AERODYNAMIC CONSTRAINTS ON THE PRODUCTION OF PALATALIZED TRILLS: THE CASE OF THE SLAVIC TRILLED [R]

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ABSTRACT

Production of a trill depends on several articulatory and aerodynamic constraints. These constraints can be held responsible for various sound changes in Slavic languages which all involve depalatalization or frication of Proto-Slavic palatalized trilled r. As soon as a trill is affected by palatalization, the aerodynamic conditions are changed and the possibility of trill production lowers. Small deviations in aperture size and air velocity can lead to a failure of a trill. This paper proposes a phonetic explanation for the depalatalization and/or frication of the Proto-Slavic palatalized trilled r by considering the detrimental effects of articulatory and aerodynamic constraints on the production of a palatalized trill.

1. INTRODUCTION

It is known that it is difficult to maintain both trilling and palatalization simultaneously because of articulatory and aerodynamic constraints. The raising of the blade and front of the tongue required for palatalization may make it more difficult to maintain the aerodynamic conditions necessary for trilling (Ladefoged & Maddieson 1996).

This observation can be used to explain one of the sound changes which happened in almost all of the Slavic languages. Proto-Slavic palatalized trilled r underwent depalatalization and, in some cases, spirantization. Peculiar articulatory properties of palatalized trills were noticed and commented on by a number of researchers, but, as far as I know, there was no attempt to integrate the available information and explain the sound change pattern of depalatalization and/or frication of the Proto-Slavic trilled r in various Slavic languages by considering detrimental effects of articulatory and aerodynamic constraints on the production of a palatalized trill.

2. SOUND CHANGE

The Proto-Slavic palatalized r (which we assume to be trilled) underwent various sound changes in Slavic languages. These changes can be different outcomes of solving the same articulatory/aerodynamic problem.

The palatalized trilled *r*:

(1) depalatalizes (in almost all of the Slavic languages at some point, except Russian and Sorbian);

(2) undergoes spirantization (becomes a trilled fricative in Czech and a fricative in Polish).

The following table shows the reflexes of Proto-Slavic palatalized r in various Slavic languages (adopted from Carlton 1991):

Proto-Slavic	[r ^j]	
Russian	+	
Belorussian	-	
Ukrainian	±	
Polish	[3]	
Czech	[<u>r</u>]	
Slovak	-	
Upper Lusatian	±	
Lower Lusatian	+	
Slovenian/Slovene	[rj]	
Serbo-Croatian	-	
Macedonian	-	
Bulgarian	±	

+ still present in all environments

- former palatalization is entirely lost

± former palatalization is partially lost

The sound change which involves depalatalization and frication of the palatalized trilled r in Slavic languages can be accounted for using a fairly simple phonetic explanation. The proposed explanation attempts to show that the trilled r disfavors palatalization due to aerodynamic constraints on the production of trills. Such 'distaste' for palatalization is manifested in various Slavic languages by the different degrees of sound change. The least possible degree can be noticed in Russian, where a full opposition between palatalized and non-palatalized r is preserved. The difference between the production of these two sounds is manifested word-initially: the nonpalatalized r at the beginning of a word is always trilled and usually consists of two taps in normal speech and up to 4 or 5 taps in hyper articulated speech, while the palatalized r in the same environments regularly has only one full tap. The following spectrogram (Figure 1) exemplifies this phenomenon, showing words [rat] 'glad' and [r^jat] 'row' pronounced by a female speaker of Russian (note the three-tap trill in the first word which starts with a non-palatalized [r] as opposed to a single full

tap at the beginning of the second word which starts with a palatalized $[r^{j}]$).



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

So, Russian seems to have a very rudimentary indication of the change which did not proceed any further. The furthest degree of the sound change is the complete merger of $[r^j]$ with fricatives $[\int]$ and [3] as in Polish (which preserves the non-palatalized trill). The same aerodynamic and articulatory constraints on the production of palatalized $[r^j]$ can lead to detrillization (tongue blade is too massive for vibration) or spirantization (raising of tongue blade changes the aperture and increases the turbulence of the air flow which makes frication noise).

