Trills and Palatalization: Consequences for Sound Change

Darya Kavitskaya, Yale University
Khalil Iskarous, Haskins Laboratories
Aude Noiray, Haskins Laboratories
Michael Proctor, Yale University & Haskins Laboratories

1. Introduction

It has been long noticed that it is difficult to maintain both trilling and palatalization (Brok 1910, Shevelov 1979, Ladefoged & Maddieson 1996, Kavitskaya 1997, among others). Various suggestions as to why this should be the case have been made in the literature. The general idea present in most accounts is that trilling and palatalization involve different constraints that make conflicting demands and are thus incompatible. For instance, Ladefoged & Maddieson 1996 claim that the raising of the blade and front of the tongue required for palatalization interferes with the aerodynamic conditions necessary for trilling. However, no phonetic studies have been attempted to clarify the exact nature of the incompatibility between trilling and palatalization.

We propose that conflicting physical constraints on the tongue dorsum can be held responsible for the sound changes that involve depalatalization of Proto-Slavic palatalized trilled /r^j/. We show that palatalization, trilling, and different phonological environments impose conflicting demands on the dorsum, resulting in a physical instability that has phonological consequences.

2. Depalatalization of the trill in modern Slavic languages

Slavic languages provide a rich test case for the study of the depalatalization of the trill. The palatalization of the Proto-Slavic trilled /r^j/ is affected to a different degree in almost all Slavic languages. Table 1 shows the reflexes of the plain and palatalized trill in modern Slavic (see also Kavitskaya 1997).

Proto-Slavic		**r^j**	**r**
East Slavic	Russian	+	[r]
	Belarusian	–	[r]
	Ukrainian	±	[r]
West Slavic	Polish	[ʒ]	[r]
	Czech	[r̝]	[r]
	Slovak	–	[r]
	Upper Sorbian	±	[r] or [ʀ]
	Lower Sorbian	+	[r] or [ʀ]
South Slavic	Slovenian	[rj]	[r]
	Serbian	–	[r]
	Croatian	–	[r]
	Macedonian	–	[r]
	Bulgarian	±	[r]

Palatalization
+ still present in all environments
– entirely lost
± partially lost

Table 1. Reflexes of the Proto-Slavic trill (adapted from Carlton 1991)

While /r/ is preserved in all Slavic languages, /r^j/ is retained in only a few of them. Table 1 demonstrates that the palatalized trill is either completely lost, as in Belarusian (East Slavic), Polish, Czech, and Slovak (West Slavic), and Serbian, Croatian and Macedonian (South Slavic), partially lost, as in Ukrainian (East Slavic), Upper Sorbian (West Slavic), and Bulgarian (South Slavic), or fully preserved, as in Russian (East Slavic) and Lower Sorbian (West Slavic). Note that it is evident from Table 1 that the depalatalization of the trill occurred independently in different Slavic languages and is not a proto-Slavic sound change.

Belarusian provides an example of a language in which /r^j/ underwent depalatalization in most dialects. The sound change happened in the period from the 12^{th} to the 14^{th} century. However, the /r/-/r^j/

opposition was subsequently restored in some areas because of the Russian influence (Wexler 1977). The data in (1) show that the nature of the /r^{j}/ in Belarusian is indeed restorative since it is not attested in the words like ‘glad’ and ‘crawfish’ in either pre-Belarusian or modern Russian cognates.

(1)	Belarusian	pre-Belarusian	Russian	
	r^{j}at	radʊ	rad	‘glad’
	r^{j}ak	rakʊ	rak	‘crawfish’

Partial depalatalization is exemplified by the dialects of Ukrainian. While in the Carpathian region the original distribution of /r/ and /r^{j}/ is preserved, palatalization is completely lost in the areas from Volhynia to Podolia in the 15th century. However, there are intermediate dialects where palatalization of a trill is lost only partially, depending on the environment. For instance, in the Lvov area, there are dialects where /r^{j}/ is lost everywhere except before /i/, everywhere except before /a/, only syllable-finally, and only in unstressed syllables. The palatalization loss can be dated around the end of the 16th century. In Standard Ukrainian, /r^{j}/ is limited to the prevocalic position (Shevelov 1979).

