SOUND CHANGE AND THE STRUCTURE OF SYNCHRONIC VARIABILITY: PHONETIC AND PHONOLOGICAL FACTORS IN SLAVIC PALATALIZATION

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This article investigates the development of the palatalization contrast in Slavic from diachronic, synchronic, and phonetic perspectives. The diachrony of this contrast is an important test case for theories of the actuation of sound change, since the Slavic language family shows an impressive diversity in the realization of the original contrast, with Russian, for instance, preserving the contrast, Slovak maintaining it only for some consonants, and Slovenian showing complete merger. A diachronic study of the contrast reveals a generalization about which consonant pairs are more or less likely to undergo merger, and an acoustic-phonetic study of Russian points to the aspects of synchronic phonetic variability that correlate with merger. We then use the methods of the acoustic theory of speech production and synchronic phonology to further understand the development of the sound change. The results and interpretation point to a tight interplay between phonetics and phonology in the realization of the change.

Keywords: Slavic, Russian, palatalization, sound change, interspeaker variability

1. INTRODUCTION. The debate over the relationship between synchronic grammars and change, termed the STRUCTURE-HISTORY ANTINOMY by Weinreich and colleagues (1968), has been a central issue in the study of sound systems and their change from the time of the Neogrammarians till today (Blevins 2007, de Lacy & Kingston 2013). Weinreich and colleagues attributed the antinomy to two related ideas deeply rooted in structuralist phonology (Lehmann 1968). First is the view that a theory of synchronic phonology is possible only if variation and heterogeneity within a community are ignored or relegated to simultaneous static idiolects. The second issue was the identification of diachronic explanation with phonetic explanation, which was seen to be doubly problematic for historical linguistics in Weinreich et al. 1968 because the notion of grammar was excluded from this field and because phonetic explanation could not determine why the same sound would not have the same history in whichever language it occurred in, if similar systems were present. The problem of how to relate structure and history is indeed a difficult one, and it is well attested in other scientific fields that need to combine systemic structure and variation, such as biology (Gould 2002).

Weinreich and colleagues attempted to resolve this debate by positing the new idea of ORDERLY HETEROGENEITY, a concept that combines the main concerns of synchronic and diachronic phonology, at the center of a theory of sound change. The term attempts to diffuse the tension between the idea of an ordered structure and variation in all of its types. They then outlined a program for such a theory, defining the notion of orderly heterogeneity as coexistence and interaction between structure and variation, and posing several problems that such a theory must be able to solve. Crucially, the problems are formulated in such a way that they do not assume an opposition between pattern and variation, or between the phonetic substance of the change and the social and linguistic contexts of the change, since it is the opposition of these notions to each other in structuralist theory that lies at the basis of the structure-history antinomy. The theory of sound change delimited by these questions, as Weinreich and colleagues carefully

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pointed out, would of course not attempt to predict the next state of a language from the current state, but rather the theory would investigate the constraints on change and how and why change is carried out. Indeed, their first problem is the constraints on change imposed by phonetic, linguistic, and social factors. The solution to this problem, they felt, would help answer three subsidiary questions: (i) embedding: how the sound change is embedded within linguistic and social contexts; (ii) transition: how to relate successive states of a language that differ from each other continuously; and (iii) evaluation: how sound change is subjectively carried out in individual speakers-listeners. Weinreich and colleagues felt that answering all of these questions would allow one to approach the most fundamental problem of all, ACTUATION: how all of the factors—phonetic, phonological, and social—coalesce to explain why a certain change occurs in one time and place, but not in other times and places, when seemingly similar conditions hold; that is, what the possible directions of change are given the linguistic state. The solution to this problem that takes seriously phonological, phonetic, historical, and social dimensions of change would potentially overcome the two fundamental ideas at the basis of the antinomy.

These problems, formulated at the inception of the program, are still mostly unsolved. We believe that this is due largely to the complexity of human language as a biological and historical cultural form. Another, more subjective, reason for why this program has been difficult to carry through is its breadth of approach: it not only necessitates the investigation of sound patterns from phonetic, phonological, historical, and social viewpoints, but as a prerequisite to understanding a particular pattern of change, it also requires the study of cases in which the sounds are stable and nonchanging. That is, the program is against both disciplinarian isolation (investigating one aspect and not the others, for example, phonetic but not phonological or social) and linguistic isolation (investigating one language in which a sound changes, and ignoring others in which no change occurs under similar circumstances).

In this work, we investigate the development of contrastive palatalization in twelve Slavic languages from several points of view: diachronic phonology, acoustic and articulatory phonetics, and theoretical phonology. The palatalization contrast, which was present in an earlier form of all these languages for most consonants, is now present for some consonants in some languages, but absent to different degrees in other languages. Therefore, this is the exact type of situation that will enable us to investigate why the same sound in an early form of a language changes in one daughter language, but stays the same in another. By studying this change from several different methodological angles, we aim to show, in the spirit of the Weinreich et al. 1968 program, that phonetic and phonological factors in the change cohere in a far more fundamental way than is usually appreciated. Indeed, we argue that phonetics and phonology cooperate, each stabilizing the other. Admittedly, this article does not delve into the social/cultural/contact aspects of the actuation and evaluation of sound change, aspects that are difficult to investigate for already-completed changes but that need to be investigated for a full understanding of the sound change. However, by approaching the diachrony of Slavic palatalization from the point of view of the theory of sound change envisaged in Weinreich et al. 1968, we show that with ideas and tools now existing in phonology and phonetics, it is perhaps possible to continue and extend the program that Weinreich and colleagues outlined and initiated.

We first provide an outline of the historical phonology of Slavic palatalization (§2), concluding with a set of generalizations about which consonants are more and less likely to undergo palatalization loss. Sections 3 and 4 present the methods and results of an acoustic study on the palatalization contrast in Russian. A discussion follows of the acoustic-articulatory (§5.1) and phonological (§5.2) factors involved in the sound change. Our argument for a synchronic grammar comes from the STATE-PROCESS model of diachronic typology proposed by Joseph Greenberg (Greenberg et al. 1963, Greenberg 1965, 1978, 1995). Unlike modern discussions that assume a zero-sum competition between diachronic and synchronic accounts, we show how detailed work on diachronic typology by Hoenigswald (1960, 1961) and Greenberg necessitates a listing of the possible synchronic grammar states for a valid discussion of diachronic typologies. In the conclusion (§6), we discuss how our work furthers the answers to the questions asked by Weinreich and colleagues.

2. PALATALIZATION IN SLAVIC. Palatalization is important to the understanding of the diachronic development of the Slavic languages. While contrastive palatalization of most consonants has been reconstructed for Late Proto-Slavic (Shevelov 1965, Carlton 1991), modern Slavic languages exhibit a full range of effects connected with palatalization, from its complete loss to a partial loss of the contrast to the situation where the contrast is (almost) fully retained. Given this diversity of palatalization reflexes, Slavic provides an excellent ground for a study of the diachronic processes of palatalization development and loss. Moreover, we believe that the diachrony of palatalization in Slavic is invaluable for the understanding of contrast development in general.

There are several uses of the term PALATALIZATION that are invoked by Slavists. On the one hand, phonetically, palatalization results from the coarticulation of consonants with a neighboring vocalic segment. The phonologization of this phonetic effect gives rise to phonemic palatalization as a secondary articulation (Rubach 2007 dubs this SURFACE PALATALIZATION), pervasive in Slavic. On the other hand, Slavists also use the term to describe the change of the primary articulation of a consonant in the vicinity of a front vowel (termed CORONALIZATION by Rubach 2007). Slavic is rich with this kind of historical change as well, exemplified by the first palatalization of velars in 1. Synchronic alternations of this type are also abundant (cf. Russian *krik* 'cry' vs. *kritʃat^j* 'to cry', *sluga* 'servant' vs. *sluʒit^j* 'to serve').[1]

(1) The first palatalization of velars in Proto-Slavic (Carlton 1991:115)

*k	>	tʃ:	*kri**k** + æti	>	*kri**tʃ**ati[2]	'to cry'
*g	>	ʒ:	*slu**g** + iti	>	*slu**ʒ**iti	'to serve'
*x	>	ʃ:	*ru**x** + æti	>	*ru**ʃ**ati	'to break, ruin'

We believe that we can gain a better insight into the history of palatalization in Slavic if we understand the phonetics of palatalization. For the data analysis, we use a method that allows us 'to study sound change in the lab' (Ohala 1989:173). We look for the 'seeds' of the sound change in the language that preserves the contrast, Russian in our case, and compare the results with the diachronic fate of the contrast in the Slavic language family. This approach has been successfully applied before (see Ohala 1989, 1992, among many other contributions by John Ohala on this topic, and Barnes & Kavitskaya 2001 for a study of compensatory lengthening in Slavic).

In this article, we look at palatalization as secondary articulation in Russian and consider how the phonetic facts of Russian potentially relate to the retention or loss of the

[1] We use the International Phonetic Alphabet (IPA) throughout the article, but do not show the effects of vowel reduction.

[2] [æ] refers to a low front vowel written as *ě* in most literature on historical Slavic (e.g. in Carlton 1991). The nasalized mid front vowel [ẽ] is traditionally written as *ę*.

palatalization contrast in other Slavic languages. An example of the palatalization contrast in Russian can be seen in Figure 1, which shows tongue tracings for a palatalized and a nonpalatalized labial (adapted from Bolla 1981, plates 38–39). It can be seen that even though the primary constriction is the same in both [b] and [bʲ], the latter has a constriction in the palatal region, while the former does not (Fant 1960, Bolla 1981, Padgett 2003b, Timberlake 2004, Kochetov 2006, Litvin 2014).

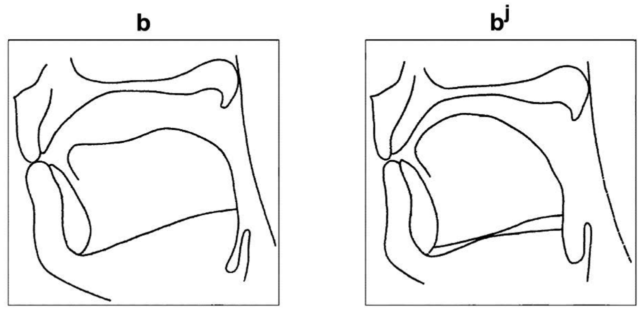


FIGURE 1. Tracings of the articulatory structures for [b] and [bʲ] in Russian (adapted from Bolla 1981).

Palatalized velars are not considered here since they are marginal even in modern Russian, the language that preserves contrastive palatalization for most consonants. As will become evident in §2.1, the Slavic data are notoriously complex, and by no means do we attempt to account for every detail of the history of the palatalization contrast in every Slavic dialect. However, we believe that our approach presents a novel way of looking at the development of palatalization in Slavic and at the connection between synchronic variability and sound change in general.

2.1. AN EXCURSUS ON THE HISTORY OF PALATALIZATION IN SLAVIC. Before we can discuss the retention and loss of palatalization contrasts in the individual modern Slavic languages, an excursus into the Proto-Slavic and Late Proto-Slavic consonant system is necessary. There are several sources of palatalized consonants in the modern Slavic languages: palatalized consonants arise from consonant-*j* sequences, from the phonologization of regressive palatalization by various front vowels, and from the phonologization of palatalization caused by the syncope and apocope of short high front vowels, known as JERS (the front jer [ɪ] and the back jer [ʊ]) (Shevelov 1965, Carlton 1991, Schenker 1995, among others).

According to the general view (e.g. Shevelov 1965, Carlton 1991), the earliest palatalization of consonants can be reconstructed back to Proto-Slavic, from about the fifth to eighth centuries AD. At that time, the coalescence of consonants with the following [j] (dubbed as JOTATION) occurred. Jotation of velars and fricatives resulted in fricatives and affricates, with a change in the place of articulation (2a). Sequences of a labial followed by a [j] became a labial followed by a palatalized [lʲ] through liquid epenthesis (2b), and the remaining consonant-*j* sequences coalesced into palatalized consonants (2c).[3]

(2) Palatalization from jotation
  a. Jotation of velars and fricatives: *gj, *zj > ʒ; *xj, *sj > ʃ; *kj > tʃ
  b. Jotation of labials: *bj > blʲ, *pj > plʲ, *vj > vlʲ, *mj > mlʲ
  c. Cj > Cʲ: *nj > nʲ, *lj > lʲ, *rj > rʲ, *dj > dʲ, *tj > tʲ

[3] We do not investigate the development of larger clusters with [j] (such as /skj/, /stj/, /zgj/, /zdj/, etc.).

