whalen (2019), our study relies on

[7] For the last three, which may seem more questionable, cf. *тюрьма* [tʲurʲˈmˠa] 'prison', *тюкать* [ˈtʲukˠətʲ] 'bang', *сюда* [sʲuˈdˠa] 'hither', *вовсю* [vɐˈfsʲu] 'with all one's might' and *кювет* [kʲuˈvʲetˠ] 'ditch (along a road)'.

| | Plosive | | | | Fricative | | | |
|---|---|---|---|---|---|---|---|---|
| | /i/ | | /u/ | | /i/ | | /u/ | |
| | /Cˠ/ | /Cʲ/ | /Cˠ/ | /Cʲ/ | /Cˠ/ | /Cʲ/ | /Cˠ/ | /Cʲ/ |
| Labial | *быт*<br>[bˠitˠ]<br>‘life’ | *пит*<br>[pʲitˠ]<br>’drunk (pp)’ | *пуд*<br>[pˠudˠ]<br>‘pood’ | *бюст*<br>[bʲustˠ]<br>‘bosom’ | *фыт*<br>[fˠitˠ] | *физ*<br>[fʲisˠ]<br>‘fizzy drink’ | *фут*<br>[fˠutˠ]<br>‘foot’ | *фют*<br>[fʲutˠ] |
| Coronal | *тыс*<br>[tˠisˠ] | *тис*<br>[tʲisˠ]<br>‘yew’ | *тут*<br>[tˠutˠ]<br>‘here’ | *тюс*<br>[tʲusˠ] | *сыт*<br>[sˠitˠ]<br>‘satisfied’ | *сито*<br>[ˈsʲitˠə]<br>‘sieve’ | *суд*<br>[sˠutˠ]<br>‘court’ | *сют*<br>[sʲutˠ] |
| Dorsal | *кыт*<br>[kˠitˠ] | *кит*<br>[kʲitˠ]<br>‘whale’ | *кус*<br>[kˠusˠ]<br>‘bite’ | *кют*<br>[kʲutˠ] | *хыт*<br>[xˠitˠ] | *хитрый*<br>[ˈxʲitrˠij]<br>‘sly’ | *худо*<br>[ˈxˠudˠə]<br>‘badly’ | *хют*<br>[xʲutˠ] |

Table 2: Word list.

multiple repetitions from multiple speakers, as well as quantitative analysis, something often not true of earlier work. Second is our use of principal component analysis, which allows us to find the major correlated patterns of tongue movement related to the palatalization contrast. Though PCA brings its own challenges of interpretation, it avoids the potential disadvantages of relying on isolated measurement points on the tongue characteristic of some articulatory studies. Finally, we focus on the palatalization contrast before the vowels /i,u/, something that has very rarely been done in the past (but see Biteeva, 2021).[8] This is an interesting omission in the literature, since the high vowel environment is where the Russian (and Irish) palatalization contrast is most perceptually robust. Placing $C^j$ before [u] and $C^\gamma$ before [i] creates maximal contrast between the tongue body posture of the consonant and following vowel; observing the contrast in this context can potentially tell us a great deal about the nature of Russian secondary articulations.

## 4.2 Results

As in Bennett et al. (2018), we carried out a principal component analysis to identify significant patterns of tongue body movement in our Russian data.[9]. Figure 5 shows the first two principal components derived from the Russian ultrasound data, which together account for about 67% of the data variability. PC1 captures variation between a higher, fronter tongue position and a somewhat lower, backer one, which we understand

[8]The reason for this omission is probably confusion about the nature of the sequence *Cы*, discussed in section 2, in particular failure to understand that the consonant in this context is velarized, and/or that the vowel is front.

[9]This analysis differed from Bennett et al. (2018) in first range-normalizing the data by speaker before applying the PCA. Points on the x-axis were normalized to the range [0,1] using the formula in (1-a), and points on the y-axis were normalized using the formula in (1-b); these transformations were done separately for each speaker.

(1) a. $X_{norm} = (X_{raw} - min(X_{raw}))/range(X_{raw})$
b. $Y_{norm} = (Y_{raw} - min(Y_{raw}))/range(X_{raw})$

to represent an important component of the Russian palatalization contrast. Just as with the Irish PC1, the tongue root and tongue body covary in this PC1, and it is not possible in principle to say whether it is one, the other, or both that are active.

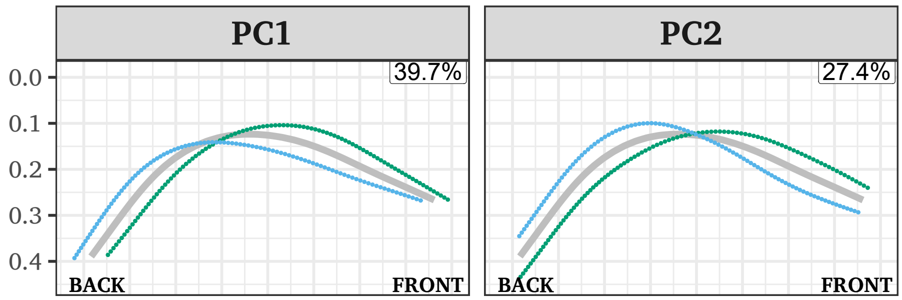


Figure 5: First two principal components derived from Russian ultrasound data, including frames from three temporal landmarks (consonant onset, midpoint, and offset). Front of tongue is to the right.

Unlike the Irish case, no PC derived from the Russian data seems to capture any independent pharyngeal dimension of movement. However, PC2 captures correlated movement between a fronter tongue body position and a backer and *higher* tongue body position. This likely captures another component of the Russian palatalization contrast, one of active *velarization*.

We can support this interpretation of PC2 by examining tongue shapes more directly. Figure 6 shows loess curves for [pˠ]/[bˠ] versus [pʲ]/[bʲ] before the vowels [i] (left panel) and [u] (right panel), for Russian Speaker 1. Each curve is a kind of 'average' tongue shape and position, created by means of a local smoothing function over five repetitions (using the 'loess' function in R).[10] The front of the mouth is to the right. This figure and the following show tongue positions at the moment of the release of the consonant, when secondary articulations are roughly at their extremes (Ladefoged & Maddieson, 1996; Kochetov, 2002, 2006; Bennett et al., 2018). As can be seen, the tongue body is as high for [pˠ]/[bˠ] as it is for [pʲ]/[bʲ], in either vowel context. The same observation can be made for [fˠ] vs. [fʲ] in Figure 7.

Figure 8 shows [fˠ,sˠ,xˠ] before [i] (left panel) and [u] (right panel), for Speaker 1 again. We understand the sound [xˠ] to be [+high,+back] by definition. As can be seen, the tongue body is comparably high and back during [fˠ] and [sˠ], whether the following vowel is [i] or [u].

The significance of these facts should be clear: as discussed earlier, a [+high] tongue body is not compatible with active pharyngealization or tongue root retraction. These results therefore do not support claims of active pharyngealization or tongue root retraction for Russian. Litvin (2014) makes a similar argument based on different ultrasound data. In a similar vein, Biteeva (2021) notes that palatalized consonants are very distinct from velarized ones in the tongue front and body area but overlap much more in the area of "the post-dorsum and the root" (p.202). (The Appendix provides plots like Fig.

[10]We depart from Bennett et al.'s 2018 methods in fitting the model within a polar space rather than a Cartesian space, as advocated by Mielke (2015).