In West Slavic, specifically in Czech and Polish, the palatalization of the trill was resolved through fricativization. In Czech, /r^{j}/ underwent spirantization, becoming a trilled fricative, as in (2). The change was completed around the 13th century.

(2) Spirantization of palatalized trill in Czech: *r^{j} > r̝

The examples in (3) show reflexes of the palatalized trill in modern Czech with the corresponding Russian cognates.

(3)	Czech	Russian	
	[r̝at]	[r^{j}at]	‘row’
	[r̝eka]	[r^{j}eka]	‘river’
	[par̝it]	[par^{j}it]	‘steams’

In Polish, the sound change went one step further, resulting in the detrillization of the trilled fricative (Stieber 1973), as in (4). This change is also dated around the 13th century.

(4) Detrillization of trilled fricatives in Polish: r̝ > ʒ

In summary, Proto-Slavic /r^j/ has a diverse set of reflexes in modern Slavic languages. That is, these languages seem to be sensitive to some incompatibility between the component features of /r^j/. Palatalization does not seem to freely combine with trills, in the same way that it combines with stops, nasals, or fricatives. It is possible that the diversity of reflexes of /r^j/ is simply an accident of Slavic diachrony. However, that is not likely due to the historical independence of the development of different reflexes in different Slavic languages, as shown in Table 1.

3. Phonetic study

3.1. Hypothesis: physical conflict between palatalization and trilling

The hypothesis we pursue is that there is *physical* conflict between trilling and palatalization, culminating in an instability of the segment /r^j/. This instability is then resolved in different ways by the various Slavic languages discussed earlier. The hypothesis of physical incompatibility, as opposed to accidental incompatibility, is supported by similar difficulties that other languages encounter in combining various rhotics with palatal articulations. Hamann (2003) shows that retroflexion and palatalization are cross-linguistically incompatible, and that previously cited counter-examples of palatalized retroflexes in Toda and Kashmiri are not phonetically realized as palatalized retroflexes. She argues that for both languages, what is sometimes transcribed as a retroflex with a secondary palatalization is really a sequence of a rhotic and a palatal. In a study of alveolar taps and trills in Catalan, Recasens (1991) showed that trills have greater coarticulatory resistance to /i/ than do taps, suggesting an incompatibility between the palatal articulation of /i/ and trilling. Moreover, Hall (2000) has shown through a study of secondary palatalization of various apical rhotics that there is a general ban on palatalized apical rhotics. His data come from a wide variety of language families. There is, therefore, cross-linguistic evidence for the instability of palatalized rhotics.

Russian is a language that is reported to have preserved the palatalized trill /rʲ/, unlike most other Slavic languages. Therefore, Russian provides an excellent test-bed for seeing how potential conflicts are resolved. We have conducted an acoustic and an articulatory study to investigate the phonetic realization of /rʲ/ in Russian. The acoustic study focused on the frequency of vibration in /rʲ/ vs. /r/, since that is one of the most distinguishing features of trills (Lindau 1985). If palatalized trills in Russian are truly trilled, we would expect similar frequencies of vibration for /r/ and /rʲ/. The articulatory study focused on the involvement of the dorsum of the tongue in the articulation of trills, as compared to other alveolar segments. The dorsum is important, since if it is retracted in trills, such retraction would be incompatible with palatalization, which requires dorsum fronting. In addition, the tongue back and dorsum have been shown to retract for other rhotics, like retroflex and bunched articulations in American English (Delattre and Freeman 1968), and has been argued to underlie the incompatibility of retroflexes and palatalization (Hamann 2003).

Even though several studies have discussed the interaction of rhotics and palatalization, and some have implicated the tongue dorsum as the cite of interaction, we do not know of articulatory or acoustic studies that focus on this issue. The current contribution, through an acoustic and articulatory analysis, aims to investigate the interaction of trilling and palatalization through physical conflicts on the configuration of the tongue dorsum.