Thus, after the time of jotation, the /l/-/l^j/, /n/-/n^j/, /r/-/r^j/, /t/-/t^j/, and /d/-/d^j/ palatalization contrasts were present in all dialects of Proto-Slavic (Schenker 1995:85). Additionally, an /s/-/s^j/ contrast was present dialectally from the end of early Proto-Slavic (Schenker 1995:85), and /m/-/m^j/, /b/-/b^j/, /p/-/p^j/, and /v/-/v^j/ may have been present only in West Slavic dialects where the epenthetic [l] was lost (Carlton 1991:158–59).

More palatalization of consonants by front vowels arose during the Late Proto-Slavic period. Table 1 provides the inventory of Late Proto-Slavic phonemes according to Schenker (1995:102).[4]

	LABIAL	DENTAL	ALVEOLAR	PALATAL	VELAR
STOP	p b	t d		t^j d^j	k g
SPIRANT	v	s z	ʃ ʒ	s^j z^j	x
AFFRICATE		ts dz	tʃ		
NASAL	m	n		n^j	
LIQUID		l r		r^j l^j	
GLIDE				j	

TABLE 1. Consonantal phonemes of Late Proto-Slavic.

At the period of the disintegration of Late Proto-Slavic, additional palatalizing changes happened in individual languages.[5] The following overview of palatalization of specific consonants by specific vowels in various Slavic languages is based on Carlton 1991, which is itself only a simplified summary of the changes.

Palatalization of consonants in Slavic languages depended on the quality of the following vowel, on the quality of the consonant itself, and on the position of the consonant in the syllable. Late Proto-Slavic had five front vowels: [i e æ ẽ ɪ]. All five of these vowels palatalized preceding consonants in Russian, Belarusian, Polish, Slovak, and Upper and Lower Sorbian. In Ukrainian, only [æ], [ẽ], and the weak front jer [ɪ][6] were the triggers of palatalization.[7] In Czech, [i] and [æ] were always palatalizing, and [ẽ] palatalized preceding consonants only in some cases. In most dialects of Bulgarian, only the stressed [æ] was palatalizing. Finally, front vowels did not palatalize consonants in Slovenian,[8] Serbo-Croatian, Macedonian, and West Bulgarian, and thus all palatalized consonants that these languages have come via palatalization from jotation.

While most of the Proto-Slavic palatalization contrasts were present prevocalically, word-final and preconsonantal palatalization contrasts were introduced with the syncope of short high front vowels in weak positions. This syncope created closed syllables and consonant-final words, some of which ended in palatalized consonants, as illustrated in 3.

[4] This table is adapted from Schenker (1995:102) and converted to the IPA. We keep all of the other interpretations that concern the designation of the consonants in question as [palatal], as well as the manners of articulation used by Schenker.

[5] A different approach could be taken under which the palatalization was regular, and different Slavic languages underwent context-specific depalatalizations.

[6] Jers merged with longer vowels in strong positions and disappeared in weak positions, sometimes with the palatalization of the consonant preceding the front jer. A jer is defined as being in a weak position if it is word-final or followed by a vowel in the next syllable, and as being in a strong position if it is in a syllable followed by a weak jer or if it is stressed, which is possible only in monosyllabic words (Carlton 1991:165).

[7] The set of vowels that triggers palatalization in Ukrainian is surprising from the perspective of any phonetically grounded model of sound change. We can conjecture that in Ukrainian a hypocorrective dissimilatory change caused depalatalization of consonants in the environment of nonlow front vowels [i] and [e].

[8] *Slovene* is used interchangeably with *Slovenian* in the Slavic literature.

(3) Word-final palatalization from the fall of the front jer in Russian
*solɪ > sol^j 'salt'
*dɪnɪ > d^{j}en^j 'day'

These complex developments resulted in the situation outlined in Table 2. This table is based on a similar table provided by Carlton (1991:162) and is combined with data from other sources on the historical phonology of Slavic and the structure of the consonantal inventories of modern Slavic languages (Bondarko 1977, Timberlake 2004 on Russian; Shevelov 1979, 1993 on Ukrainian; Wexler 1977, Mayo 1993 on Belarusian; Stieber 1973, Rubach 1984 and p.c., and Rothstein 1993 on Polish; Stone 1993, Schuster-Šewc 1996, and Schaarschmidt 1997, 2002 on Sorbian; Short 1993a on Czech; Krajčovič 1975, Rubach 1993, and Short 1993b on Slovak; Scatton 1993 on Bulgarian; Koneski 1983, Friedman 1993 on Macedonian; Browne 1993 on Serbian and Croatian; Priestly 1993 and Greenberg 2000 on Slovenian). Table 2 shows the presence or absence of Proto-Slavic palatalization contrasts in modern Slavic languages. Plus signs indicate that the palatalization contrast is still fully present in a given language, and minuses show the absence of contrast. ' _V' signifies that the contrast is preserved only prevocalically.[9] Finally, there are cases where the contrast is kept, but the original palatalized Proto-Slavic consonant has a different phonetic instantiation. In these cases, the phonetic instantiation of the palatalized consonant is given in the corresponding cell.

PROTO-SLAVIC	EAST SLAVIC			WEST SLAVIC					SOUTH SLAVIC			
CONTRAST	R	Ukr	Br	P	US	LS	Slk	Cz	Blg	M	SC	SL
v-v^j	+	–	_V	_V	_V	_V	–	–	_V	–	–	–
p-p^j	+	–	_V	_V	_V	_V	–	–	_V	–	–	–
b-b^j	+	–	_V	_V	_V	_V	–	–	_V	–	–	–
m-m^j	+	–	_V	_V	_V	_V	–	–	_V	–	–	–
d-d^j	+	+	d-dz^j	d-dʑ	d-dʒ^j [a]	d-ʒ^j	d-ʑ	d-ʑ	_V	–	–	–
t-t^j	+	+	t-ts^j	t-tɕ	t-tʃ^j	t-ʃ^j	t-ɕ	t-ɕ	_V	–	–	–
z-z^j	+	+	+	z-ʑ	–	–	–	–	_V	–	–	–
s-s^j	+	+	+	s-ɕ	–	–	–	–	_V	–	–	–
n-n^j	+	+	+	n-ɲ	n-ɲ _V	+	n-ɲ	n-ɲ	_V	n-ɲ	n-ɲ	–
l-l^j	+	+	+	w-l	w-l [b] _V	w-l _V	l-ʎ	–	_V	l-ʎ	l-ʎ	–
r-r^j	+	_V	–	r-ʒ	_V	+	–	r-r̝	_V	–	–	–

TABLE 2. Palatalization contrast in modern Slavic languages. Key: R: Russian, Ukr: Ukrainian, Br: Belarusian, P: Polish, US: Upper Sorbian, LS: Lower Sorbian, Slk: Slovak, Cz: Czech, Blg: Bulgarian, M: Macedonian, SC: Serbian and Croatian, Sl: Slovenian. '+': contrast is still present in all environments; '–': contrast is absent, with only the nonpalatalized variant present; '_ V': restricted presence of contrast—only before vowels.

[a] Upper Sorbian [dʒ^j] and [tʃ^j] are described as prepalatal affricates by Stone (1993), as palatal affricates by Schaarschmidt (2002), and as palato-alveolar by Rubach (p.c.).

[b] The Krjebja dialect of Upper Sorbian preserves /l/-/l^j/ opposition (Schuster-Šewc 1996:25).

It is important to note that Table 2 contains a summary of the information that is most representative of palatalization in the major Slavic languages. First, it does not show how the palatalization contrasts shown in the table were acquired. For instance, consider the fate of two Proto-Slavic palatalized consonants, [n^j] and [z^j]. It is evident from Table 2 that [n^j] is the most stable palatalized consonant in Slavic: it is preserved in most Slavic languages in most environments. This palatalized [n^j] comes from different

[9] The phonetics and phonology of the palatalization contrast in prevocalic vs. postvocalic contexts is the subject of a detailed investigation by Kochetov (2002, 2004).

sources in different Slavic languages. For instance, in Czech the Proto-Slavic palatalized [nʲ] is preserved if it originates from the sequence *nj, while front jers do not palatalize [n], as in 4a. The same situation holds for Serbian, in 4b. In other languages—for instance, in Polish, Ukrainian, and Russian, as in 4c, 4d, and 4e, respectively—front jers palatalize [n], which is an additional source of palatalization.

(4) Palatalized Proto-Slavic (PSl) *nʲ in modern Slavic languages

a. Czech

kuːɲ	< *konʲɪ	<	PSl *konjɪ	'horse'
pɛɲ	< *pɪnʲɪ	<	PSl *pɪnjɪ	'stump'
dɛn	< *dɪnɪ	<	PSl *dɪnɪ	'day'

b. Serbian

koɲ 'horse'
paɲ 'stump'
dan 'day'

c. Polish

kɔɲ 'horse'
dʑɛɲ 'day'

d. Ukrainian

pʲɛnʲ 'stump'
kʲinʲ 'horse'
dɛnʲ 'day'

e. Russian

pʲenʲ 'stump'
konʲ 'horse'
dʲenʲ 'day'

For the palatalized [zʲ], the situation is different. It follows from Table 2 that [zʲ] was lost in many languages. In most languages, it merged with [z], as in Czech in 5a, but Russian kept it, as in 5b.

(5) Palatalized Proto-Slavic *zʲ in modern Slavic languages

a. Czech

zɛmɲɛ < PSl *zemja 'land'

b. Russian[10]

zʲemlʲa < PSl *zemja 'land'
knʲasʲ < PSl *kʊnẽdzɪ 'prince'

Once again, even though the exact paths of palatalization retention and loss are different for different languages, it remains uncontroversial that [nʲ] is retained much more often than [zʲ].

Second, Table 2 also glosses over vast dialectological differences; for example, in Polish, the contrast between the originally palatalized and nonpalatalized labials exists, but while in Eastern Polish the labials are palatalized, in Standard Polish they surface as sequences of a palatalized labial followed by a palatal glide: [mʲj vʲj pʲj bʲj] (Wierzchowska 1971, Rubach 1984, 2007).

Before discussing many of the details of Table 2, we would like to note several obvious generalizations. The first is that the contrast is lost for some or all pairs of consonants in several languages. This is not surprising from a typological perspective: even though palatalization of consonants by high vowels is extremely common in the world's

[10] In Russian, word-final /zʲ/ devoices to [sʲ].

languages (Bateman 2007), only a handful of languages, such as Irish, Marshallese, Japanese, Tundra Nenets, and some others, show a palatalization contrast. The synchronic rarity of the contrast despite the prevalence of phonetic palatalization is a possible indicator that there is a diachronic FORCE against the development of this type of contrast. Of course, this force must have been overcome in the case of Proto-Slavic, but it seems to have been effective enough in the descent from Proto-Slavic to the daughter languages that merger occurred widely in those languages. The other equally obvious generalization is that the contrast is maintained in many pairs in many languages, with or without phonetic enhancement of the contrast (Stevens & Keyser 1989). Specifically, in several Slavic languages, there is a change from a secondary contrast to a primary one (e.g. palatalized nasals often become palatal nasals, which are then primarily contrasted with dental nasals). Also in some cases, such as the lateral in Polish, lexical differentiation between words that were distinguished by having plain and palatalized consonants in Proto-Slavic continues as a contrast between some other consonant ([w] in this case) and a plain nonpalatalized consonant ([l] in this case). As has been noted by many researchers, plain members of the plain/palatalized pairs are phonetically velarized in Russian (Trubetzkoy 1939, Reformatskii 1958, Fant 1960, Bolla 1981, among others).[11] Both the change of the contrast phonetically from a secondary one to a primary one and the velarization of the plain consonants can be seen as ways of phonetically bolstering or enhancing the phonological contrast in the consonants and languages that maintain it. Phonetic bolstering of the contrast is an instance, of course, of what Martinet (1952) referred to as a functional factor in diachrony that motivates some synchronic pattern.