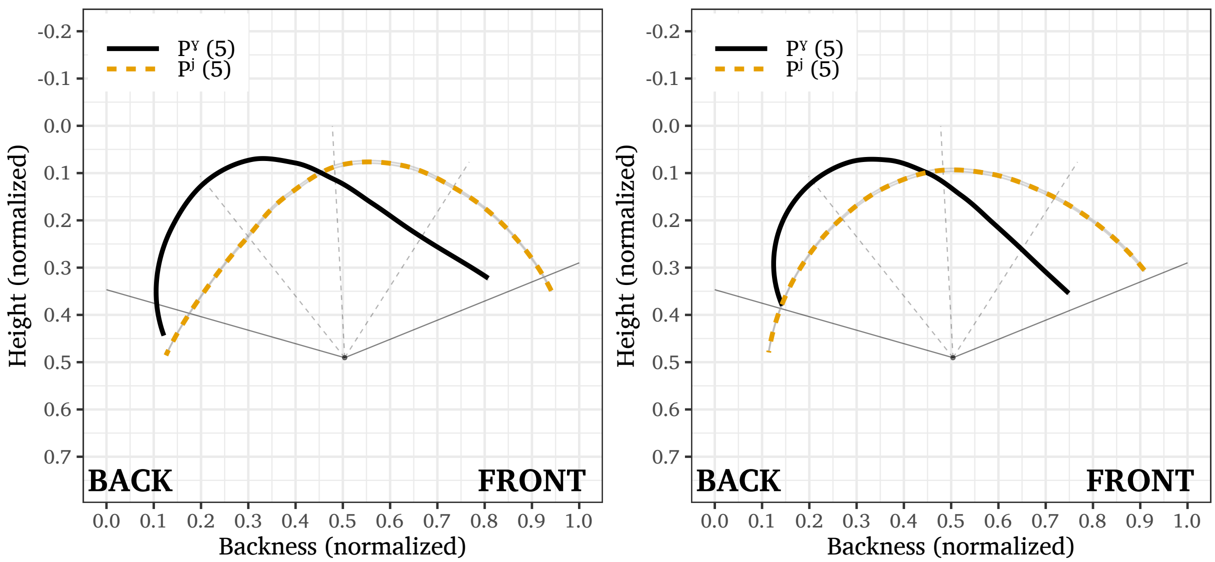


Figure 6: Velarization (solid line) and palatalization (dashed) of [p]/[b] at consonantal offset before [i] ('ы', left) and [u] (right), Speaker 1.

6-10 for all three speakers in our study; the full set of loess plots contrasting matched /Cʲ Cˠ/ pairs in this data set may be downloaded at `https://github.com/rbennett24/articles/blob/master/Russian_pal/Russian_loess_plots.zip`.)

Figure 9 is an alternative PCA analysis of the Russian data, encompassing only the data from consonant offset. It makes sense to consider this subset of the data since palatalization tends to peak at consonant offset in CV contexts, particularly for palatalized /Cʲ/ (see e.g. for Kochetov 2002 Russian, and Bennett et al. 2018; Padgett et al. 2023 for Irish). In particular, Bennett et al. (2018) find that the tongue body of palatalized consonants is somewhat backer and lower at consonant onset than at consonant offset in Irish, at least for some consonants and vowel contexts. Therefore the lowering associated with PC1 in Fig. 5 may be an artifact of including data from consonant onset in the PCA. Indeed, in Figure 9 we now see that PC2 involves raising simultaneous with *either* backing or fronting; PC1 appears to reflect raising of the tongue body alone. It is interesting to note here that this PC analysis leads to results that seem qualitatively more similar to those of Bennett et al. (2018) for Irish, though that Irish analysis included data from all three consonant landmarks. Our overall conclusion here based on Figure 9 is the same as those we made earlier: there is support for backing and *raising* in the case of velarized consonants, rather than backing and lowering.

Based on a different ultrasound study (though one focused mainly on Russian vowels), Cavar & Lulich (2021) argue that the palatalization contrast is based on the feature [ATR], with palatalized and non-palatalized consonants being [+ATR] and [-ATR] respectively. As we have argued here, we do not think that non-palatalized consonants can be [-ATR] if this implies active tongue root retraction, since those consonants generally have a high tongue body. We have argued instead that they are [+high,+back]. Cavar & Lulich's 2021 strongest argument for [ATR] based on their articulatory study is that their tongue root measurements are less variable than their tongue dorsum mea-

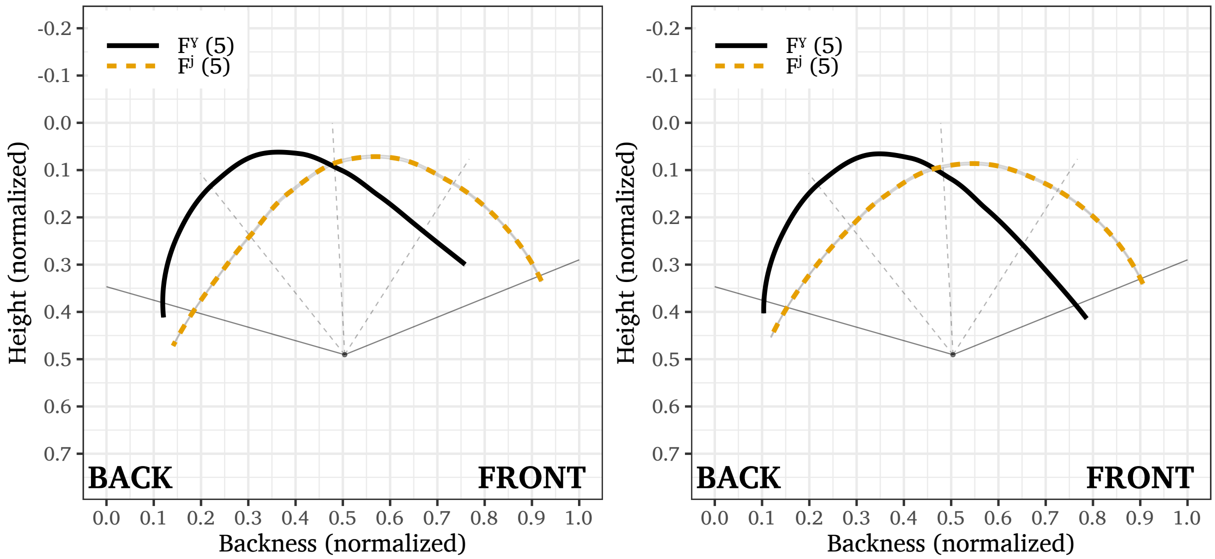


Figure 7: Velarization (solid line) and palatalization (dashed) of [f] at consonantal offset before [i] ('ы', left) and [u] (right), Speaker 1.

surements, implying more stable articulatory targets corresponding to the palatalized and non-palatalized categories (p.35). However, Cavar & Lulich find a slightly better *separation* of categories (effect size) based on tongue *dorsum* measurements compared with tongue root measurements, and a priori this seems just as reasonable an indicator of what's important. Since there are other interpretations of the variability finding, and since Cavar & Lulich (2021) were in any case examining vowels in the context of palatalized and velarized consonants, rather than observing the consonants directly, we don't find their results to be inconsistent with our own conclusions.[11]

Our results should be qualified in a couple of ways. First, not all velarized consonants have equally high tongue bodies in Russian. For example, it can be seen in Figure 8 that the tongue body is a bit lower in [s$^{\gamma}$] than in [f$^{\gamma}$] or [x$^{\gamma}$]. This difference is more pronounced in the case of the stops, as shown in Figure 10. It is expected that [k$^{\gamma}$] would have the highest tongue body, since the tongue body is achieving not just velarization but velar place closure for this sound. But velarization of [t$^{\gamma}$] is weaker in terms of height than that of [p$^{\gamma}$]/[b$^{\gamma}$]. These differences hold for Speakers 2 and 3 as well. It is interesting that Bennett et al. (2018) also find weaker velarization of coronals in Irish; similar results have been reported for Russian using ultrasound, EMA, and MRI imaging (see e.g. Kochetov 2002, 2009; Litvin 2014; Kedrova et al. 2008; Biteeva 2021 and references there).