3.2. Methods and results

Data were collected from 5 native speakers of Russian (4 Female, 1 Male). The Haskins Digital Ultrasound System (Noiray et al. 2008) was used to image the tongue at 127 Hz. Acoustic data was simultaneously collected and synchronized with the tongue motion data. One and two syllable words were recorded, with /r/, /rʲ/, /t/, /tʲ/, /s/, /sʲ/, /l/, and /lʲ/ in the following environments: word-initial, word-medial, and word-final, flanked by the vowels /a/, /e/, /u/, /i-ɨ/. Four repetitions were collected from each speaker. A total of 384 tokens were recorded. Example words for /r-r^j/ pairs with the vowel /a/ are given in (5).

(5) a. Word-initial

rat	'glad'	r^jat	'row'

b. Word-medial

paˈrat	'parade'	paˈr^jat	'soar-3PL'

c. Word-final

par	'steam'	par^j	'steam-IMP'

Since the focus of the acoustic study is on the difference in frequency of vibration between /r/ and /r^j/, only the data for those two consonants are included. Figure 1 shows spectrograms of the male Russian speaker's pronunciation of the words [rat] 'glad' and [r^jat] 'row'.

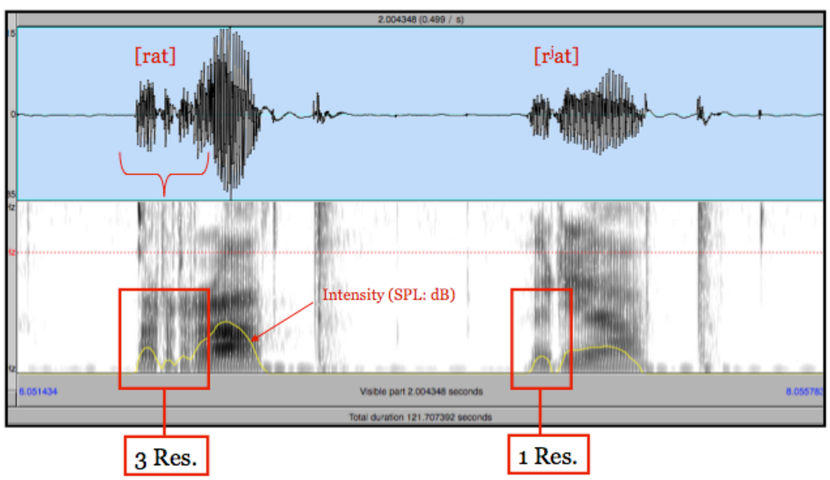

Figure 1. Spectrograms of the words [rat] 'glad' and [r^jat] 'row'

A trill contains portions where the vocal tract is briefly closed (tap like articulations) interspersed with portions where vocal tract resonances can be seen, which will here be called "resonants." As can be seen in the Figure, [r] contains 3 resonant portions, whereas [r^j] contains only one. The same pattern is seen throughout the rest of the data. Figure 2 shows a bar plot of the mean and standard deviations of the number of resonant portions in the two rhotics across different environments.

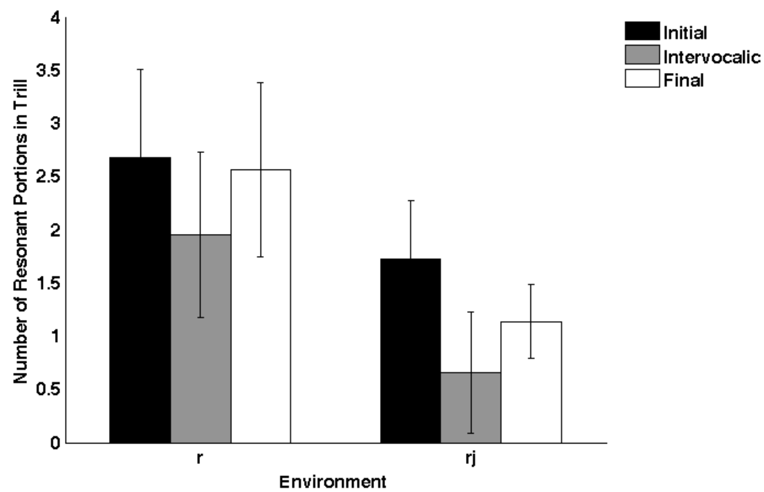

Figure 2. The number of resonant portions in /r/ and /r^j/ as a function of environment (word-initial, intervocalic, word-final)