The first generalization emerging from Table 2 therefore seems to point to a force for merger, while the second seems to point to a force for contrast maintenance. These two opposing forces of contrast preservation (Martinet 1952) and loss of contrast, or merger (Hoenigswald 1960), have different effects on the different languages. After discussing many specific details from Table 2, we return to a discussion of a less obvious generalization concerning certain classes of consonants that are more or less likely to lose the contrast, and we discuss some phonetic forces motivating this generalization, and the interaction between these phonetic forces and the two forces of merger and contrast preservation.

PALATALIZATION IN MODERN SLAVIC LANGUAGES: CONTRAST. We now consider a more in-depth picture of palatalization and palatalization contrast in modern Slavic languages. The following discussion provides an illustration of the existing contrasts summarized in Table 2.

South Slavic. The South Slavic languages kept the original palatalization contrast the least. Among these languages, Bulgarian stands out in that it preserves the palatalization contrast most fully (6). Even in Bulgarian, however, the contrast is preserved only prevocalically before nonhigh vowels, and it is neutralized elsewhere, as the alternations in 7 demonstrate (Scatton 1993).

(6)	/b/-/b^j/	bal	'ball dance'	b^{j}al	'white'
	/r/-/r^j/	grad	'city'	br^{j}ag	'shore'

[11] It has been further claimed that the phonological difference between plain and palatalized consonants in Russian is in fact the difference between velarized and palatalized (Farina 1991; see Padgett 2001, 2003a for discussion), but we assume a more traditional phonological representation.

(7)	/l^j/	kral	'king'	kral^{j}at	'the king'
	/n^j/	dɛn	'day'	dɛn^{j}at	'the day'
	/r^j/	tsar	'czar'	tsar^{j}at	'the czar'
	/z^j/	kn^{j}az	'prince'	kn^{j}az^{j}at	'the prince'

Unlike Bulgarian, the closely related Macedonian preserves only the original /n/-/n^j/ and /l/-/l^j/ contrasts, with *l^j becoming the palatal [ʎ] and *n^j becoming the palatal [ɲ] (Koneski 1983, Friedman 1993). The minimal pair in 8a illustrates the /l/-/ʎ/ contrast in Macedonian. The /n/-/ɲ/ contrast in Macedonian is marginal, as [ɲ] does not occur word-initially except in a few borrowings. According to Friedman (1993:257), in literary Macedonian, roots with [ɲ] are borrowed from northern dialects, where the contrast is preserved, as in 8b. Derived [ɲ] occurs in the literary language, as in 8c.

(8) a. /l/-/ʎ/ contrast in Macedonian: bɛla 'white' bɛʎa 'trouble'
b. /ɲ/ in northern dialects: kɔɲ 'horse' baɲa 'bath'
c. Derived [ɲ] in literary Macedonian: nɔsɛɲɛ 'carrying' (from *nosi* 'carry')

Serbian and Croatian keep only two original palatalization contrasts, /l/-/l^j/ and /n/-/n^j/. The reflex of *l^j is a palatal lateral approximant [ʎ], and the reflex of *n^j is a palatal nasal [ɲ], shown by the pairs in 9 (Browne 1993, Bakran 1996).

(9)	/n/-/ɲ/	norats	'diver'	ɲoriti	'to dive'
		negovati	'to nurture'	ɲega	'he.3SG.ACC.M/N'[12]
	/l/-/ʎ/	ludi	'crazy.PL'	ʎudi	'people'

Finally, Slovenian lost the palatalization contrast for most consonants in most dialects (Priestly 1993, Greenberg 2000). The /n/-/ɲ/ contrast is preserved word-finally in some dialects of Slovenian, where prepalatal [ɲ] alternates with a sequence of dental [n] followed by a palatal glide [j] prevocalically; compare *kɔɲ* 'horse.NOM.SG' with *kɔnja* 'horse.GEN.SG' (see descriptions and discussion in Bajec et al. 1956, de Bray 1980, and Rubach 2008).

West Slavic. West Slavic presents the most complex case of palatalization-contrast retention and loss. Polish (Stieber 1973, Rothstein 1993, Rubach 2007, David Frick, p.c.) keeps the contrast for labials prevocalically, as in 10a, and neutralizes it in the coda, as in 10b, where the underlying palatalized /b^j/ loses its palatalization word-finally.

(10) a.	/p/-/p^j/	pasta	'toothpaste'	p^{j}ast	name; 'native Pole'
	/m/-/m^j/	mɔtwɔx	'mob'	m^{j}ɔtwa	'broom'
b.	/b^j/	gɔwɔmp	'pigeon'	gɔwɛmb^{j}a	'pigeon.GEN.PL'

As shown in 11, the original opposition is preserved in coronal consonants, with affricativization of palatalized stops resulting in prepalatal affricates (*t^j > tɕ, *d^j > dʑ), and with the change of the place of articulation of palatalized fricatives to prepalatal as well (*s^j > ɕ, *z^j > ʑ) (Rubach 1984, 2003). The place of articulation of the palatalized nasal shifts to the palatal, and there is also a shift in the opposition for the laterals, where the original nonpalatalized lateral becomes a labiovelar glide, while the original palatalized lateral depalatalizes (*l > w, *l^j > l). The distinction between the rhotics is also preserved, but the palatalized rhotic undergoes depalatalization and fricativization, surfacing as [ʒ] in Modern Polish.

[12] Abbreviations used in glosses here and throughout are as follows: DIM: diminutive, F: feminine, GEN: genitive, IMP: imperative, M: masculine, N: neuter, NOM: nominative, PL: plural, PPL: past participle, PST: past, SG: singular.

(11)	t/tɕ:	tɛn	'that one'	tɕɛɲ	'shadow'
	d/dʑ:	dam	'give.1SG'	dʑadɛk	'grandfather'
	s/ɕ:	sadɔvʲitɕ	'to seat'	ɕadatɕ	'to sit down'
	w/l:	wɛp	'forehead'	lɛpkʲi	'sticky'
	n/ɲ:	nam	'to us'	ɲaɲa	'nanny'
	r/ʒ:	rada	'counsel'	ʒɔnt	'row; line; rank'

Both Upper and Lower Sorbian preserve the palatalization contrast for labials in prevocalic position and lost the contrast in fricatives, merging /s/-/sʲ/ and /z/-/zʲ/ as [s] and [z] (Stone 1993, Schaarschmidt 1997). Also, both languages keep the phonemic distinction between palatalized and nonpalatalized nasals and rhotics. Phonetically these differ though: while in Upper Sorbian the nasal is a palatal [ɲ], according to most descriptions,[13] in Lower Sorbian it is a palatalized [nʲ]. Also, in Upper Sorbian, both rhotics are uvular trills (Stone 1993 lists 'lingual' rhotics as archaic). The minimal pairs in 12 illustrate some of the oppositions in Upper Sorbian.

(12)	p/pʲ:	pana	'mister.GEN.SG'	pʲana	'piano.GEN.SG'
	m/mʲ:	mɛskank	last name	mʲɛskank	last name
	t/tʃʲ:	tɛma	'topic'	tʃʲɛmnɨ	'dark'
	d/dʒʲ:	dɛlɛ	'down'	dʒʲɛlɛ	'part.NOM.PL'
	n/ɲ:	dna	'bottom.GEN.SG'	dɲa	'day.GEN.SG'
	ʀ/ʀʲ:	ʀat	'glad'	ʀʲat	'row'

The contrast between palatalized and nonpalatalized consonants is neutralized in word-final position in Upper Sorbian. The historically palatalized consonants are preceded by a palatal glide, as in *dʒʲejn* 'day', where the originally palatalized word-final nasal surfaces as plain with the preceding [j] (Stone 1993).

There seems to be disagreement between the descriptions in Carlton 1991, Stone 1993, and Schaarschmidt 1997 with respect to the preservation of /t/-/tʲ/ and /d/-/dʲ/ contrasts in Upper and Lower Sorbian. While Carlton (1991:162) lists these contrasts as present in both languages, Stone (1993) states that Upper Sorbian only has a /t/-/tʃʲ/ phonemic distinction and Lower Sorbian has neither. The consonantal inventories seem to be highly dependent on the dialect. Schaarschmidt (1997) describes four contemporary phonological systems of Sorbian dialects (specifically, the dialects of Dissen, Bergen, Halbendorf, and Radibor), all of which have different palatalization distinctions preserved. We thus go with Carlton's summary in counting the contrast as preserved at least in some dialects of both Upper and Lower Sorbian.

In Czech (Townsend 1990, Short 1993a, Grepl et al. 1995) and Slovak (Rubach 1993, Short 1993b), the contrast between palatalized and nonpalatalized labials and fricatives is lost. The /d/-/dʲ/, /t/-/tʲ/, and /n/-/nʲ/ contrast is kept, but the palatalized variants of the coronal stops and the nasal have a different surface phonetic realization in Czech and Slovak, just like in most other West Slavic languages. Czech and Slovak differ in that Slovak keeps the palatalized [lʲ] (and the /l/-/lʲ/ contrast) and Czech does not, while Czech keeps the /r/-/rʲ/ contrast (*rʲ becomes a trilled fricative[14]) and Slovak does not.

East Slavic. Finally, among the East Slavic languages—Russian, Ukrainian, and Belarusian—the palatalization contrast is most fully retained in Russian, as illustrated by the inventory in Table 3 (Bondarko 1977, Timberlake 2004).

[13] Schuster-Šewc (1996) lists the Upper Sorbian nasals as [n] and [nʲ].

[14] See Howson et al. 2014 for a different characterization of the Czech trilled fricative on the basis of an ultrasound study.

	labial	apical	(alveo)palatal	velar[a]
voiceless stop	p pʲ	t tʲ		k (kʲ)
voiced stop	b bʲ	d dʲ		g (gʲ)
voiceless affricate		ts	tʃʲ	
voiceless fricative	f fʲ	s sʲ	ʃ ʃʲː [b]	x (xʲ)
voiced fricative	v vʲ	z zʲ	ʒ	
glide			j	
nasal	m mʲ	n nʲ		
lateral		l lʲ		
trill		r rʲ		

Table 3. Russian consonantal inventory.

[a] Velars are marginally contrastive in Russian, which is why we do not address the palatalization of velars in this article.

[b] [ʃʲː] is not a palatalized counterpart of [ʃ] and merits its own story, but this is outside of the scope of this article.

The palatalization contrast is preserved in most positions in Russian, as exemplified in 13 for some of the existing palatalization pairs (for a more complete list of pairs that exemplify the contrast prevocalically see the appendix).[15] The examples in 13a illustrate the contrast word-initially, in 13b there are some minimal pairs with contrastive palatalization word-medially, and 13c provides some examples of word-final contrast. In 13d, there are near-minimal pairs which demonstrate that palatalization is contrastive in Russian preconsonantally, but this contrast is present only to some extent and depends on the identity of the consonants in the cluster; for instance, for coronal stops the contrast is neutralized to the plain coronal before other coronals (Kochetov 2002, 2006).[16]

(13) Russian contrastive palatalization

a. Word-initial

/m/-/mʲ/	mat	'foul language'	mʲat	'crumpled.PPL.M'
/v/-/vʲ/	vol	'ox'	vʲol	'he led'
/s/-/sʲ/	suda	'court of law.GEN.SG'	sʲuda	'here, this way'

b. Word-medial

/m/-/mʲ/	toma	'volume.PL'	tomʲa	'tormenting'
/d/-/dʲ/	voda	'water'	brodʲa	'wondering'
/n/-/nʲ/	dna	'bottom.GEN.SG'	dnʲa	'day.GEN.SG'
/r/-/rʲ/	parat	'parade'	parʲat	'soar.3PL'

c. Word-final

/t/-/tʲ/	brat	'brother'	bratʲ	'to take'
/f/-/fʲ/	krof	'shelter'	krofʲ	'blood'
/l/-/lʲ/	stal	'become.3SG.PST'	stalʲ	'steel'
/r/-/rʲ/	udar	'hit'	udarʲ	'hit.IMP'

d. Preconsonantal

/l/-/lʲ/	polka	'shelf'	polʲka	'polka'
/n/-/nʲ/	banka	'jar'	banʲka	'bath.DIM'
/t/-/tʲ/	rʲetka	'rarely'	rʲetʲka	'reddish'

Ukrainian differs from Russian in that it does not preserve contrastive palatalization of labials, as in 14a. As shown in Table 2, Standard Ukrainian contrasts most apical con-

[15] No voiced obstruents are possible word-finally in Russian due to word-final devoicing.