Second, the tongue body of velarized consonants is overall not as high for Russian Speaker 3 compared to Speakers 1 and 2, at least in comparison with that speaker's palatalized consonants. Figure 11 shows this for palatalized and velarized [p]/[b] (compare Figure 6 showing Speaker 1); the velarized tongue body is similarly less high for all

[11] Assuming that the finding that the tongue root is somewhat less subject to variability holds up, it could for example be due to purely physiological considerations; perhaps the tongue root is more constrained overall in its motion than is the tongue body, as suggested in e.g. Gick et al. (2012, pp.178-9).

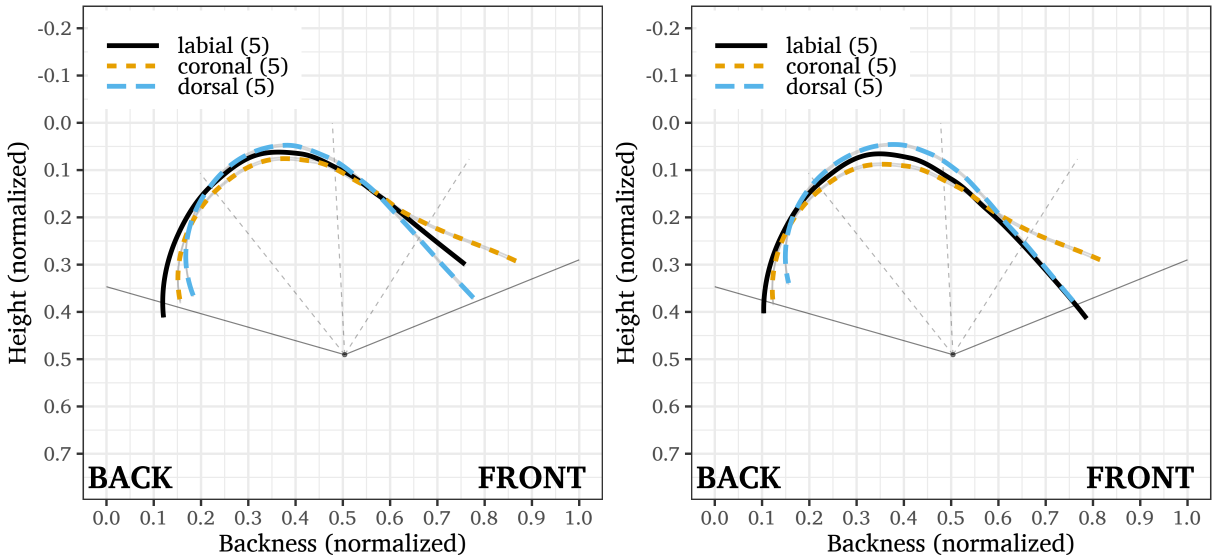


Figure 8: Velarization of [f] (solid), [s] (short dash) and [x] (long dash) at consonantal offset before [i] ('ы', left) and [u] (right), Speaker 1.

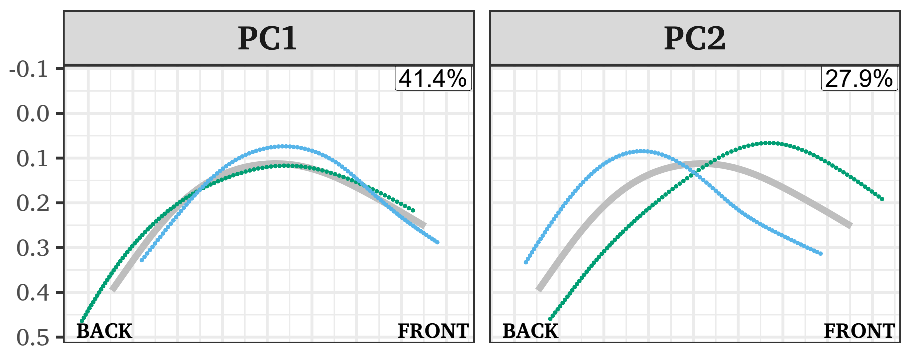


Figure 9: First two principal components derived from Russian ultrasound data, including only frames from consonant offset. Front of tongue is to the right.

of this speaker's consonants.

It is possible that Speaker 3's consonants could be described as uvularized instead of velarized. In fact, others have claimed that non-palatalized consonants in Russian can be uvularized instead of velarized. Litvin (2014) makes this claim, and her results suggest that this depends on the consonant, while Roon & Whalen (2019), making the same claim, suggest that it is more likely speaker-dependent. Our results discussed above arguably support both claims. If Russian consonants can sometimes be uvularized, what does this mean for our own arguments above? We cannot do justice to this complex topic here, but some remarks are called for.

On the one hand, uvulars commonly cause vowels to lower, and they have often been treated as [-high] (e.g. Chomsky & Halle, 1968). What's more, uvulars are known to pattern with pharyngeal (and sometimes laryngeal) consonants in a range of languages and to cause tongue root retraction as well as lowering in vowels, leading researchers to

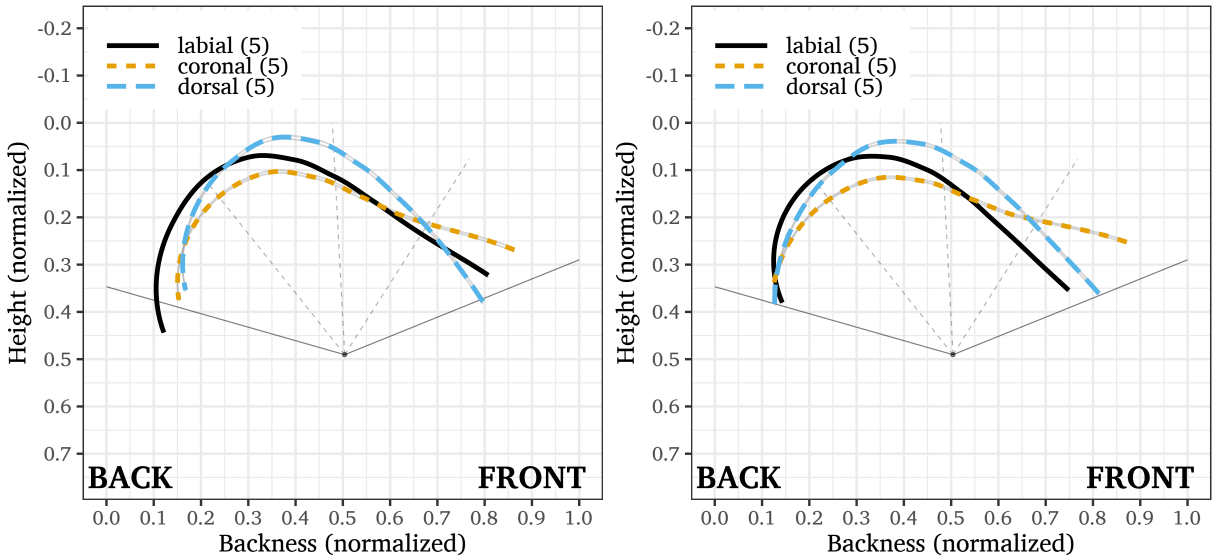


Figure 10: Velarization of [b] (solid), [t] (short dash) and [k] (long dash) at consonantal offset before [i] ('ы', left) and [u] (right), Speaker 1.