For /r/, the mean number of resonant portions are 2.68 (0.82), 1.95 (0.77), 2.56 (0.81) in initial, intervocalic, and final positions, respectively. For /r^j/ the means and standard deviations are 1.7 (0.54), 0.65 (0.56), and 1.13 (0.34). As can be seen from the descriptive statistics, /r^j/ always has, on average, fewer resonant portions than /r/. Moreover, intervocalic position exhibits fewer resonant portions than initial and final position, for both categories. A repeated measures ANOVA revealed that /r/ has significantly more resonant portions than /r^j/ ($p < .001$, $F(1,262) = 168.35$). Environment (Initial vs. Intervocalic vs. Final) also had a significant effect on the number of resonant portions ($p < .001$, $F(2,261) = 21.54$), and a Tukey post hoc test confirmed that the mean for the intervocalic environment is lower than the other two.

The goal of the ultrasound study was to investigate the position of the dorsum of the tongue during the trilling and palatalization. In the first experiment, we used B-Mode ultrasound, which images the entire tongue from blade to near the hyoid at 127 Hz. After edge detection, the configuration of the tongue at the most extreme position for each vowel and consonant were found, using both the spectrogram and the ultrasound data. Figure 3 compares the position of the dorsum during /d/ before /a/, /r/ before /a/, and /r/ before /ɨ/, for two tokens of each syllable for the male subject.

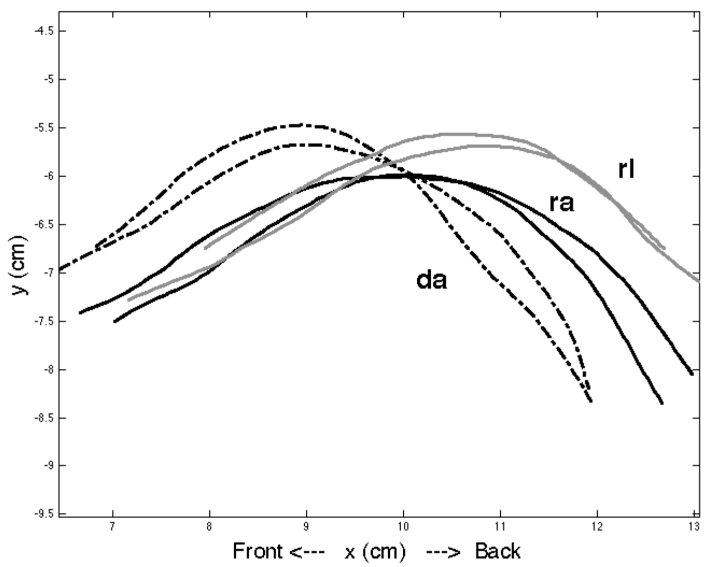

Figure 3. Comparison of tongue configurations during /r/ before /a/ and /I/ and /d/ before /a/.

As can be seen from the figure, /r/ shows a retracted dorsum. The /a/ following /d/ would be expected to apply a backward force on the dorsum during the /d/, through coarticulation, and the same coarticulatory process applies to the /r/ preceding /a/. But the dorsum retraction during /r/ is a great deal more than that during the /d/, and is unlikely to be due to coarticulation only. If the retraction of the dorsum for /r/ in /ra/ were due only to the /a/, then we would not predict that the dorsum would also be retracted for /r/ in /rɨ/, as is the case in Figure 3.

In the second experiment we used M-Mode ultrasound to investigate the changes in the vocal tract cross-section in the velar-uvular region, in

/r/ vs. /r^j/, since it is this section that is expected to exhibit the greatest difference for the non-palatalized vs. palatalized trill. In M-Mode imaging, the experimenter chooses a vocal section, and the scanner shows the change in the midsagittal distance across time in that section. Figure 4 shows what occurs in the velar-uvular region in /ara/ vs. /ar^{j}a/.