[16] The precise conditions on preconsonantal palatalization are outside the scope of this article.

sonants in all positions, except for the /r/-/r^j/ contrast, which is no longer present in the coda in Standard Ukrainian, as in 14b (Shevelov 1979).[17]

(14) a. hɔlup ‘pigeon’ (cf. Russian *golup^j*)
b. hirkɨj ‘bitter’ (cf. Russian *gor^{j}kij*)

Belarusian keeps most palatalization contrasts but less so than Russian. First, in Belarusian, the contrast between palatalized labials is lost in the coda, as in 15a. Second, while the Proto-Slavic /t/-/t^j/ and /d/-/d^j/ contrast is preserved, *t^j is realized as [ts^j] and *d^j is realized as [dz^j], as in 15b (Wexler 1977, Mayo 1993).

(15) a. s^{j}ɛm ‘seven’ (cf. Russian *s^{j}em^j*)
b. dz^{j}ɛn^j ‘day’ (cf. Russian *d^{j}en^j*)
b^{j}its^j ‘to beat’ (cf. Russian *b^{j}it^j*)

Table 2 shows that Belarusian lost the /r/-/r^j/ contrast, completely depalatalizing the *r^j, as in 16a. The /r/-/r^j/ opposition was subsequently restored in some areas, presumably under Russian influence. However, the restoration of the palatalized trill went further in Belarusian; the examples in 16b show instances of hypercorrectively restored [r^j] in words that never had palatalized trills (cf. Russian cognates).

(16) a. senɪtɛbra ‘September.GEN.SG’ (cf. Russian *s^{j}ent^{j}abr^{j}a*)
branɪsku placename (cf. Russian *Br^{j}ansk*)
tʃɛtɨrɔx ‘four.GEN’ (cf. Russian *tʃetɨr^{j}ox*)

b.

Belarusian		Pre-Belarusian	Modern Russian
r^{j}at	‘glad’	radʊ	rat
r^{j}ak	‘crawfish’	rakʊ	rak

Palatalization in modern slavic languages: phonetics. In this subsection, we summarize the phonetic exponents of the contrast in the modern languages, based on existing descriptions. A general overview of palatalization in Slavic is provided in Rubach 2011.

Russian palatalized consonants stay presumably as they were in Proto-Slavic, with palatalization as a secondary articulation. As noted above (Fant 1960, Bolla 1981, Padgett 2003b, Timberlake 2004, Kochetov 2006), nonpalatalized consonants in Russian are phonetically velarized. Bulgarian is the closest to Russian in preserving all Proto-Slavic contrasts at least prevocalically, and Pritchard (2012) reports that Bulgarian palatalized consonants are phonetically exactly like those in Russian.

As mentioned in the previous section, in certain contrastive pairs that remain in modern Slavic languages, the phonetic substance of the reflexes of Proto-Slavic plain-palatalized pairs is different. Often, instead of a coronal primary articulation combined with predorsal secondary articulation, the primary gesture becomes palatal. *n^j and *l^j, which are the most common palatalized consonants to be preserved, frequently undergo this change of place, becoming prepalatal (such as [ɲ] in Polish, Upper Sorbian, Slovak, Czech, Serbian, Croatian, and Macedonian and [ʎ] in Slovak, Macedonian, Serbian, and Croatian (Rubach 2011)). Proto-Slavic palatalized fricatives *s^j and *z^j also undergo the change of place in Polish, becoming alveopalatal sibilant fricatives [ɕ ʑ]. When the contrast that involves the Proto-Slavic *t^j and *d^j is preserved, the modern reflexes of these consonants often change not only place of articulation, becoming prepalatal, but also manner of articulation, either acquiring a fricated component or be-

[17] Palatalization reflexes differ in various dialects of Ukrainian. For instance, the palatalization of [r] was independently lost in the Polissian area around the eleventh century, in Volhynia around the fifteenth century, and in the Lvov area by the end of the sixteenth century (Shevelov 1979:636).

coming fricatives. The former is the case for Belarusian, Polish, and Upper Sorbian, while the latter happens in Lower Sorbian, Slovak, and Czech. Several studies describe these segments as prepalatal or palatal (Wierzchowska 1980, Rubach 1993, Padgett & Żygis 2007, Żygis & Padgett 2010). Padgett and Żygis (2007:298), in an extensive study of Polish fricatives, describe the alveolopalatals [tɕ dʑ ɕ ʑ] that arise from palatalized dental stops and fricatives (Stieber 1973) as having 'a great deal of tongue blade/body raising and fronting' and being 'inherently strongly palatalized'. Even in Russian, which keeps the /t/-/tʲ/ and /d/-/dʲ/ contrasts, the phonetic realization of the palatalized dentals is fricated at the release (Timberlake 2004:54). It may seem that a potential factor in determining whether a language will maintain or lose a contrast is the density of the contrastive system, with denser systems being less hospitable for a contrast. But Polish is the language with one of the densest coronal inventories, yet it preserves the palatalization contrast with enhancements, which further crowd the coronal space. Thus there does not seem to be evidence for density as a major factor in contrast maintenance.

In standard Polish and Sorbian, the historical nonpalatalized *l has become a [w] in all environments, while the palatalized lateral underwent depalatalization, resulting in contrast shift. Finally, the Proto-Slavic *rʲ, while undergoing merger with its nonpalatalized counterpart in several Slavic languages (Belarusian, Slovak, Macedonian, Serbian and Croatian, Slovenian), changed to a voiced palatoalveolar fricative in Polish (Stieber 1973) and a trilled fricative in Czech (but see Howson et al. 2014 and Howson et al. 2015 for two other proposals of the precise phonetic characteristics of this unusual segment).

2.2. A basic pattern in the diachrony of slavic palatalization. It follows from Table 2 that Russian keeps more of the Proto-Slavic palatalization contrasts than any of the other Slavic languages, which lose palatalization for some consonants or all consonants, in some positions or in all positions. To be more specific, we can look at the number of languages that retain palatalization consonant by consonant. For the purposes of this article, we concentrate on contrasts in prevocalic environment, which is generally the last position to lose contrastive palatalization; that is, if palatalization is retained preconsonantally or word-finally, it is also retained prevocalically.[18] In order to obtain a quantitative measure of the likelihood of each consonant to retain the contrast, we need some count of the number of languages that retain the contrast for each of the consonants. We also need to normalize that count by the overall number of languages. Such counts would be highly biased, and the resulting likelihoods invalid, if the sample of languages were biased. A biased sample would, for instance, include more languages representing a single pattern, and a few languages representing another pattern. This could happen if a single intermediate ancestral language (intermediate between Proto-Slavic and the daughter languages) lost a contrast before diverging into a number of daughter languages. An example of this bias would be if we had counted Serbian, Croatian, Bosnian, and Montenegrin as different types of languages. Of course, these are separate languages, but from the point of view of this sound change, they represent a single token of a general type. If each of these languages were then counted as a single token, the count would be biased.

We believe that the sample we have is as unbiased as possible, meaning that the counts we use over these twelve languages are type counts, not token counts. Each of these types represents many tokens (dialects and/or languages). It is extremely difficult, however, to do a full analysis of the dialect continuum and use a true token count, and this approach

[18] The examination of all positions with respect to the loss of palatalization contrast is left for future work.

may be faulty anyway, since some of the main languages have many more dialects than others. Table 2 also may seem unbalanced from a geographic perspective, since there are three East Slavic languages, five West Slavic languages, and four South Slavic languages. Our goal was not, however, to be geographically balanced. The languages chosen have been found by many Slavists (e.g. Carlton 1991) to be truly representative of the diversity of the development of the Slavic palatalization contrast. It just so happens that there are more types represented in the West Slavic region than the others.

We use the following metrics for palatalization retention: a palatalized consonant is assigned a 1 if the palatalization contrast is still present in a modern Slavic language, and a 0 if the contrast is not present, that is, if palatalized and plain consonants merged. Table 4 is constructed on the basis of the data in Table 2 on twelve major modern Slavic languages.

PALATALIZATION CONTRAST	# OF LANGUAGES	LOG ODDS
Labials: /v/-/v^j/, /p/-/p^j/, /b/-/b^j/, /m/-/m^j/	6	0.00
Dental stops: /d/-/d^j/, /t/-/t^j/	9	1.09
Coronal fricatives: /s/-/z^j/, /s/-/s^j/	5	–0.33
Coronal nasals: /n/-/n^j/	11	2.39
Laterals: /l/-/l^j/	10	1.60
Rhotics: /r/-/r^j/	7	0.33

TABLE 4. Generalization underlying diachronic variability, with the number of Slavic languages that maintain each phonological contrast, and the log odds of phonological contrast maintenance vs. merger. Palatalization contrast: 1: still present prevocalically, 0: absent prevocalically.

For the calculation in column 2 of Table 4, we assigned a 1 to all languages in which the contrast still remains, regardless of the phonetic nature of the consonant that is reconstructed as palatalized in Proto-Slavic. For instance, the Proto-Slavic /n/-/n^j/ contrast was preserved in all languages in Table 2 except for Slovenian, while the /m/-/m^j/ contrast survived in only six of the twelve languages. Dental stops have a score of 9, meaning that the contrast was preserved in nine Slavic languages and lost in three. Note, however, that the stops are preserved as palatalized [d^j] and [t^j] only in three of the twelve languages: Russian and Ukrainian (East Slavic) and Bulgarian (South Slavic). In Bulgarian, the contrast is preserved only prevocalically, as is indicated by _ V in Table 2. In the other languages, that is, in Belarusian (East Slavic) and in all West Slavic languages, the Proto-Slavic palatalized [d^j] and [t^j] change their place and manner of articulation, becoming palatal stops, affricates, and fricatives, but keep the palatalization gesture.

A basic pattern therefore emerges, which is numerically quantified in the third column of Table 4 via the LOG-ODDS RATIO, a basic tool in categorical data analysis (Agresti 2012). The log odds of contrast is obtained by dividing the probability of contrast maintenance by the probability of merger and taking the logarithm: $log\left(\frac{P(Contrast)}{P(Merger)}\right)$. The generalization that can be easily gleaned from Table 4 is that one set of contrasts (/t/-/t^j/, /d/-/d^j/, /n/-/n^j/, /l/-/l^j/) have a high odds of being phonologically preserved, whereas another set of contrasts (/s/-/s^j/, /z/-/z^j/, /r/-/r^j/, /p/-/p^j/, /b/-/b^j/, /m/-/m^j/) have a very low odds of being phonologically preserved. The question we attempt to answer in the following sections is: why? The sets of consonants that are more and less likely to undergo merger do not constitute natural classes in standard feature theories (e.g. Chomsky & Halle 1968, Sagey 1986, Hayes 2009). A detailed phonetic study of Russian could therefore shed light on why certain consonants are more or less likely to undergo merger.

Sections 3 and 4 present the methods and results of an acoustic phonetics experiment on Russian, the purpose of which is to try to establish what is different about the consonants whose palatalization contrast has a high odds of being preserved from those with low odds. The basic hypothesis we pursue is most closely associated with Jespersen (1922) and Ohala (1989) and is discussed at length in §5: sound change develops from a pool of synchronic variability. What we want to understand is what aspect of the variability is important. Our basic tool is to investigate the spectral characteristics distinguishing the palatalized and nonpalatalized consonants of each pair, and the variability thereof.

3. METHODS.

3.1. DATA AND PARTICIPANTS. Twelve native speakers of Russian, six male and six female, were recorded directly onto a Macintosh computer under quiet conditions, using a Mobile M-Audio preamplifier and Rode NTG-2 shotgun microphone. The data were recorded into Praat (Boersma & Weenink 2015) in .wav format at a sampling rate of 44 kHz, 16 bit quantization. The recordings took place in the San Francisco Bay area. All participants were monolingual in Russian until at least the age of twenty and now exhibit different levels of fluency in English. The age range of the participants was between twenty-five and seventy-six. None of the participants had any reported history of speech or hearing problems.

The participants all speak Standard Russian, even though some of them were born in the republics of the former USSR that are now separate countries (see Table 5 for information on gender, age, and the place of birth of the participants). The speakers who were born in Ukraine and Belarus are from the regions where Russian is either the only language or the prevalent language spoken. Our data do not show statistical differences between the speakers of the Moscow dialect (seven speakers) and the other dialects (five speakers).