posit that they are specified [pharyngeal], [RTR] (retracted tongue root) or the like, as well as being [dorsal] (Elorrieta, 1992; Bessell, 1992; McCarthy, 1994; Rose, 1996). On the other hand, even if uvulars in some languages have [pharyngeal] or [RTR] specifications, it does not follow that all uvulars, or secondary uvularization in Russian, have such properties. Furthermore, even if uvulars are lower (as well as further back) than velars, they are nevertheless often described as having a tongue body that is *raised from a neutral position*, just as with velars (see discussion in Ghazeli, 1977; McCarthy, 1994; Litvin, 2014; Sylak-Glassman, 2014). In terms of the Laryngeal Articulator Model discussed in the last section, such a raising and backing gesture is consistent with activity of the styloglossus muscle group and does not in itself suggest pharyngeal activity. Therefore, while Subject 3's data does not obviously support our claim that non-palatalized consonants in Russian have high tongue bodies that are inconsistent with pharyngealization or [-ATR], it also does not militate against this claim. Meanwhile, the data of Subjects 1 and 2 provide positive evidence for this claim.

A reviewer points out that the head-stabilization system used in the current study does not fully eliminate movement along the sagittal plane of the ultrasound probe during recording (Scobbie et al., 2008). The reviewer specifically notes that tongue root advancement during palatalized consonants might have the effect of pushing the probe slightly forward. In this scenario, the probe would move forward at the same time that the tongue root and body move forward. As the reviewer notes, this would lead to *under*-estimation of the amount of tongue body fronting associated with palatalization. As a consequence, our estimates of tongue body fronting for palatalized consonants might be overly conservative. If true, this only strengthens our case that tongue body fronting and backing are the primary articulatory correlates of palatalization and velarization in our Russian data.

Finally, we should be cautious in drawing conclusions based on three speakers. How-

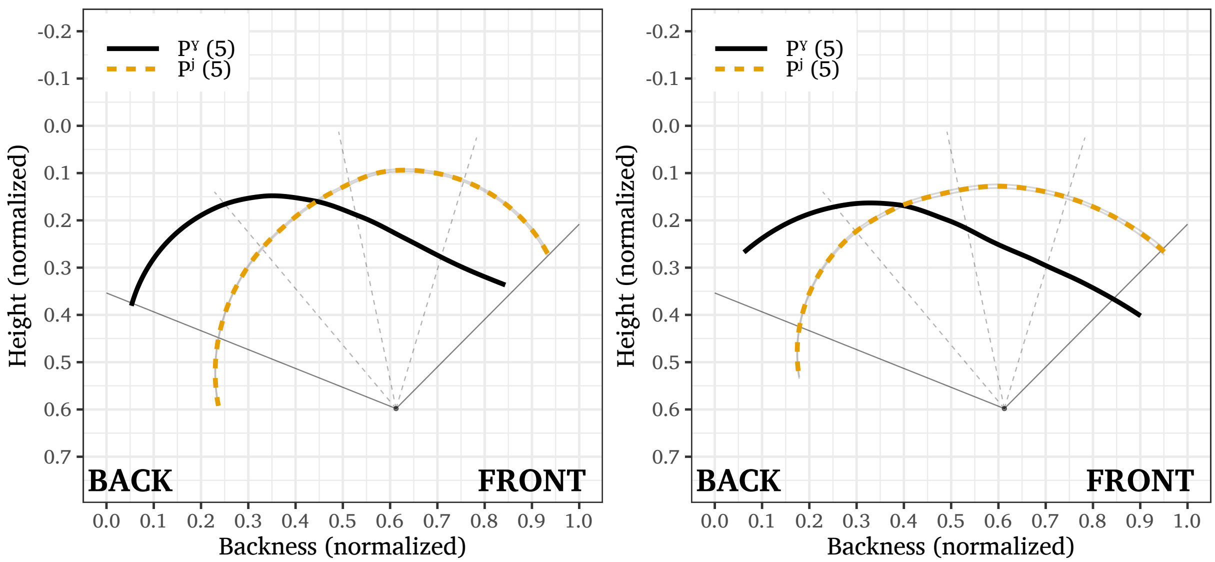


Figure 11: Velarization (solid line) and palatalization (dashed) of [p]/[b] at consonantal offset before [i] (‘ы’, left) and [u] (right), Speaker 3.

ever, our finding that non-palatalized consonants are velarized–in particular, at least in many cases [+high] as well as [+back]–is consistent with findings of other recent articulatory studies (see discussion in section 3). Litvin (2014) especially argues explicitly that Russian non-palatalized consonants have raised tongue bodies and cannot be pharyngealized.

# 5 Russian consonant-vowel interactions

Russian is rich with consonant-vowel (C-V) interactions, and we might look to these to further understand the nature of the palatalization contrast. If the contrast involves the tongue body features [back] and [high], we should expect to see evidence that these features are active in C-V interactions; if instead the contrast is based on active pharyngealization or [ATR], we should expect to see evidence of *those* properties in C-V interactions.

Cavar & Lulich (2021) argues that the Russian palatalization contrast is based on the feature [ATR] (advanced tongue root), with palatalized consonants (henceforth ‘$C^j$’) being [+ATR] and velarized consonants (henceforth ‘$C^{\gamma}$’) being [-ATR]. We will refer to this as ‘the [ATR] hypothesis’. According to this hypothesis, Russian C-V interactions can be better understood as involving [ATR], and relying for example on [back] is actually disadvantageous to understanding those interactions. The evidence involves stressed vowel allophony.

Russian stressed vowels change quality depending on the surrounding consonants. For example, /e/ is realized as [ɛ] in the context $C^{\gamma}$__$C^{\gamma}$, e.g. [ʂˠɛstˠ] ‘pole’, but is higher and fronter in the context $C^j$__$C^j$, e.g. [t͡ʃʲestʲ] ‘honor’ (examples from Yanushevskaya & Bunčić (2015)). This does resemble a change in [ATR] values; however, it could equally be seen as coarticulation with palatalization, which involves a raised and fronted tongue body. As we will see, effects on the other stressed vowels /i,a,o,u/ clearly implicate the tongue body rather than [ATR].

## 5.1 Back vowel fronting and the [ATR] hypothesis

The back vowels /a,o,u/ are fronted between palatalized consonants (Avanesov, 1972; Hamilton, 1980; Timberlake, 2004; Yanushevskaya & Bunčić, 2015). Compare the examples on the left and right in Table 3.[12]

| | | | | | |
|---|---|---|---|---|---|
| тут | tˠutˠ | 'here' | чуть | t͡ʃʲu̟tʲ | 'a little' |
| тот | tˠotˠ | 'that (m.sg.)' | тётя | tʲo̟tʲə | 'aunt' |
| мат | mˠatˠ | 'crumpled' | мять | mʲætʲ | 'to crumple' |

Table 3: Back vowel fronting between palatalized consonants

It is unclear whether this process should be understood as phonetic or phonological. On the one hand, careful sources (e.g. Avanesov, 1972; Yanushevskaya & Bunčić, 2015) describe a process that sounds gradient: the initial portion of a back vowel is fronted after $C^j$ when no $C^j$ follows, the final portion is fronted before $C^j$ when no $C^j$ precedes, and the entire vowel is fronted between two $C^j$*s*. This description suggests a coarticulatory phonetic process. On the other hand, the fronting between two $C^j$*s* can seem categorical and is often transcribed with unambiguously [-back] [y,ø,æ]. For the sake of discussion we assume a phonological process conditioned by the two-sided environment $C^j\_\_C^j$, but the points made in this section hold whether we assume assimilation or coarticulation.