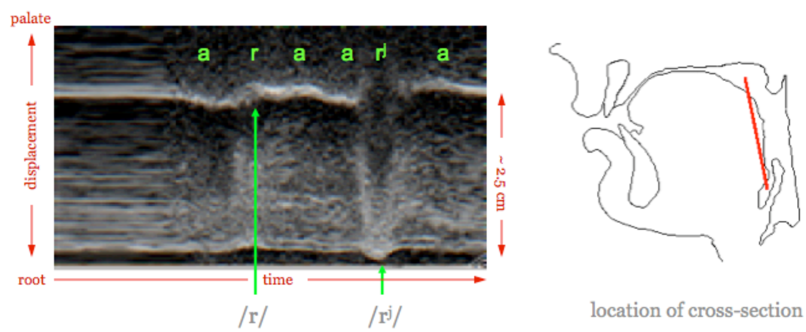

Figure 4. M-Mode comparison of the midsagittal distance function of /r/ and /r^j/ in the uvular region.

The right panel of the figure shows the cross-section selected. The upper bright white time series in the left panel shows the changes in that section, through the changes in the air layer right above the tongue (the white layer). During /ara/, the cross-sectional aperture is slightly higher during the /r/, than during the /a/. In contrast, during /r^j/, the tongue dorsum advances to such an extent that the cross sectional aperture at this location increases by almost 2.5 cm. During the /r/, the tongue is retracted, but during /r^j/, advancement of the root making the uvular region vertically continuous with the pharynx. This is an indication of the extent of the effect of palatalization on the tongue dorsum.

4. Discussion

Our interpretation of the results of the acoustic study is that the amount of trilling for a given trill is gradient, when comparing /r/ and /r^j/ in different environments. Within each environment, /r/ has a higher frequency of trill vibration than /r^j/, and for both segments, word initial and final environments exhibit a higher frequency of trill vibration than intervocalic environment. It therefore seems that there are two factors that weaken trilling, palatalization and intervocalic environment. Our claim is that conflicting demands on the tongue dorsum explain both the effect of the V_V environment and palatalization on trilling.

Even though the tongue tip is the primary articulator in the production of Russian trills, the tongue back seems to be necessarily retracted, as shown in the ultrasound data in the previous section, as well as in the Recasens (1991) study of Catalan trills. To understand the need for dorsum retraction during tongue tip trills, it is necessary to consider the physical state of the tongue tip required for the initiation of trilling. McGowan (1992) has shown through simulation that the tongue tip has to be of a very specific effective mass, so that velocity of air above the tip would allow the tip to flutter. The muscles of the tongue contract in such a way as to manage the effective mass of the tongue that will collaborate with the aerodynamic conditions required for trilling. The purpose of tongue back retraction during the tongue tip trill is to stabilize the tongue dorsum. Retraction immobilizes the dorsum, so that trilling can affect only the front portion of the tongue. If the entire tongue is mobile and has the same effective mass, a great deal of the vibration energy would be dissipated in the by the more massive dorsum, inhibiting the vibration of the tip. Immobilization through retraction renders the dorsum highly massive and incapable of flutter.

Two factors can conflict with trilling by inhibiting the retraction of the dorsum. First, palatalization requires the dorsum of the tongue to be fronted into the palatal region. Palatalization therefore weakens, and may totally inhibit, trilling due to its fronting of the tongue back. Second, vowel-to-vowel articulation in a VCV environment requires the dorsum position to be managed more by the vowels than by the intervening consonant. Öhman (1966) showed that tongue dorsum motion in VCV sequences is continuous, with the consonant acting as a perturbation on the smooth V_V motion. Perkell (1969) attributed the vowel-wave and consonant-perturbation notion to different muscular systems being active in vowel and consonant production. Since the trill does not have as much control of the tongue back in a VCV environment, as in a CV or VC environment, we would expect weaker trilling in VCV, as evident in the data in Figure 1.

As discussed earlier, /rʲ/ is a segment that has a diverse set of reflexes in the modern Slavic languages. Trilling requires the dorsum to be retracted, while palatalization requires it to fronted, and the surrounding vowel(s) pull the dorsum to their preferred position due to coarticulation. The competition between trilling, palatalization, and the surrounding vowels on the dorsum in /rʲ/ is a plausible reason for the instability of the segment in the diachronic development of Slavic, and perhaps other languages.