The palatalized trill becomes a tap in languages where it is preserved, such as in Modern Russian, Bulgarian, and Ukrainian. In Ukrainian and Bulgarian, the palatalized trill underwent depalatalization at various points in history, but its palatalization was partially restored; Modern Ukrainian and Bulgarian have the palatalized $[r^j]$, except when a trill is followed by front vowels. Depalatalization of $[r^j]$ in the environment of front vowels in Slavic languages seems to be due to entirely different reasons which won't be considered in this paper.

Shevelov (1979) describes depalatalization of $[r^{j}]$, which occurred in the period from the 10th to the 13th century in all the Slavic languages, except Russian, Sorbian, and partly Ukrainian (in some dialects), as 'caused primarily the complicated articulation of that consonant, in conjunction with a relatively limited functional load this sound had outside of several specific morphological categories.' The first part of this explanation treats the r^{j} >r sound change as conditioned by articulatory constraints on palatalization and trilling (Shevelov is one of a few authors who consider the loss of the palatalized trill in Slavic to be related to phonetic phenomena, even though he does not explain what he means by the 'basic trilling articulation', and there is a substantial disagreement in the literature on this question), but the second part of the explanation adds some pragmatic implications to the articulatory constraints which are unlikely to interact. The notion of 'relatively limited functional load' of a sound seems to be very relative in nature and thus lacking substance.

Ukrainian r lost its palatalization in several dialects in Polissian area by or in the 11th century, and several centuries later, in Volhynia and in the Lvov region of West Ukraine. Later the palatalization in Ukrainian was partially restored through the contact with Russian (Shevelov 1979).

In Belorussian, Slovak, Serbo-Croatian and Macedonian, palatalization of *r* was altogether lost in most of the dialects. Pre-Belorussian *r* underwent depalatalization in most dialects in the period form the 12th to the 14th century, but the r-r^j opposition was subsequently restored in some areas because of the Russian influence. The secondary character of the restoration of $[r^j]$ in North East dialect of Belorussian is obvious from the instances of hyper correct replacement: e.g. $[r^jat]$ "glad" (< pre-Belorussian [radu], Modern Russian [rad]), $[r^jak]$ "crawfish" (< pre-Belorussian [raku], Modern Russian [rak]) (Wexler 1977)

In Czech, the depalatalization of $[r^j]$ happened through spirantization. The palatalized $[r^j]$ first changed to palatalized trilled fricative[r], which later lost its palatalization. This change was completed in Czech around the 13th century:

Czech	Russian	
[rat]	[r ^j at]	"row"
[reka]	[r ^j eka]	"river"
[parit]	[par ^j it]	"steams"

The only regularly occurring trill we know of that is made with the blade of the tongue is [r] in Modern Czech. This trill is typically made with the laminal surface of the tongue against the alveolar ridge (Ladefoged & Maddieson 1996). Short (1987) describes this sound as 'a rolled post-alveolar fricative (never the sequence of [r] plus [3] attempted by non-Czechs)'. Ladefoged & Maddieson (1996) agree with Short's description, although they say that they would rather use the term 'trilled' because the term 'rolled' is unclear. They maintain the Short is 'also correct in noting that the frication is not of 3 type', but in their observation 'this sound is usually a sequential combination of a trill and a fricative. The frication has a distinctive whistle-type of relatively narrow-band noise. It is often partially voiceless.'

It can be argued that aerodynamic constraints discussed above are responsible for the sound change in Czech. First, physiologically articulation of a trill can be claimed to be similar to that of a fricative than to a tap or a flap articulation. 'The degree of controlled muscular contraction, i.e. the degree of interaction between protagonist and antagonist muscles necessary for trills is similar to that used by fricatives' (Hardcastle 1976). This claim partially justifies the proposed explanation of sound change in Czech on physiological grounds. Second, while trilled r is palatalized, the tongue tip is lowered and the air flows through the aperture which is very similar to the one required for fricative articulation. Third, palatalization tends to add frication component to palatalized consonants, to which there are various examples of sound changes.