In line with the [ATR] hypothesis, Cavar & Lulich (2021) argues that [+ATR] and not [-back] is the feature value that assimilates in this process. That paper acknowledges (pp.33-4) that a [-back] spreading analysis is consistent with its ultrasound data, but suggests several reasons to prefer the [ATR] analysis. Space does not allow us to address all of the arguments in detail, but the principal one comes from phonological patterning: if [back] were spreading from consonants to vowels, we would predict not only that /a,o,u/ front around $C^j$ but that /i,e/ back around $C^{\gamma}$. However, this is a straw man, since no one claims that consonants spread [+back] to /e/. (On /i/, see the next section.) Rather, phonologists simply posit a rule of [-back] assimilation affecting /a,o,u/. (See references above.)

Cavar & Lulich (2021) describes the output of this process as [a̟,ɵ,ʉ] and therefore seems to agree that /a,o,u/ are primarily *fronting*. This might seem reasonable, since tongue root advancement generally leads to tongue body fronting (see discussion in section 3). The problem is that, when we examine languages that are *known* to have an [ATR] contrast, such as those of Sub-Saharan Africa, we find that [ʉ,ɵ,a̟] are really improbable outcomes of assimilation to [+ATR]. Sources very consistently find the most robust acoustic correlate of [ATR] to be the first vowel formant, which correlates with perceived height, not backness (see Casali, 2008; Rose, 2018, for an overview). This is why a typical vowel system with an [ATR] contrast looks something like that shown in

[12] Fronted /o,u/ are variously described as front [y,ø] or centralized [ʉ,ɵ]. Our transcriptions follow Yanushevskaya & Bunčić (2015) and are meant to be agnostic about this.

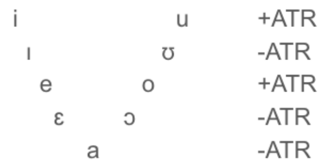


Figure 12: A typical 9-vowel ATR system.

Figure 12, assuming for discussion a common nine-vowel inventory (where [ɪ,ʊ,ɛ,ɔ] are the [-ATR] counterparts of [i,u,e,o] respectively).

It is true that [ATR] can affect the second vowel formant, which correlates with perceived backness; but across [ATR] languages, effects on F2 are much less robust and reliable than those on F1. When there are systematic effects on F2/backness, [-ATR] vowels are typically a bit more centralized than their [+ATR] counterparts, as shown in Figure 12 (see Starwalt, 2008, in addition to the references above). In the case of the back vowels, this is the *opposite* of what happens in Russian. The Russian [ATR] hypothesis proposes that back vowels centralize when [+ATR]. While one *can* find examples like this in the literature on [ATR], they are far from the norm.[13]

Across [ATR] languages, the low vowel phoneme usually lacks any [+ATR] counterpart, as shown in Figure 12. When such a counterpart does exist, it is normally *higher* in the vowel space than /a/ (often transcribed as [ə] or [ʌ], see references above), not fronter, as proposed by the ATR hypothesis for Russian.

The most robust acoustic correlate of the palatalization contrast in Russian is the second vowel formant (Jakobson et al., 1952; Bondarko & Zinder, 1966; Purcell, 1979); effects on F1 are secondary. This fact strongly suggests that the contrast is primarily one of the tongue body, not the tongue root.

## 5.2 The vowel /i/ and the [ATR] hypothesis

The Russian [ATR] hypothesis assumes that all consonants specified for [ATR] spread [ATR] to a neighboring vowel. Turning to the phoneme /i/, this means that this vowel is [+ATR] in the context of $C^j$ and [-ATR] in the context of $C^{ɣ}$. Therefore, in place of the familiar allophonic rule /i/ → [+back] / [C, +back] ___ we have /i/ → [-ATR] / [C, -ATR]___. Though Cavar & Lulich (2021) transcribes the output of this rule as [ɨ], that paper's ultrasound analysis finds this vowel to be front, as we have argued here. This provides Cavar & Lulich (2021) with an argument for [ATR] spreading: if '[ɨ]' is [-back], then it cannot be derived by spreading of [+back].

Our own analysis, discussed in section 2, is that '[ɨ]' is simply [i] after a velarized consonant, and there is no allophonic rule at all. While Cavar & Lulich (2021) assumes that all vowels, including front vowels, are subject to spreading from consonants, we don't assume this for /i/, and as noted in the previous subsection, generally no one else claims this for /e/.

[13]For example, a few languages in Starwalt (2008) have an [u] that is fronter than [ʊ], though in all of them [o] is further back than [ɔ]. See Ladefoged & Maddieson (1996) as well.

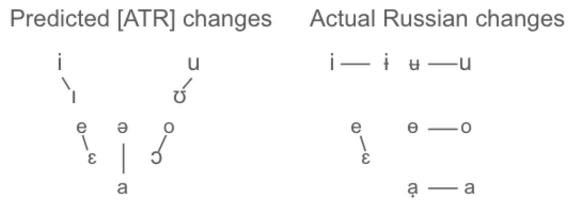


Figure 13: Russian vowel changes predicted by [ATR] (left) vs. [back] (right) analyses.

If Russian 'ы' really were the product of [-ATR] assimilation, it would be an odd one. Across scores of languages known to have an [ATR] contrast, the front, high and [-ATR] vowel is transcribed as [ɪ]. (See again Figure 12.) Yet Russian 'ы' doesn't resemble [ɪ]; it is better (though not ideally) captured by the usual transcription [ɨ]. In section 2 we argued that it is actually [ˠi]; the symbol ' [ɨ]' is a reasonable transcription under degrees of reduction or phonetic undershoot. The actual [ˠi] nature of 'ы' seems even less compatible with a [-ATR] specification than [ɨ] does.[14]

Summing up the discussion of Russian and [ATR]: if [ATR] were actually spreading from Russian consonants to vowels, then we should expect outcomes like those shown on the left in Figure 13. But Russian is much more accurately described by the changes on the right of Figure 13. Only the effects on /e/ could plausibly be attributed to the feature [ATR], though they are equally well understood as involving coarticulation with the tongue body features of Russian consonants. As mentioned earlier in this section, the precise changes affecting Russian vowels are complex and depend on whether a $C^j$ precedes, follows, both, or neither (and likewise for a $C^ɣ$). These effects may be phonetic or phonological, depending on the context. For the sake of discussion the 'actual Russian changes' depicted here assume the environments $C^j$__$C^j$ versus $C^ɣ$__$C^ɣ$ for maximal clarity of effect.

## 5.3 Other C-V interactions

Apart from stressed vowel allophony, there are other kinds of consonant-vowel interaction in Russian that might cast some light on the nature of the palatalization contrast.

First, Russian consonants affect vowels in unstressed syllables too (see for example Halle, 1959; Avanesov, 1972; Lightner, 1972; Bondarko, 1998). Most notably, /e,a,o/ raise and front in unstressed positions when following a palatalized consonant. Examples are given in Table 4, where the forms on the right are adjectives derived from those on the left. The vowels /i,u/ retain their quality when unstressed (a-b), while /e,a,o/ are described as merging with /i/ (c-e).[15]

Generative analyses of this process rely on the manipulation of the features [back] and [high] or their equivalent (e.g. Padgett, 2004; Iosad, 2012). For example, Iosad (2012) treats it as spreading of a VPlace [coronal] feature, which is an analog of [back] in unified

[14]Things may be different in the related languages Ukrainian and Polish, where the vowel in question does seem to be something like [ɪ] (Holden & Nearey, 1986; Pompino-Marschall et al., 2016; Lulich et al., 2017).