5. Conclusions

In this paper, we have shown that conflicting articulatory constraints on the dorsum constitute the source of the instability of palatalized /rʲ/. The instability has phonetic consequences in Russian and provides evidence for our hypothesis that this physical conflict is a part of an explanation for the depalatalization of /rʲ/ in Slavic.[1] We believe that similar reasoning explains the distribution of taps and trills in Farsi (tap intervocalically, as in [beɾid] ‘go’ vs. trill elsewhere, as in [rah] ‘road,’ [ærteʃ] ‘army,’ [qædri] ‘a little bit,’ [ʃir̥] ‘lion’).

This paper represents only the beginning of a larger research project. In the future, we plan to collect more articulatory and acoustic data on Russian which will allow us to study the dynamics of /rʲ/ in various contexts in more detail. We also plan to extend the Russian study to other modern Slavic languages that exhibit the contextual conditioning of depalatalization and study the various resolutions of the physical conflict in question. Specifically, since fricativization can be a resolution of the instability of /rʲ/, as in Czech and Polish, a separate study is called for. Finally, the future study of Slavic palatalized trills will allow us to consider implications of the proposed type of explanation in other language families e.g., Romance or Bantu, where the instability of /r/ in the environment of front vowels has been reported.

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[1] Note, however, that another part of the explanation is potentially connected to the acoustics of trills: e.g., word-final trills depalatalize in some dialects of Ukrainian since the cues for palatalization are in the following vowel. It is outside of the scope of this paper to deal with these effects.

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References

Brok, O. 1910. *Ocherk fiziologii slavianskoi riechi.* Sankt-Peterburg: Otdelenie russkago iazyka i slovesnosti Imp. Akademii nauk.

Carlton, T. R. 1991. *Introduction to the phonological history of the Slavic languages*. Slavica Publishers.

Delattre, P. and D. Freeman. 1968. A dialect study of American r's by x-ray motion picture. *Linguistics* 44: 29-68.

Hall, T. A. 2000. Typological generalizations concerning secondary palatalization. *Lingua* 110: 1-25.

Hamann, S. 2003. The phonetics and phonology of retroflexes. PhD dissertation, University of Utrecht. Utrecht: LOT.

Hardcastle, W. J. 1976. *Physiology of speech production.* Academic Press, Inc.

Kavitskaya, D. 1997. Aerodynamic constraints on the production of palatalized trills: the case of the Slavic trilled [r]. *Proceedings from the 5th European Conference on Speech Communication and Technology*. Volume 2: 751–754. University of Patras, Rhodes, Greece.

Ladefoged, P. & I. Maddieson. 1996. *Sounds of the World's Languages*. Blackwell Publishers.

Lindau, M. 1985. The story of /r/. In V. Fromkin, eds., *Phonetic linguistics: Essays in honor of Peter Ladefoged*, 157-168. New York: Academic Press.

McGowan, R. 1992. Tongue-tip trills and vocal-tract wall compliance. *The Journal of the Acoustical Society of America* 91(5): 2903-2910.

Maddieson, I. 1989. Aerodynamic constraints on sound change: The case of bilabial trills. *UCLA Working Papers in Phonetics* 72:91-115.

Noiray, A., Iskarous, K. and D. H. Whalen. 2008. Digital acquisition of ultrasound imaging of the tongue. *The Journal of the Acoustical Society of America* 123: 3885.

Öhman, S.E.G. 1967. Numerical model of co-articulation. *The Journal of the Acoustical Society of America* 41: 310-320.

Perkell, J. 1969. *Physiology of Speech Production: Results and Implications of a Quantitative Cineradiographic Study*. Research Monograph 53. The MIT Press, Cambridge, MA.

Recasens, D. 1991. On the production characteristics of apicoalveolar taps and trills. *Journal of Phonetics* 19: 267-280.

Shevelov, G. 1979. *A Historical Phonology of the Ukrainian Language*. Heidelberg: Carl Winter.

Stieber, Z. 1973. *A Historical Phonology of the Polish Language*. Heidelberg: Carl Winter.

Stone, M. 1990. A three-dimensional model of tongue movement based on ultrasound and x-ray microbeam data. *The Journal of the Acoustical Society of America* 87: 2207-2217.

Tucker, A.N. 1929. *The comparative phonetics of the Suto-Chuana group of Bantu languages*. University of London.

Wexler, P. 1977. *A historical phonology of the Belorussian language*. Heidelberg, C. Winter.