PARTICIPANT	GENDER	AGE	PLACE OF BIRTH
S1	male	40	Simferopol, Ukraine
S2	male	45	Moscow, Russia
S3	female	76	Moscow, Russia
S4	male	76	Moscow, Russia
S5	male	27	Novokuznetsk, Russia
S6	male	25	Moscow, Russia
S7	female	44	Moscow, Russia
S8	male	53	Minsk, Belarus
S9	female	43	Moscow, Russia
S10	female	50	St. Petersburg, Russia
S11	female	42	Donetsk, Ukraine
S12	female	44	Moscow, Russia

TABLE 5. Experiment participants' gender, age, and place of birth.

The participants were asked to read Russian words with word-initial, intervocalic, and word-final palatalization contrasts (see the appendix for the full list of words used).[19] The vowel adjacent to the consonant in question was always [a].[20] Target con-

[19] Each word was pronounced in isolation, and the visual prompts were presented to the speakers with one word per slide. We did not use a carrier phrase in order to avoid coarticulation from the preceding word. Each pronounced word was thus itself an intonational phrase. Three native-speaking listeners trained in linguistics determined that there was no list intonation.

[20] The vowel [a] was chosen for several reasons. First, this vowel allows the most palatalization contrasts before it: only palatalized consonants are possible before the high front vowel [i], and only nonpalatalized consonants occur before the high central vowel [ɨ], and there are only a few lexical items with nonpalatalized consonants before [e]. The palatalization contrast before rounded [u] and [o] is also more restricted. Second, using just one vowel allowed us to keep the size of the experiment manageable.

sonants in initial and intervocalic positions were followed by stressed vowels, and target consonants in final position were preceded by stressed vowels. In general, Russian has vowel reduction in unstressed syllables, where /a/ reduces to [ə] after nonpalatalized consonants and to [ɪ] after palatalized consonants. However, the syllable that precedes the stressed one has the FIRST DEGREE OF REDUCTION, and /a/ in it surfaces as either a full [a] or a more central [ʌ] (Timberlake 2004).

We used real Russian words where possible. None of the words in the experiment presented any difficulties to the speakers. Most words were either one or two syllables long, except for one token where it was difficult to find a real word of one or two syllables for the relevant condition, so we used a trisyllabic word instead. Since Russian has word-final devoicing, voiced and voiceless obstruents neutralize word-finally; however, some speakers did not fully devoice word-final obstruents when reading the prompts.[21]

3.2. MEASUREMENTS AND STATISTICS. The consonants were segmented semi-automatically with visual inspection through MATLAB scripts for combined amplitude-based and zero-crossing-based segmentation (as was discussed earlier, only prevocalic consonants were analyzed). LPC spectra were calculated with one pole per 1 kHz of a preemphasized 40 ms window. Spectral analysis was performed for consonants and for the beginning of vocalic transitions after the consonants. For stops, the window was placed at the center of the burst, and for sibilants, nasals, and the liquid, the window was centered at the midpoint of the segment. For the rhotic, the window was placed at the tap closest to the vowel. If the segment was less than 40 ms long, which sometimes happened in the case of consonant bursts, then the entire burst was spectrally analyzed. When the segment was longer than 40 ms in duration, the middle 40 ms was spectrally analyzed. Vocalic transitions were analyzed by taking the first 40 ms after F1 energy started in the vowel following each of the consonants investigated. The spectra were then used as dependent variables in a statistical analysis where the spectrum measured in a plain consonant was compared to the spectrum in a palatalized consonant.

Most work on quantifying acoustic differences between segments or other categories focuses on the difference in a single variable, like a formant, a duration, or an articulatory distance, and then performing an ANOVA or a mixed-effects model to quantify the relation between the categorical variable and the single numerical measure investigated. In this study, we attempt to determine how spectra of palatalized consonants differ from those of nonpalatalized consonants, and spectra are entire functions, with Frequency as the continuous independent variable and Energy as the continuous dependent variable, not single numbers. We want to establish how the spectrum of [n], for instance, differs on average from the spectrum of [nʲ], and to compare that difference to the difference between the spectra of [s] and [sʲ].

Several methods have been proposed to test effects of a continuous variable on a curve. One relies on the growth-curve model approach (Singer & Willett 2003, Iskarous et al. 2011), where the curve of the dependent variable is parameterized by several moments, where the first moment expresses the linear trend in the curve, the second moment expresses the parabolic trend, and so forth. These moments are then used as dependent variables, instead of the original curve, as part of a hierarchical mixed-

[21] This is an indication that the speakers' productions were influenced by the visual prompts, which also included the orthographic indication of palatalization and thus could have influenced the production of palatalization as well. However, three native-speaking linguists who heard the stimuli indicated that the palatalized consonants in them sounded natural. In addition, while word-final devoicing in Russian is an example of incomplete neutralization (Kharlamov 2014), palatalization seems categorical.

effects model. The problem with using this approach here is that spectra can be auditorily quite different from each other due to a small portion of the frequency domain having different energies, with the general linear, quadratic, and cubic trends being quite similar in the spectra. Another mixed-effects-based approach is generalized additive modeling (Wieling et al. 2014), which allows for flexible modeling of highly complex curves like spectra, but we have found it difficult to obtain a statistic using this approach that will directly compare one set of curves with another set of curves that could be interpreted as overall spectral difference.

The method we used was SSANOVA (Gu 2002), a method similar to ANOVA but designed for investigating the difference in entire functions. The method is flexible in terms of fitting nuances in curves, is statistically well understood, and yields a statistic that allows for a straightforward, holistic measure of spectral distinctiveness: cosine diagnostic (Gu 1992). This statistic basically measures an angle between two abstract vectors in a high-dimensional space, which represent the spectra of different categories (e.g. the angle between the [n] spectra vector and the [nʲ] spectra vector). SSANOVA has previously been used in speech research to analyze articulatory data (Davidson 2006), as well as acoustic measures (Nance 2014). In SSANOVA, bayesian confidence intervals are placed around estimates of the within-category tendencies across categories, at each level of the independent variable of the functions investigated.[22] Statistics are calculated that summarize the amount of difference between the sets of functions due to measurements in the different categories. Applied to spectra in the investigation of interspeaker variability, the method allows us to determine at which frequencies speakers consistently differentiate between the two consonants investigated, if any. The method is described in detail in Gu 2002 and Davidson 2006. We illustrate how it works by examining how it quantifies the difference between the spectra that phonetically manifest the palatalization contrast in the different consonants under investigation. This method works well for consonant spectra, since energy tends to be diffusely represented in such spectra.

To quantify the difference in vocalic transitions after plain and palatalized consonants, we used Cohen's *d* (Cohen 1992), since formant energy in vocalic portions of the signal is high peaked and nondiffuse. For each spectral band (1 kHz), we measured the mean difference in spectral energy for the palatal and plain members of each pair, normalized by the pooled standard deviations. The Cohen's *d* measurement allows us to express the difference between two distributions in standard deviations. We first present the spectral differences at the vowel transition, and then turn to the SSANOVA results during the spectrum of the consonant.

4. Results. We present analyses of the spectral differences between palatalized and plain consonants at the formant transition and the middle of the consonant.

Figure 2 shows the acoustic contrast between palatalized and plain consonants, as measured by maximal Cohen's *d*, during the formant transition. If two distributions differ by two standard deviations, it means that they contrast quite well acoustically. For this data, Cohen's *d* was measured at each frequency band, and Fig. 2 shows the maximal Cohen's *d* for each of the consonant pairs. As can be seen, the formant transition shows excellent contrast between each of the pairs in Russian. That is, there is probably sufficient acoustic contrast between the members of each pair to allow for phonological contrast between them.

[22] This is not strictly true, since a smoothing penalty is added.

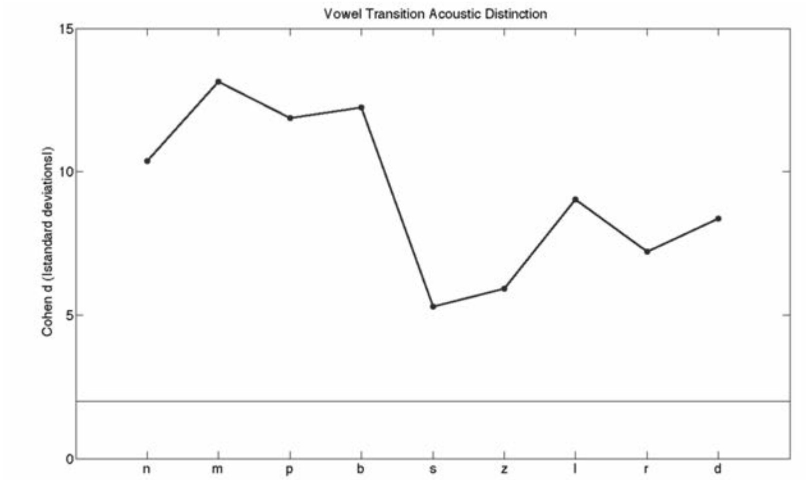
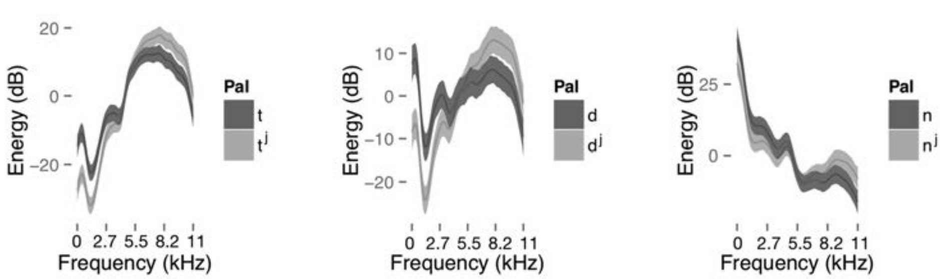


FIGURE 2. Acoustic contrastiveness between plain and palatalized stops, as measured by Cohen's *d*, as a function of consonant.

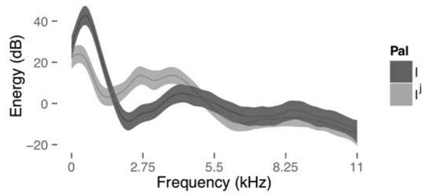
Figure 3 shows the spectra for the three pairs of dental stops, /t/-/tʲ/, /d/-/dʲ/, and /n/-/nʲ/, for an average of initial and intervocalic positions. The first panel (Fig. 3a) shows the difference between [t] spectra (dark gray) and [tʲ] spectra (light gray). The variability within each of the Bayesian confidence intervals shows intersubject (not intertoken) variability for the twelve subjects. For each subject, the spectra for the different tokens were first averaged, so that the variability on each confidence interval would not be artificially reduced due to high correlation between the tokens within each subject. In spectral regions where the confidence intervals overlap greatly, the spectra are not distinct, whereas when there is little to no overlap, the spectra for the two categories (palatalized and nonpalatalized) are phonetically distinct. It can be seen that /t/ and /tʲ/ are distinct from each other at both ends of the frequency spectrum, as is also the case for the /d/-/dʲ/ contrast in Fig. 3b. For /n/-/nʲ/, the two sets of spectra overlap in the mid-range end of the spectrum, but are well distinguished below 2 kHz (and at the highest frequencies), with little to no overlap there.



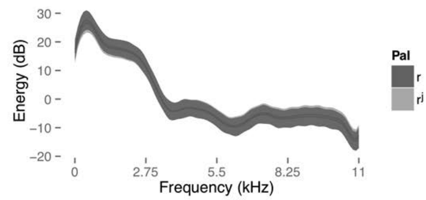
a. /t/-/tʲ/. b. /d/-/dʲ/. c. /n/-/nʲ/.

FIGURE 3. Spectral contrast for the dental stops.

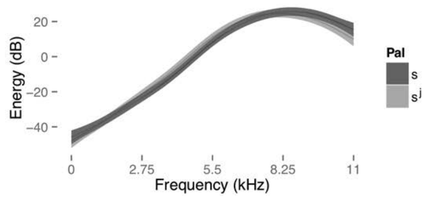
Figure 4 shows the data for the coronal fricatives and liquids. It can be seen that /l/-/lʲ/ are distinct in the entire lower half of the spectrum, but that /r/-/rʲ/, /s/-/sʲ/, and /z/-/zʲ/ have no spectral distinction anywhere in the spectrum, across speakers.