In Polish, the change of $[r^j]$ to [r] went further, and the complete sound change looks like $r^{j} > r > 3/\int$. The change from $[r^{j}]$ to [r] in all environments (preserved until now in Czech) is dated to about the 13th century, although it may have taken a longer time to be accomplished. This particular sound change in Polish went from the palatalized Common Slavic [r^j] through a trilled fricative [r] as in Czech to a full-fledged fricatives [3] or $[\int]$. An initial stage of the coalescence of [r] with [3] and [[]]seems to have left traces in Polish as early as the late 14th century (Stiebner 1973) even though [r] fully changed into [3] and $[\int]$ in the eighteenth century. The sound change in question took a different possible direction in Polish than in, for example, Belorussian, where trilled $[r^{j}]$ depalatalized because of aerodynamic constraints on the cooccurrence of trilling and palatalization. In Polish, palatalized [r^j] first underwent spirantization because of the high turbulence noise caused by the changes of aperture due to palatalization, and then it becomes 'detrilled' as in Russian because the tongue blade is too massive to vibrate.

3. PRODUCTION OF TRILLS

3.1 Articulatory properties of trills

There is a considerable disagreement in the literature about the nature of the trilled r in general and the detrillization of the palatalized r. Articulatory descriptions of the Russian r differ to the extent that there is still no firm agreement between Russian scholars if the palatalized r should be considered as coronal. Many researchers comment of the detrillization of the trilled r, but they do not necessarily attribute it to the detrimental effect of palatalization.

The fact that the palatalized r is prone to detrillization was first noticed by Brok (1910). According to Brok's description, the raising of the tongue blade towards the hard palate, which is requires for the palatalization of r, results in the forward movement of the tongue tip. This movement changes the place of articulation: the palatalized trill stops being coronal. When r is palatalized, the sides of the tongue are touching larger area of the upper gums than during the production of the nonpalatalized r. The vibrating part of the tongue tip gets smaller and touches approximately the lower part of the upper incisors' gum. Brok claims that all these articulatory changes make it harder to produce clear taps, which accounts for the fact that $[r^j]$ is 'always ready' to depalatalize.

Bolla (1981) describes both palatalized and nonpalatalized r as rolled, alveolar, apical, coronal, apicoalveolar sounds. According to Bolla, the noise component of the non-palatalized [r] is produced by 1-2 taps in wordinitial and intervocalic positions and about 3-4 taps elsewhere, and the noise component of its palatalized counterpart is always produced by about 3-4 taps of the tongue tip, overlooking completely the effects of palatalization on trilling which can be clearly seen in our data. Most of the literature also disagrees with the Bolla's description. Matusevich (1976) mentions that the number of taps in Russian r can be different depending on its position in a word: it has one or two taps at the beginning of a word before a consonant or a vowel (as in [rat] 'glad', [rd^jet^j] 'redden') or after a consonant (as in [pravo] 'right'), only one tap intervocalically (as in [para] 'couple'), and only at the end of a word it has 3-4 taps, the last one or to of which are usually devoiced (as in [par] 'steam'). However, Matusevich maintains that the palatalized and non-palatalized r have the same number of taps in all the environments, which is not what we see in our data.

3.2 Aerodynamic properties of trills

Now we need to consider aerodynamic properties of trills. The primary characteristic of a trill which can be called 'an aerodynamic phenomenon' (Maddieson 1989) is the vibration of one speech organ against another, driven by aerodynamic conditions. The tongue tip is placed close enough to hard palate, so that when a current of air of the right strength passes through the aperture created by this configuration, the channel opens and closes repeatedly, producing a trill. When the tongue tip reaches the closed position, Bernoulli force sucks the mobile tongue tip towards the hard palate, then a back pressure develops and forces the structures apart, and then the cycle repeats itself. According to Ladefoged & Maddieson (1996), in its essentials, the trill 'is very similar to the vibration of the vocal folds during voicing; in both cases there is no muscular action that controls each single vibration, but a sufficiently narrow aperture must be created and an adequate airflow through the aperture must occur. The aperture size and airflow must fall within critical limits for trilling to occur, and quite small deviations mean that it will fail. So with trills, as with voicing, there is a potential conflict between an acoustic definition (more than one period of actual vibration) and articulatory definition (positioning of the articulators in a configuration such