[15]These transcriptions are fairly broad. For example, the vowel fronting described earlier is not transcribed, and unstressed /i/ is more like [ɪ] in this context.

| | | | | | | |
|---|---|---|---|---|---|---|
| a. | вид | vʲitˠ | ‘species’ | видовой | vʲidˠɐˈvoj | (adj.) |
| b. | ключ | klʲut͡ʃʲ | ‘key’ | ключевой | klʲut͡ʃʲiˈvoj | (adj.) |
| c. | дело | ˈdʲelˠə | ‘business’ | деловой | dʲilɐˈvoj | (adj.) |
| d. | слёз | slʲosˠ | ‘tears (gen.pl.)’ | слезоточивый | slʲizətɐˈt͡ʃʲivˠij | ‘tear (gas) (adj.)’ |
| e. | ряд | rʲatˠ | ‘row, series’ | рядовой | rʲidɐˈvoj | ‘ordinary’ |

Table 4: Underlying /i,e,a,o/ realized as [i] in unstressed syllables when following $C^j$

feature theory (Clements & Hume, 1995), and a concomitant change in vowel height. It might be possible to construct an analysis of these facts by means of [+ATR] instead, but it would not be straightforward. The common understanding of this feature would imply the outputs [e,ə,o] for /e,a,o/; even assuming Cavar & Lulich’s 2021 interpretation of [+ATR] for Russian, the implied output is [e,a̟,ɵ] rather than [i].[16]

Second is a sound change that occurred in the history of Russian: the vowel /e/ backed to [o] following a palatalized consonant, unless another palatalized consonant followed. This has led to alternations such as *печь* [pʲet͡ʃʲ] ‘to bake’ vs. *пёк* [pʲokˠ] ‘he baked’.[17] This can be plausibly analyzed as a dissimilation in the feature [back] between /e/ and a preceding $C^j$ (along with an assumption that a back non-low vowel in Russian must be round). But dissimilation in [+ATR] would predict the incorrect output [ɛ].

Finally, it is worth mentioning the *process* of secondary palatalization itself. As is well known, there are morphological contexts in which a front vowel in Russian causes a preceding consonant to acquire secondary palatalization, as shown in Table 5. Examples (a) and (b) show palatalization triggered by /e/ when it is the dative singular or prepositional singular ending (resp.). Those in (c) and (d) show palatalization by /i/ in the case of a verbalizing suffix /-i-/ and diminutive suffix /-ikˠ/ (resp.).

| | | | | | | |
|---|---|---|---|---|---|---|
| a. | гроза | grˠɐˈzˠa | ‘storm (nom.)’ | грозе | grˠɐˈzʲe | ‘storm (dat.)’ |
| b. | вода | vˠɐˈdˠa | ‘water (nom.)’ | воде | vˠɐˈdʲe | ‘water (prep.)’ |
| c. | ход | xˠotˠ | ‘motion’ | ходить | xˠɐˈdʲitʲ | ‘to walk’ |
| d. | пёс | pʲosˠ | ‘dog’ | пёсик | ˈpʲosʲikˠ | ‘dog (dim.)’ |

Table 5: Palatalization before front vowels

Processes of secondary palatalization are widely attested, and they are generally triggered by vowels or glides that are [-back] (see Bateman, 2007, 2011, for an overview and references). This fact suggests that palatalization itself is defined (at least in part) as [-back], assuming we are dealing with a kind of assimilation. That is how the Russian facts are often analyzed. Yet according to the [ATR] hypothesis it must be *[+ATR]* that is spreading from vowel to consonant. Such an assumption poses a problem for the

[16] Padgett & Tabain (2005) find that this process is not actually neutralizing, though see Iosad (2012) for a counterargument. If this process is due to coarticulation rather than phonological assimilation, our argument carries over. Coarticulation of [e,a,o] with tongue root advancement does not plausibly lead all of these vowels to sound like [i].

[17] Subsequent changes led to the generalization becoming opacified in contemporary Russian.

[ATR] hypothesis not already discussed: if secondary palatalization could really be defined as [+ATR], then we would predict examples of secondary palatalization triggered by [+ATR] vowels–whether front or *back*–and this should happen not only in Russian but in other, uncontroversially [ATR] languages. We are unaware of any any evidence supporting such a prediction.

Throughout section 5 on consonant-vowel interactions we have focused on the claim that Russian palatalization is implemented by means of the feature [ATR]. We have not, for example, compared the Russian facts to those of languages known to employ active pharyngealization of consonants, as in Arabic dialects. However, this comparison would lead to similar conclusions to those seen above, and for similar reasons. Pharyngealized consonants–as well as uvulars in some cases, see discussion in section 4–tend to cause backing and *lowering* of neighboring vowels (see discussion in Al-Tamimi, 2017). There is no evidence from Russian phonetics or phonology that non-palatalized consonants have a lowering effect on vowels. The only fact we know of that bears on this question is the behavior of unstressed /e/ after non-palatalized consonants. In that context, /e/ *raises* to [i], e.g., ***цех*** [t͡sˠexˠ] '(factory) shop' vs. ***цеховой*** [t͡sˠixˠəˈvˠoj] '(factory) shop (adj.)'. This fact rather supports an understanding of Russian non-palatalized consonants as velarized, having raised tongue bodies.

# 6 Conclusion

The possibility that the Russian palatalization contrast is one of pharyngealization or [ATR] should be explored, since the contrast involves systematic changes in tongue root position and pharyngeal cavity volume. However, we cannot conclude based on these changes alone that the contrast depends on *active* engagement of the tongue root, i.e., engagement of the laryngeal (aryepiglottic) constrictor mechanism. (See references and discussion in section 3.) We have argued here, based on an ultrasound study, the phonetics and phonology of Russian consonant-vowel interactions, and a typological understanding of [ATR] and pharyngealization, that the facts of Russian do not actually support an active role for pharyngealization or [ATR]. Instead, all facts point to active engagement of the tongue body or dorsum, implicating features like [back] and [high].

Having said this, more research needs to be done, particularly on the articulatory bases of pharyngealization and [ATR], and on the articulatory facts around the Russian tongue root.