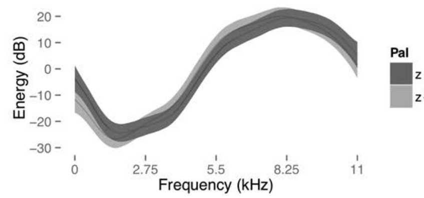
a. /l/-/lj/.



b. /r/-/rj/.



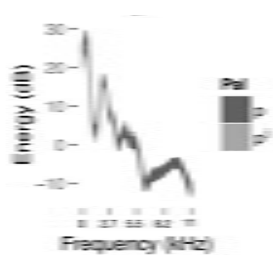
c. /s/-/sj/.



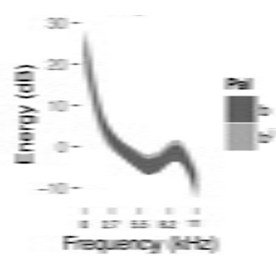
d. /z/-/zj/.

FIGURE 4. Spectral contrast for the coronal continuants.

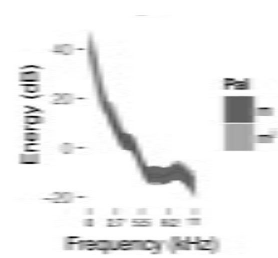
Figure 5 shows the data for the labials. Similar to the coronal fricatives and rhotics, the labials show little to no spectral distinction anywhere in the spectrum, across speakers. /p/-/pj/ and /b/-/bj/ show no spectral difference, but for the bilabial nasal /m/-/mj/ there is marginal difference at the very lowest end of the spectrum.



a. /p/-/pj/.



b. /b/-/bj/.



c. /m/-/mj/.

FIGURE 5. Spectral contrast for the labial stops.

To relate the spectral-distinctiveness data to the odds of contrast maintenance vs. merger, we attempted to predict the log odds of contrast maintenance from a numerical quantity that summarizes the distinctiveness across the spectrum for each consonant pair. The cosine diagnostic, mentioned in the previous section, quantifies the degree to which the functions differ from each other across the categories. One of the goals of this article is to determine the phonetic rationale, if any, for the odds that a particular consonant will retain the palatalization gesture. The hypothesis we have been pursuing is that spectral distinctiveness of the consonant is a predictor for the odds of contrast maintenance. To test this hypothesis, we regressed the log odds of maintenance as a dependent variable against spectral distinctiveness as an independent variable. If the regression analysis shows a significantly direct relationship between the two, we take that as support for the hypothesis. Figure 6 presents a scatterplot showing the Slavic odds of contrast maintenance as a function of synchronic spectral distinctiveness in modern-day Russian.

The correlation between the two variables was $r = 0.70$. We also regressed the log odds against spectral distinctiveness (LOGISTIC REGRESSION), with a resulting $F(1,8) = 7.9528$, $p = 0.022$. Thus there is a significant relationship between spectral distinctive-

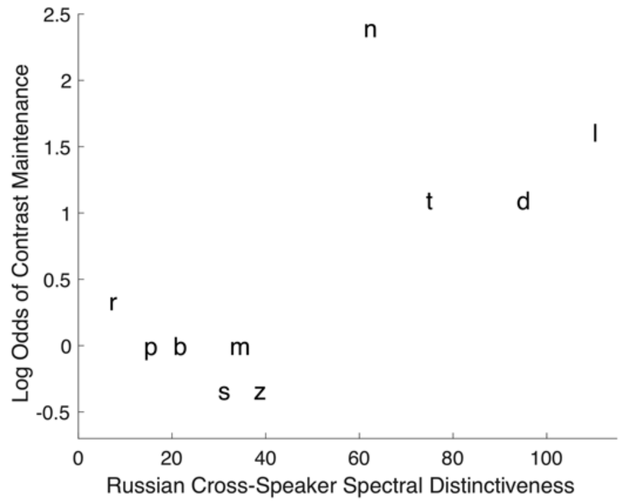


FIGURE 6. Odds of contrast maintenance as a function of spectral distinctiveness.

ness and the odds of contrast maintenance. However, it is important to note here that contrast maintenance does not imply that the contrast is maintained physically as it was. As was shown in §2, for instance, the /d/-/dʲ/ contrast is maintained in many languages, but the /dʲ/ often becomes phonetically a very different segment. This is different from the situation for the /n/-/nʲ/ contrast, where the nasal remains phonetically quite similar to a palatalized [nʲ] or perhaps becomes the closely related alveopalatal nasal.

In summary, we have provided data on the acoustic contrast between nonpalatalized and palatalized members of the pairs at the formant transition of the following vowel and during the middle of the consonant. The acoustic contrast at the formant transitions provides ample evidence for the phonological contrast, whereas the acoustic contrast at the middle of the consonant provides varying amounts of such physical distinctiveness, depending on the consonant.[23] Furthermore, there seems to be a significant relationship between the pattern of acoustic contrast at the middle of the consonant and the likelihood of maintenance of the contrast in the various Slavic languages studied.

5. DISCUSSION. Two major results have emerged from this work. First, the phonological investigation of Slavic palatalization has uncovered a basic pattern in which some consonants are more likely and others are less likely to preserve the contrast. Second, there is a significant relationship between the cross-speaker spectral distinctiveness of a contrast, measured in the middle of the consonant, and the odds that the contrast is maintained. Pairs for which there is high cross-speaker consistency in making the contrast have higher odds of contrast maintenance. However, pairs for which there is little to no phonetic differentiation within the consonant itself have higher odds of loss of contrast. This of course does not mean that low spectral differentiation causes the loss of contrast, since the contrast is maintained in Russian, which exhibits variability across speakers for pairs like /s/-/sʲ/. At this point, it is important not to interpret low spectral differentiation as merger. Indeed, the acoustic contrastiveness measured at the formant transition in Russian shows ample evidence of the phonological contrast for all consonant pairs. That is, the palatalization contrast is alive and well in Russian and is exhibited on the vowel. What the analysis in the previous section shows is not that /n/-/nʲ/

[23] It has been suggested by Bratkowsky (1980) that the palatalization contrast in Russian has been dislocated from the consonant onto the vowel. However, our findings show that several consonants still acoustically show the contrast during the consonant itself.

preserves the contrast and /s/-/sʲ/ does not. Both consonants preserve the contrast on the vowel. The results show that across speakers, the /n/-/nʲ/ contrast is preserved more uniformly in the spectrum than the /s/-/sʲ/ contrast.

In the next three subsections, we discuss the following two sources of nonuniformity involved in the sound change. (i) Consonant nonuniformity: Why do some consonants show greater spectral differentiation during the consonant than others? This is an important question, since there seems to be a link between spectral distinctiveness and contrast preservation. (ii) Language nonuniformity: Why do we get the linguistic diversity we find if similar phonetic factors exist for the speakers and listeners of the various languages? Of course, differences between communities arise out of social, cultural, and geographic factors, but are the resulting systems just arbitrarily different from each other, or are there ways to characterize the resulting contrastive systems from a systematic perspective? Many have given phonetic explanations of some sound change, and we attempt to do so as well in this article, but fewer have attempted to treat a typology of languages developing from the same language, where quite different changes have occurred, and therefore phonetic factors, which we presume to be similar across speakers of the daughter languages, are not sufficient for a full understanding of the typological diversity.

One theory that has been used to think about the development of contrast systems from a phonetic point of view is ENHANCEMENT THEORY (Keyser & Stevens 2006, Stevens & Keyser 2010). This theory argues that one way to maintain a phonological contrast that has subtle phonetic cues is to strengthen those cues so that they are more perceptually robust. We see a variety of such potential enhancements in the reflexes of the palatalization contrast in Slavic. An illustration of this from Table 2 would be the phonetic reflex of /dʲ/ in Belarusian, Polish, Sorbian, Slovak, and Czech, where the reflexes of the palatalized coronal have a sibilant portion, replacing the secondary articulation with a highly salient acoustic cue. For Polish, we see a change in primary place for the sibilants, which could also strengthen the cues for the contrast. For the nasal and lateral, many languages show a change in primary place, where the secondarily palatalized segment becomes palatal. This change in primary place also occurs for sibilants and the rhotic in Polish, and for the rhotic in Czech. As mentioned earlier, several sources have also argued that the plain consonants are velarized in Russian, which would also enhance the contrast phonetically.

One very interesting phonetic reflex of the contrast is the lateral in Polish and Sorbian. In that reflex, the plain lateral is phonetically realized as a labiovelar glide, and the palatalized segment emerges phonetically as a plain lateral. The lexical items in these languages that had been distinguished by the palatalization contrast in Proto-Slavic are now distinguished by a very different phonetic means, where words that had [l] now have [w], and words that had [lʲ] now have [l], a contrast shift. For languages that do maintain the contrast, we therefore see that phonetic change in the physical expression of the palatalized and nonpalatalized segments occurs to maintain or increase the phonetic differentiation of the phonological contrast. This is exactly what is predicted by enhancement theory, making it a valuable point of view from which to understand the phonetics of the contrast in the languages that maintain it.[24] However, it does not seem

[24] One problem with the exact predictions enhancement theory makes must be noted: the theory predicts that phonetic strengthening occurs by adding secondary gestures to acoustically/perceptually enhance some primary contrast, whereas what we actually see in Slavic is that a contrast in secondary articulation becomes a contrast in primary place (in those cases in Table 2 where the phonetic expression of the contrast is specifically indicated). However, we still believe that the theory, if modified sufficiently to account for diachrony, could be made to predict that the change from secondary to primary articulation could indeed be seen as enhancement.

that enhancement theory is sufficient to answer the questions we formulated earlier in this section about why certain consonants are more likely to maintain and others to lose the contrast, since we see enhancement in the coronal nasal as well as the coronal sibilant, for instance. That is, consonants that are likely to maintain the contrast as well as consonants that are likely to lose it may show enhancement.[25] We present additional phonetic factors at work in the next subsection.

5.1. Articulatory-acoustic factors. In order to further understand the diachronic phonology patterns and empirical acoustic results, in this section we investigate the physical characteristics of the production of Russian palatalized consonants, from the perspective of the acoustic theory of speech production (Fant 1960, Fujimura 1962, Stevens 1971, 1998, Shadle 1985, McGowan 1992, Narayanan & Alwan 1995, Howe & McGowan 2005). This theory relates the area function of the cavities in the vocal tract (filter) and the locations and magnitudes of aerodynamic sources of sound to the spectrum of the sound output from the vocal tract. That is, given the configurations of the articulators and knowledge of pressures and volume velocities in the vocal tract, as well as aerodynamic pressures and flows, the acoustic theory of speech production is able to predict the spectrum of the resulting sound.

To determine the predictions of the theory for palatalized consonants, we need to understand the articulatory configurations involved in the production of these consonants. The most basic question to be answered by such data is whether all of the consonants usually thought of as palatalized are indeed articulatorily palatalized. It is possible, for instance, that only [nʲ], [lʲ], [tʲ], [dʲ] are in fact phonetically palatalized in the actual production of these consonants. In that case, we would have an articulatory explanation of the diachronic phonology and empirical acoustic patterns presented earlier. Luckily there is ample articulatory measurement of Russian consonants, using a variety of articulatory techniques: X-ray (Fant 1960, Bolla 1981), palatography (Bolla 1981), electromagnetic midsagittal articulography (Kochetov 2002), MRI (Kedrova et al. 2008), and ultrasound (Litvin 2014). Regarding the main question of the presence of an articulatory secondary-palatalization gesture in the palatalized consonants, the studies are in agreement: all of the palatalized consonants investigated have a palatalization gesture.

These gestures can be clearly seen in the MRI study by Kedrova and colleagues (2008) for the following pairs: [p]-[pʲ], [b]-[bʲ], [k]-[kʲ], [g]-[gʲ], [x]-[xʲ], [t]-[tʲ], [s]-[sʲ], [d]-[dʲ], [z]-[zʲ], for several subjects. In all of the palatalized consonants, the front of the tongue dorsum is at a small distance from the front of the hard palate, whereas in the plain consonants, there is a much larger distance between the dorsum and the hard palate. The articulatory pattern is therefore in excellent agreement with the traditional phonological characterization of these consonant pairs. Furthermore, the articulatory results obtained in the listed studies agree with one of our main acoustic results, which is that all of the palatalized consonants have a portion near the vowel whose acoustics is indeed consistent with the presence of a palatalization gesture in articulation.