that, given the right aerodynamic conditions, vibration would occur)'. It is also important to note that a trill is not just a series of taps in a row: trills are quite different from taps in the respect that tongue body is subject to a higher degree of constraint during the production of trill that of tap (Recasens 1991).

Figure 2 shows that the oral pressure is in the same range for both non-palatalized and palatalized trills which provides additional support for the claim that the change of the place of articulation is of the direct importance to the loss of palatalization.



Figure 2. Oral pressure during utterances [rat] and [r^jat].

3.3 Consequences of articulatory and aerodynamic constraints on the production of trills

Despite all the differences in regards to the topic of the articulation of r, most of the researchers agree that the place of articulation of the palatalized $[r^j]$ is changed in comparison to the non-palatalized [r].as can be clearly seen from the following palatograms (Figure 3).



Figure 3. Palatograms showing tongue-palate contact during the production of the syllables [re] (left) and $[r^{j}e]$ (right).

Palatalization seems to result in the very tip of the tongue and the blade acting more or less like a single solid mass. This reduction of the degree of freedom of the tongue increases the effective mass and resistance of the tongue tip region, while reducing fine control of tension (McGowan 1992). All these factors would have a detrimental effect on trills. According to our data, all trills in Russian become taps intervocalically, and only palatalized trills undergo 'detrillization' word-initially, which provides evidence in support of the claim that palatalized trills are more inclined to undergo 'detrillization' as they have more constraints on their production.

4. CONCLUSION

I have proposed a phonetic explanation of sound changes which involved disfavor of palatalized trills in Slavic languages. As soon as trills are affected by palatalization which results in the forward movement of the tongue tip and the raising of the tongue body, it becomes much more difficult to maintain the aerodynamic conditions necessary for trilling.

The proposed solution which explains disfavoring of palatalized trill in Slavic can also help us understand the processes of depalatalization or 'detrillization' of trills in some non-Slavic languages, for example, voiced alveolar trill [r] is reduced to a flap before [i] in SePedi, SeSuto, and SeChuana of the Suto-Chuana group of Bantu languages (Tucker 1929).

5. REFEFENCES

[1] Bolla, K. 1981. *A conspectus of Russian speech sounds*. Slavistische Forschungen; Bd. 32

[2] Brok, O. 1910. *Ocherk fiziologii slavianskoi rechi*. Enciklopedia Slavianskoi filologii.

[3] Cartlon, T. R. 1991. Introduction to the phonological history of the Slavic languages. Slavica Publishers.

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

[5] Kolesov, V. V. 1980. Istoricheskaia fonetika russkogo iazyka. Moskva.

[6] Kucera, H. 1961. *The phonology of Czech*. Slavistic printings and reprintings. XXX.

[7] Ladefoged, P. & I. Maddieson. 1996. *Sounds of the World's languages*. 2nd edition.

[8] McGowan, R. 1992. *Tongue-tip trills and vocaltract wall compliance*. Journal of Acoustical Society of America. 91(5):2903-2910.

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

[10] Matusevich, M. I. 1976. Sovremennyi russkii iazyk. Fonetika. Moskva.

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

[12] Shevelov, G. Y. 1979. *A historical phonology of the Ukrainian language*. Historical phonology of the Slavic languages; 4.

[13] Stieber, Z. 1973. *A historical phonology of the Polish language*. Historical phonology of the Slavic languages; 5.

[14] Tucker, A.N. 1929. The comparative phonetics of the Suto-Chuana group of Bantu languages. London.

[15] Wexler, P. 1977. *A historical phonology of the Belorussian language*. Historical phonology of the Slavic languages; 3.