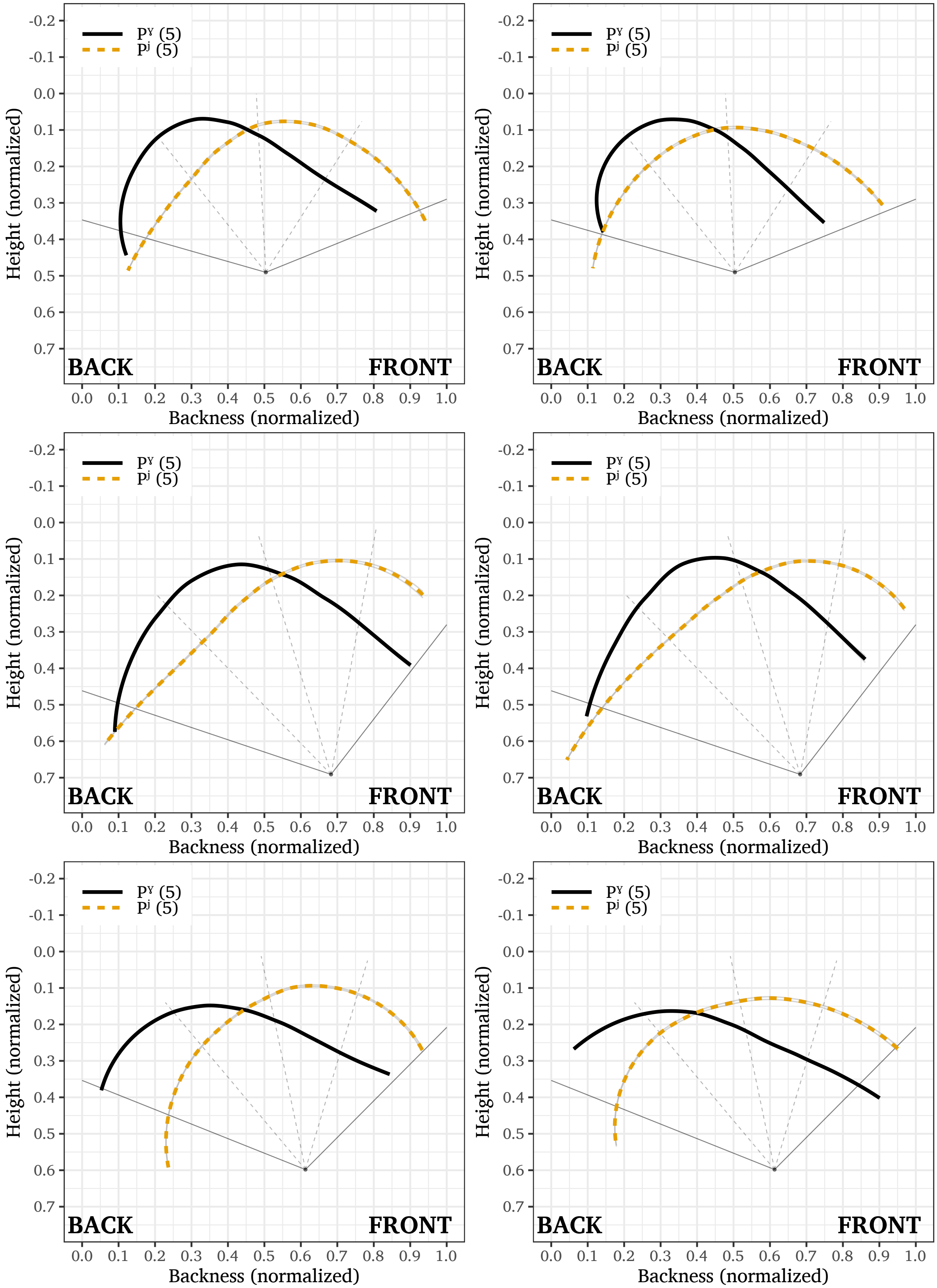


Figure 14: Velarization (solid line) and palatalization (dashed) of [p]/[b] at consonantal offset before [i] ('ы', left) and [u] (right). Speaker 1-3, from top to bottom row.

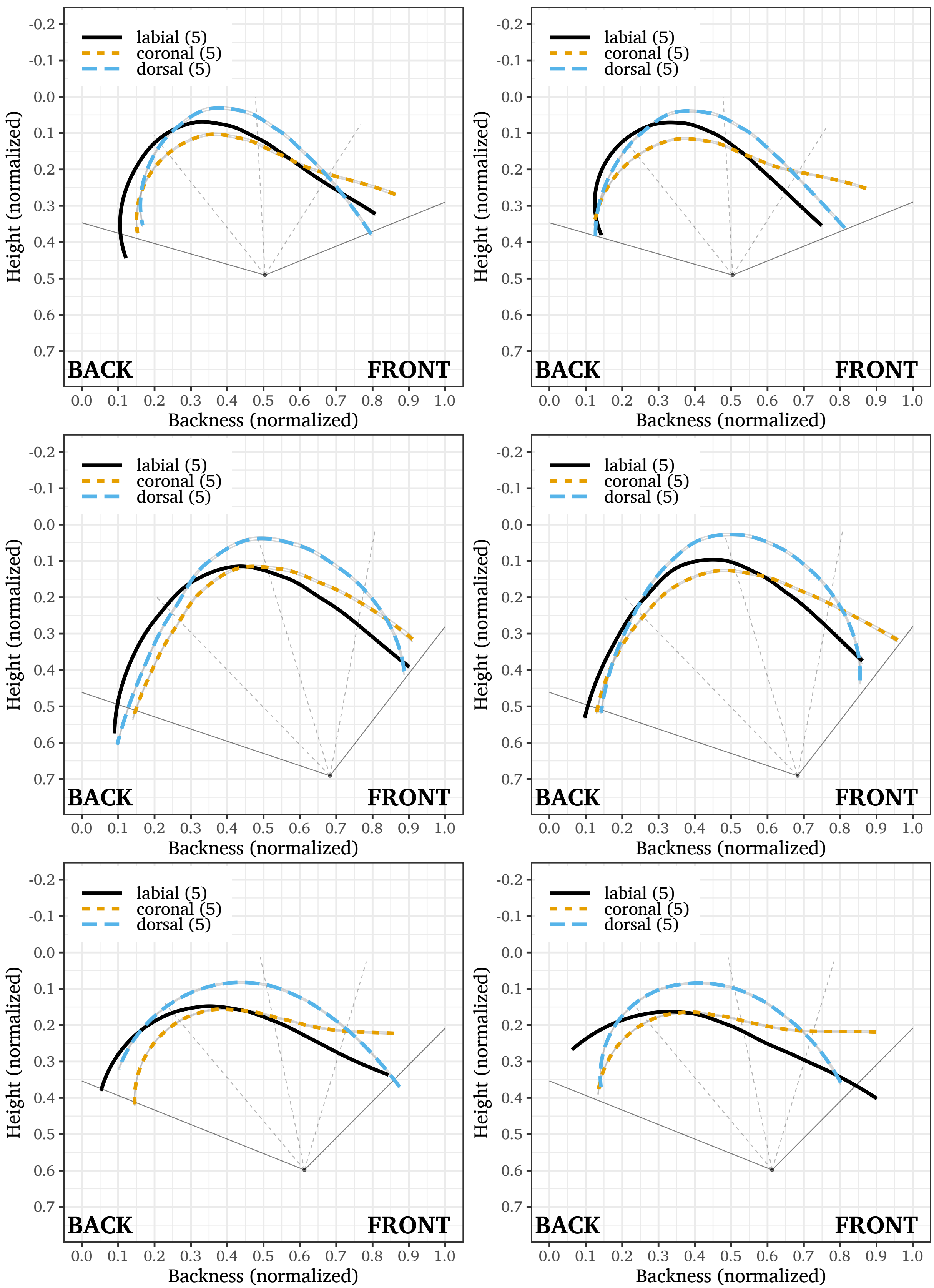


Figure 15: Velarization of [p]/[b] (solid), [t] (short dash) and [k] (long dash) at consonantal offset before [i] ('ы', left) and [u] (right). Speaker 1-3, from top to bottom row.