So if a palatalization gesture is present in all of the palatalized consonants in Russian, why then do some consonants show a high degree of acoustic differentiation between the plain and palatalized consonant in the central part of the consonant—for example,

[25] One possible use of enhancement theory as a phonetic explanation of the typology of contrasts in the modern Slavic languages is to say that if the contrast is enhanced, it is maintained, and if it is not enhanced, then it is lost. However, if enhancement were a phonetic method to bolster a phonological contrast, which is exactly what Stevens and Keyser (1989) have suggested, then we would predict that enhancement would occur to prevent merger in weak positions, such as coda position, but that is of course not the case (Hall et al. 2016). In Bulgarian, for instance, this is exactly the position where the contrast is lost.

why does the [n]-[nʲ] pair show high differentiation in the middle of the nasal murmur, whereas the [z]-[zʲ] pair shows poor differentiation in the middle of the sibilant noise, or why does the [d]-[dʲ] pair show high differentiation in the burst, whereas [b]-[bʲ] shows low differentiation in the burst?

We now show that the acoustic theory of speech production predicts that the articulatory palatalization gesture is audible in the output acoustics of certain consonants, but is predicted to be nearly silent for other consonants. It is important to note here that we are speaking only about the portion of speech during the central part of the consonant itself, not the portion close to the vowel, since we have already seen that the palatalization gesture is audible near the vowel for all palatalized consonants. When the primary constriction of the consonant has been released, the palatalization gesture is still present for an amount of time that is sufficient to influence the acoustic output for all of the consonants. We now present the predictions of the acoustic theory of speech production for each consonant pair, starting with pairs that show maintenance of contrast and then proceeding to pairs that show merger in some of the Slavic languages.

Bolla (1981) provides X-ray and palatographic data on /n/-/nʲ/, showing that the palatalized consonant clearly has a palatal constriction and a lowered velum; see Figure 7, adapted from Bolla's plates 50–51. Therefore, the sound for this consonant, which is generated at the glottis, is radiated through the nasal cavity. The dashed line indicates a lateral edge of the tongue superimposed on the solid line, which is for the midsagittal edge.

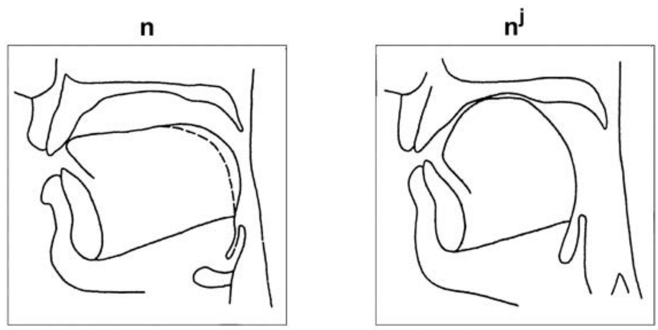


Figure 7. Tracings of the articulatory structures for [n] and [nʲ] in Russian (adapted from Bolla 1981).

Using the acoustic theory of speech production, Fujimura (1962) predicted that the oral configuration for nasal sounds would be audible in the nasal murmur, since the oral tract acts as a parallel filter to the main nasal filter taking sound from the glottis to the nostrils. Indeed, Fujimura showed that labial, coronal, and velar nasals have different patterns for formants and antiformants due to the differing articulatory configurations in the oral cavity. Basically, the oral cavity captures energy from the acoustic output at the nostrils at frequencies at which the closed oral cavity resonates; therefore at these frequencies the output at the nostrils has antiformants due to the oral configuration. Since the palatalization gesture has a major effect on the configuration of the oral tract, we would thus predict that the acoustic output from the nostrils would have antiformants at formants of the oral tract due to the palatalization gesture.

As is well known, palatalization causes F2 to be high around 2 kHz, and F3 to be low and close to F2, and we expect high energy in that F2-F3 region (Fant 1960). This effect of the palatalization gesture on the acoustics of the vowel [i] has been extensively studied for Russian by Chistovich and her school (e.g. Chistovich & Lublinskaja 1979). The high energy between 2 kHz and 3 kHz due to the palatalization gesture should therefore be expected to contribute a DIP in acoustic output at the nostrils, since the oral cavity is effectively stealing energy at these frequencies from the output at the nostrils. This is exactly what we see in Fig. 3c above, where the palatalized consonant [n^j] shows a dip in energy in the F2-F3 region of 2–3 kHz, with respect to the nasal consonant [n]. The acoustics of [n^j], as measured in our experiment, therefore confirms the prediction of the acoustic theory of speech production, showing that for this consonant, the palatalization gesture is amply represented in the acoustic output of that consonant, in the middle of the consonant.

Figure 8 provides X-ray and palatographic data on [l]-[l^j] (adapted from Bolla 1981, plates 78–79). The X-ray data show the palatalization gesture, and the palatographic data show the tip articulation in the center of the palate, while the side channels are open, as would be expected for a lateral. Therefore, the sound generated at the glottis for [l^j] comes out through the side channels of the tongue and is predicted to be shaped by the articulatory configuration in the rest of the articulatory cavity (Stevens 1998). The theory thus predicts that the palatalization gesture should be audible throughout [l^j], as the acoustic results show (Fig. 4a).

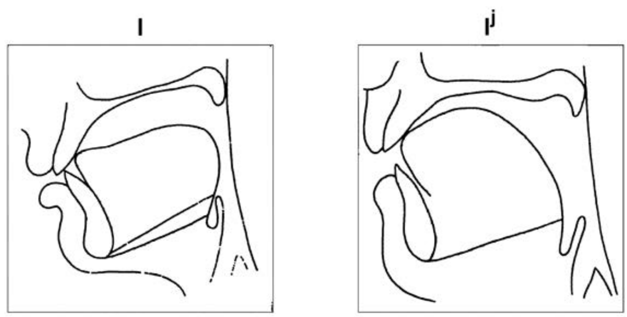


FIGURE 8. Tracings of the articulatory structures for [l] and [l^j] in Russian (adapted from Bolla 1981).

For obstruent coronal stops, sound is produced both near the glottis (voice or aspiration) and at the stop-constriction location, and it is this latter source of energy that is most relevant for the sound energy in the burst (Stevens 1998). The filter that shapes the plosive sound source in the coronal region is then filtered only by the front cavity, extending from the constriction in the coronal region to the oral output at the lips. Most importantly, the spectral shape of the burst should be highly sensitive to the length of the front cavity, but not to what is happening in the back cavity, since the back cavity is decoupled from the front by the extreme closure of the vocal tract involved in obstruents. Specifically, the burst is not predicted to be spectrally affected by the presence of the palatalization gesture in the back cavity, which is mostly acoustically inert, when an obstruent constriction is present between the front and the back cavities. It would therefore seem that the acoustic theory of speech production predicts a low level of differentiation between the plain and palatalized coronal stops, counter to the acoustically measured differentiation seen in Fig. 3a–b. But this prediction is based on the assumption that the plain and palatalized coronal stops are produced at the same location. This assumption is falsified by articulatory data.

The two studies that provide imaging evidence of the location of the primary constriction and the secondary gesture, Bolla 1981 (plates 42–43, adapted in Figure 9) and Kedrova et al. 2008, make specific comments about the different places of articulation of the stop closure for the plain and palatalized coronal consonants, evidenced in their X-ray, palatographic, and MRI data. Specifically, both studies note that the palatalized coronal obstruent stops are produced more posteriorly than the plain ones. We conjecture that this is due to the blending of the coronal and palatalization gestures for the palatalized coronal stops, due to the lack of independence of the tongue tip and early dorsum. The tongue tip is movable mostly by displacing the tongue body and/or the jaw (Iskarous et al. 2010) when those larger articulators have no task of their own. But when the tongue body has its own task, palatalization, and the tongue tip has a task as well, coronal closure, the articulators carry out both tasks simultaneously, blending their effects. The existing articulatory data show differentiation in place of closure for the plain and palatalized, which is consistent with the blending explanation. Specifically, the palatalized coronal consonant's place is more posterior, which predicts lower resonance frequency for the front cavity for the palatalized coronal obstruents than the plain ones, exactly as we see in the acoustic results of Fig. 3a–b.

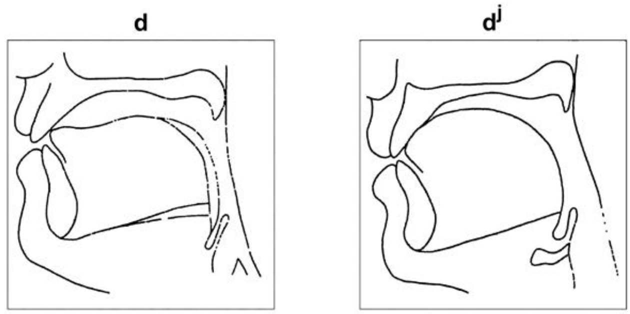


Figure 9. Tracings of the articulatory structures for [d] and [dʲ] in Russian (adapted from Bolla 1981).

Therefore, for the four consonant pairs that show higher acoustic differentiation and a higher chance of being preserved in Slavic languages, we find that the articulation of the palatalization gesture is either directly audible by filtering the acoustic energy ([nʲ] and [lʲ]) or indirectly audible by affecting the place of articulation of the stop closure ([tʲ] and [dʲ]). Interestingly, the difference between direct vs. indirect effect on the sound is correlated with the detail of the diachronic pattern. Whereas *nʲ and *lʲ are maintained almost as is (their plain palatal variants being phonetically very close to the original palatalized consonants) from Proto-Slavic to almost all daughter Slavic languages today, *tʲ and *dʲ have a more complex history, often becoming other consonants when the contrast is preserved.

For the palatalized labial obstruents [bʲ] and [pʲ], just like with the coronals, the palatalization gesture is behind the constriction, and the front cavity, which filters the sound source at the lips, is the extremely short extent of the lips themselves (Stevens 1998). Therefore, the palatalization gesture does not figure into the filtering of the sound produced at the lips (until perhaps very late into the burst, near the vowel). We saw that for the coronal obstruent stops, as well, there was no direct filtering of the sound by the palatalization gesture. But for those consonants, the tongue tip could be affected by the tongue dorsum, creating a more posterior closure and lowering the front cavity resonance. Of course, the lips are not affected by the tongue dorsum in this way, and thus the acoustic theory of speech production predicts that there is neither direct nor indirect influence of the palatalization gesture on the sound produced at the lips, as the acoustic pattern in Fig. 5a–b shows. We believe that the fact that the palatalization gesture is unable, directly or indirectly, to influence the labial burst spectrum is the cause of a general crosslinguistic dispreference for palatalized labials, thoroughly discussed by Hock (2006) in his paper '*[+labial, +palatalized]'.

For the sibilants [s^j] and [z^j], Bolla 1981 (plates 56–57, adapted in Figure 10) and Kedrova et al. 2008 show that there are palatalization gestures, with some difference, perhaps, in the orientation of the tongue tip for the plain and palatalized counterparts, most likely due to the same blending effects we see in the coronal stops, as discussed above.

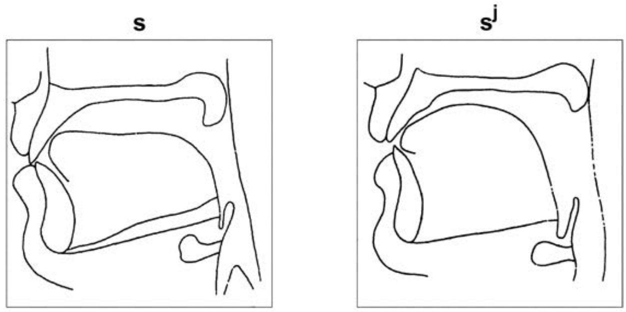


FIGURE 10. Tracings of the articulatory structures for [s] and [s^j] in Russian (adapted from Bolla 1981).