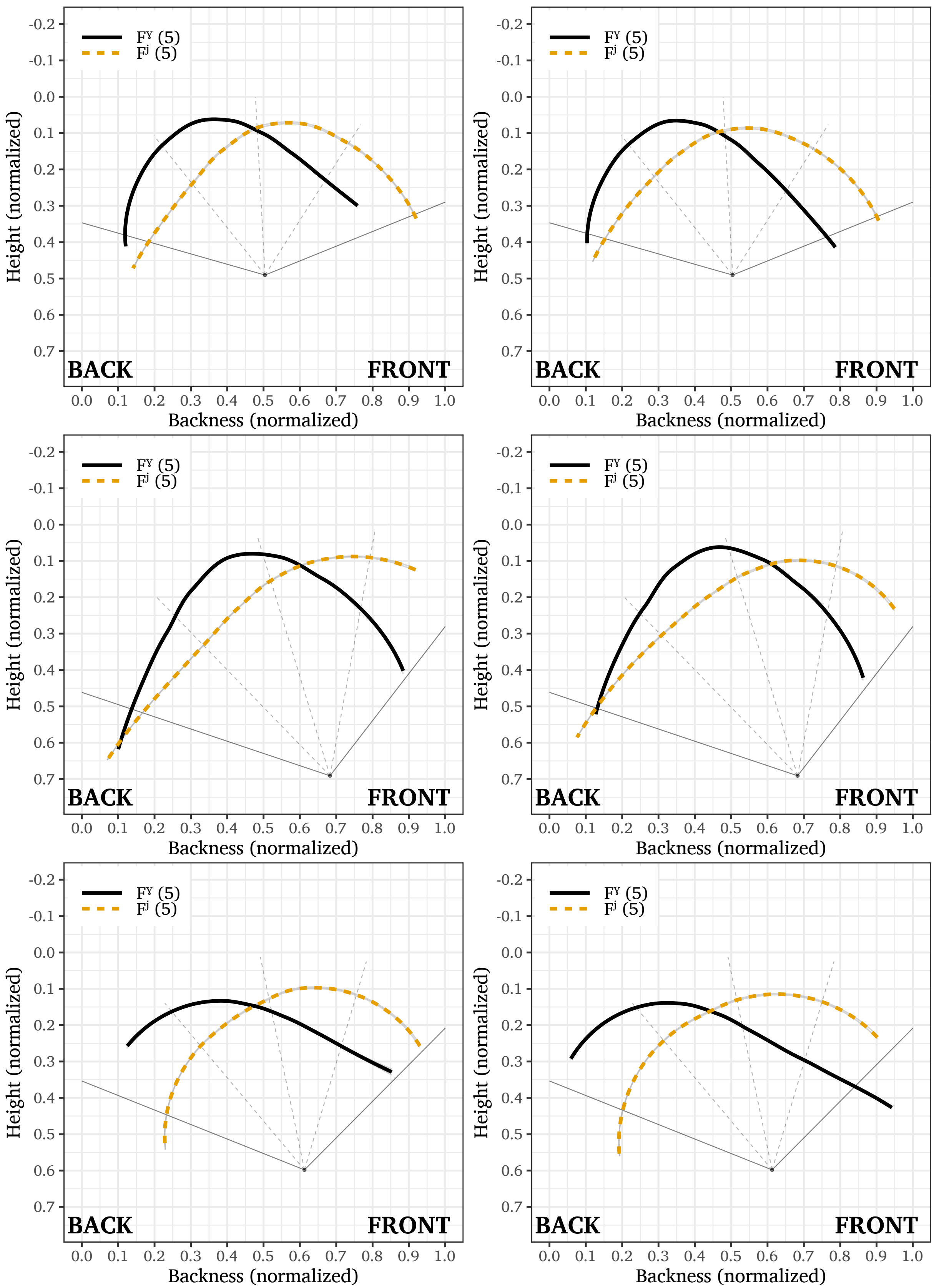


Figure 16: Velarization (solid line) and palatalization (dashed) of [f] at consonantal offset before [i] ('ы', left) and [u] (right). Speaker 1-3, from top to bottom row.

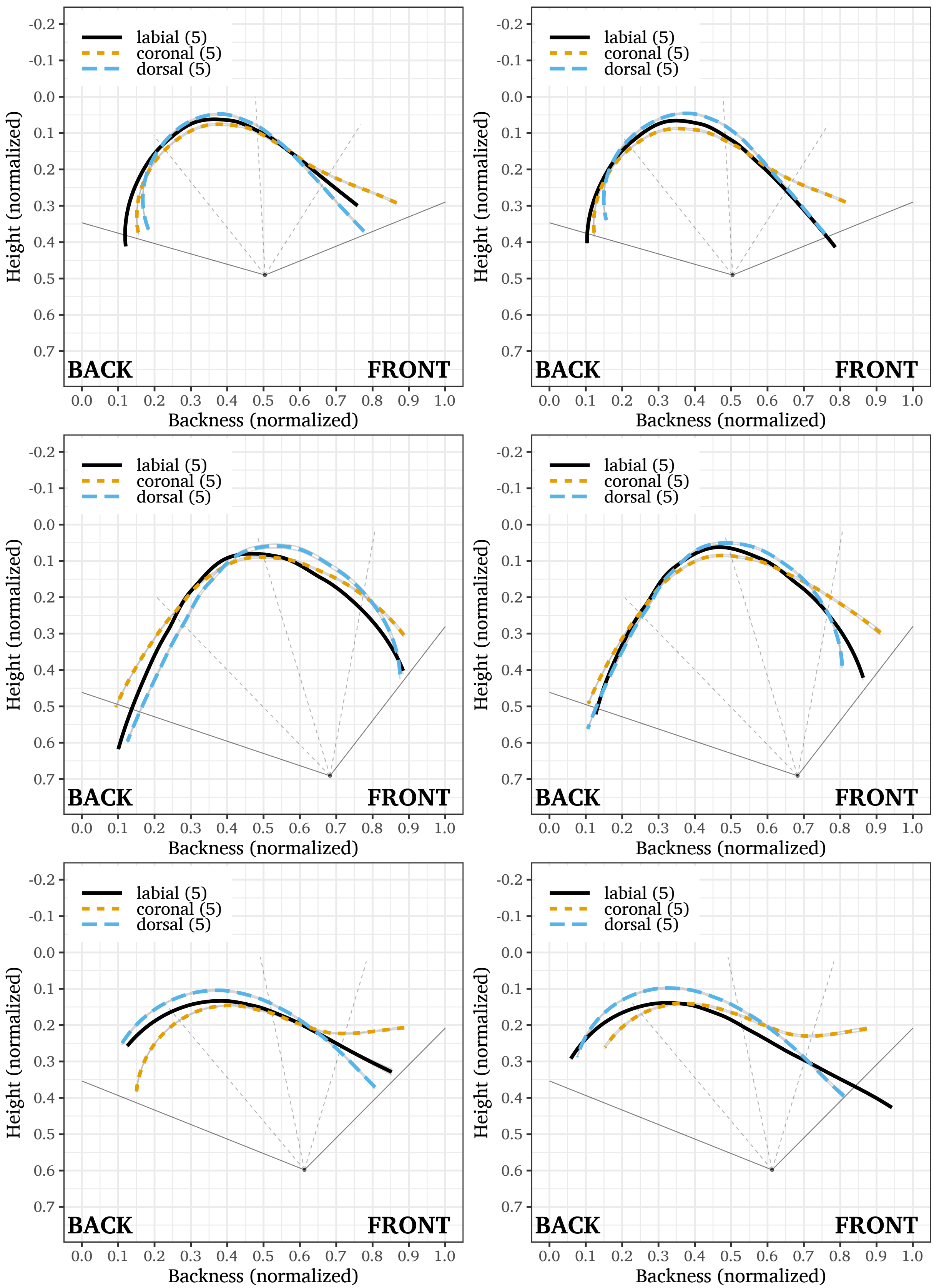


Figure 17: Velarization of [f] (solid), [s] (short dash) and [x] (long dash) at consonantal offset before [i] ('ы', left) and [u] (right). Speaker 1-3, from top to bottom row.

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