In the upper part of the spectrum, as can be seen in Fig. 4c and d, both sibilant pairs are highly overlapped spectrally. Why are the sibilant noises in the plain and palatalized counterparts not highly distinguished acoustically? As with the stops, the palatalization gesture is in the acoustically hidden back cavity, and thus the acoustic theory of speech production predicts decoupling of the back cavity and front cavity (Shadle 1985, Stevens 1998). Thus there is no direct filtering effect of the posterior palatalization gesture on the noise produced in the coronal region. What of the indirect influence on the acoustic spectrum? Why does the difference in tongue-tip orientation, observed by Bolla (1981) and Kedrova and colleagues (2008), not introduce a difference in the spectrum, as we saw with the obstruent coronal stops? The answer lies in the fact that for the sibilants, the front cavity, whose resonances we see in the spectrum, extends from the teeth, where the sound source is, not the constriction at the tongue tip (as is the case with the coronal stops), to the termination of the vocal tract at the lips. Indeed, Shadle (1985) and Howe and McGowan (2005) have argued that the most crucial determinants of the sound source are the front teeth obstacle to the air jet exiting the constriction. This obstacle acts as a highly efficient converter of kinetic energy of jet flow to audible aeroacoustic energy of vibration. Therefore, for the sibilants, both the palatalization and the tongue-tip constriction lie behind the entrance of the front cavity, which extends from the teeth to the lips. So, neither direct (palatalization) nor indirect (tongue tip) articulatory factors during the production of the palatalized sibilant lead to spectral coloring in the output acoustics.

The trill is quite a special case to consider, since it is crucially a dynamic segment. The tongue tip vibrates, alternately tapping against the alveolar ridge and then lowering. When the tongue tip taps against the alveolar ridge, a sound source is generated near the alveolar ridge, and the output sound is conditioned by the front cavity from the source to the exit of the vocal tract at the lips. Examination of Bolla's (1981) X-ray pictures shows little difference between the tap sites for the plain and palatalized counterparts, despite the clear presence of the palatalization gesture for [r^j] (Figure 11, adapted from Bolla 1981, plates 76–77).

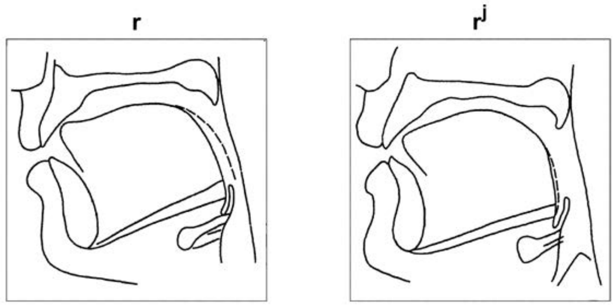


FIGURE 11. Tracings of the articulatory structures for [r] and [rʲ] in Russian (adapted from Bolla 1981).

We observe the acoustic reflection of this in Fig. 4b, which shows cross-speaker overlap in overall spectral shape for the plain and palatalized trills. This is quite consistent with the situation for the sibilants, where the palatalization gesture is acoustically hidden because it is posterior to the source. However, when the tip is down, in the open phase of the trill, the only source of sound is at the glottis (ignoring distributed low-energy sources along the walls), and now the palatalization gesture is potentially audible, since it can influence the transfer function from the glottis to the lips. But due to cross-speaker differences in entire vocal-tract size, the acoustic differences between the two trills would not show cross-speaker consistency. This is indeed what was reported in a detailed study of the acoustics of plain and palatalized trills (Iskarous & Kavitskaya 2010). In figures 4 and 5 of that article, it can be seen that each speaker distinguishes the palatalized and plain trills in the open phase of the trills, but crucially, that data had to be normalized to show within-speaker consistency. Despite the within-speaker consistency, the across-speaker spectral differentiation is poor, as opposed to the [l]-[lʲ] case, where all of the speakers examined show the distinction in the same spectral region acoustically. This illustrates that within the natural class of liquids, we see different articulatory-acoustic principles at play and different diachronic trajectories.

For the last consonant pair investigated, [m] and [mʲ], articulatory data show a clear palatalization gesture, which is also acoustically audible, as we see in Fig. 5c. The acoustic theory of speech production predicts distinguishability for the same reason as for the coronal nasal pair, since sound emitted at the glottis and output at the nostrils would be filtered by the oral cavity terminated at the lips. This explains the results of the perceptual experiment reported in Kavitskaya 2006. This study showed that listeners are able to distinguish [m] from [mʲ] very early on, even at the 30 ms gate. Therefore, the acoustic theory of speech production does predict what we observe acoustically. As we saw in §2, however, the nasal labial pair diachronically patterns with the labials, not with the nasals. This consonant is thus an exception to the phonetic account we have offered relating the detailed link between articulation and acoustics to the diachronic pattern.

To summarize, we have argued for the existence of an articulatory-acoustic constraint on the sound change in the secondary-palatalization contrast in Slavic. This constraint links the acoustic evidence for the palatalization gesture in the middle of the consonant to the likelihood of merger or preservation of contrast. In terms of the program for the study of sound change initiated by Weinreich and colleagues, discussed at the outset of this article, this subsection is a contribution to the constraints problem for this particular change. Moreover, we believe that the acoustic study and the articulatory-acoustic reasoning presented in this subsection contribute to the development of our understanding of orderly heterogeneity. The interpretation of the acoustic results we have provided is that variability among speakers in the acoustic indication of the palatalization gesture is essential to constraining the sound change, with the consonants with greater variability among speakers showing less spectral distinctiveness between plain and palatalized, leading to greater likelihood for merger. This variability is not haphazard and random, but rather is driven by the orderly laws of acoustics relating the properties of acoustic sources and filters to the output sound.

The argument based on acoustic-articulatory relations states that there is less information about the palatalization gesture emerging from the vocal tract in labial palatalized stops than in coronal palatalized stops. This predicts that perceivers are more likely to confuse labial palatalized stops with other consonants than they are likely to confuse coronal palatalized stops with other consonants. Kavitskaya 2006 presented a perception experiment where Russian listeners identified consonants from a gated signal with four gates. It was found that identification was significantly worse for labial palatalized stops than for their coronal counterparts. Listeners needed information that is close to the vowel for the palatalized labials but not the coronals, which were identified from the signal early on. This agrees exactly with the prediction of the account provided in this section, at least for the consonants covered in Kavitskaya 2006, indicating that the acoustic-articulatory factors could actually affect the speech communication process, providing evidence for a listener-based initiation of sound change (Ohala 1981, 1983, 1989, 1992).

One problem with the phonetic account presented so far is with the overemphasis on interspeaker variability, which is the only kind of variability investigated in Figs. 2–5. There are many cases of contrasts whose phonetic distinctiveness is almost purely intraspeaker, such as tonal contrasts and, to a certain extent, vowel contrasts. As an example, consider the contrast between high and low tones. Since vocal folds vary greatly in their mass and elasticity, a high tone for one speaker with heavy vocal folds could have the same F0 as a low tone for a speaker with light vocal folds. In this case, an evaluation of interspeaker variability similar to what was done earlier would show considerable interspeaker overlap between the F0 values of low and high tones, from which a similar line of reasoning would predict the difficulty of maintenance of such a contrast. This is, of course, exactly the wrong prediction, since intraspeaker distinctiveness is entirely sufficient for the maintenance of the low/high tone contrast. Based on the sufficiency of intraspeaker contrast,[26] it could be argued that if individual speakers distinguish [s]-[s^j], for instance, and if individual listeners are able to hear the contrast, then the argument based on interspeaker variability would be vacuous, even if predictive of the diachronic pattern. Indeed, visual examination of within-speaker spectra does reveal that individual speakers distinguish [s]-[s^j] not only in the formant transition, but even in the later portions of the fricative.

Why then is the account given not vacuous? There is a major difference, we believe, between tone and vowel contrasts on the one hand, and consonantal contrasts on the other, and this difference can be understood when we examine phonetic theories that try to account for the distinctiveness of contrasts despite interspeaker overlap. Perhaps the most successful such theory is the exemplar model of Johnson (1997), which has been carried through to account for aspects of diachrony in Garrett & Johnson 2013. In that model, a percept of a particular phonetic segment is made up of all heard instances of that segment, not just of a prototype (e.g. mean) or the distribution of sensed instances.

[26] The reason intraspeaker distinctiveness is not investigated here is that the statistical study would be of low power.

Moreover, these heard instances are also labeled with the speakers that produced them, not just the abstract phonetic label. When listeners hear a vowel, they classify it according to the closest sensed point in the exemplars of the contrastive phonetic elements of a linguistic system, where the metric determining closeness is based on the phonetic label as well as speaker characteristics. Such a model would then be able to label an F0 from a particular speaker as coming from either a low-tone or high-tone element of a contrast, based on how well that token resembles instances by similar speakers. The main difference between tonal or vocalic contrasts and consonantal contrasts, given this model, is that F0 and formants necessitate very few degrees of freedom in their descriptions, one to five perhaps, whereas consonantal spectra are high dimensional, since information about amplitude of many frequencies is required to characterize a spectrum. Therefore, the phonetic auditory aspects of an F0 instance may require a one-dimensional comparison of heard-token distributions, whereas the auditory aspects of a fricative may require a larger number (even if moments are used) of degrees of freedom.

Now it is well known from the machine learning literature (e.g. Bishop 2006:33) that classification in high-dimensional spaces is a much more difficult task than classification in a low-dimensional space. This phenomenon makes classifiability/distinctiveness in high-dimensional spaces so difficult that it is usually termed the curse of dimensionality (Bellman 1957). This, we believe, is the key to the interspeaker distinctiveness argument for consonantal spectra. Pairs like /t/-/tʲ/, in which both intraspeaker and interspeaker distinctiveness are present, make a large interspeaker distributional difference in the exemplars easy to identify. Pairs like /s/-/sʲ/, in which intraspeaker distinctiveness is present, but interspeaker distinctiveness is small to absent, are much harder to identify in a high-dimensional exemplar space, based solely on the intraspeaker distinctiveness. Therefore, the curse of dimensionality would make INTERSPEAKER distinctiveness the relevant measure to consider for deciding on consonant spectra classification, NOT ONLY INTRASPEAKER VARIATION. When both intraspeaker and interspeaker distinctiveness are present, as in /t/-/tʲ/, the high-dimensional classification task is easier than if only intraspeaker variation is present, as in /s/-/sʲ/.

5.2. Phonological factors. We have discussed three factors constraining the diachrony of palatalization in Slavic: (i) the general markedness of the secondary place of articulation of palatalization; (ii) the force for contrast maintenance; and (iii) the articulatory-acoustic differentiation between consonants. Each of these forces by itself makes very concrete predictions about the direction of change in the contrast, and indeed each of these forces goes a long way toward explaining the change or lack thereof in one of the scenarios we see in Table 2, but FAILS in the other attested scenarios. Specifically, (i) if the markedness of secondary palatalization were the only relevant force, then all of the languages would show complete merger, as in Slovenian; (ii) if contrast maintenance were the only relevant force, then all languages would preserve the contrast (at least in some position), like Russian, Bulgarian, and Polish; and (iii) if the articulatory-acoustic differentiation between the consonants discussed in the previous section were the only relevant force, then all of the languages would show merger with the non-palatalized member of the pair for /pʲ/, /bʲ/, /sʲ/, /zʲ/, and /rʲ/ (henceforth AA−, since their articulatory-acoustic transform does not give evidence for the palatalization) and would preserve the contrast for /tʲ/, /dʲ/, /lʲ/, and /nʲ/ (henceforth AA+), as in Slovak.

To account for diachronic diversity, it seems necessary to refer to a competition between the different forces or preferences, and to the possibility that the different forces have different strengths. For this reason, many nineteenth- and twentieth-century linguists talked about diachronic change as different means of settling the competition between simultaneously existing forces, as stated in Hoenigswald 1961:25: 'It is reasonable to suspect the interplay of two sources at work: One which holds back change in the interest of mutual intelligibility at any given time; and another force, much more obscure in its workings, which makes for change, even intense change'. Haspelmath (1999) cites many other instances of informal reference to interplay of forces. Of course, synchronic grammarians also reached the conclusion by the late 1980s (e.g. Goldsmith 1990:332) that constraint competition is at the heart of linguistic computation, culminating in the framework of OPTIMALITY THEORY (OT; McCarthy & Prince 1993, Prince & Smolensky 2004 [1993]). In this section, we present an OT account of the synchronic grammars of the modern Slavic languages, showing how variation in Proto-Slavic from an OT perspective leads to an integrated account of synchrony and diachrony.

In today's theoretical climate, which is still influenced by the antinomy between synchrony and diachrony, it may seem that a synchronic account is an inefficient duplication of explanation, since if one uses a phonetic explanation, why seek a phonological one as well? The notion that synchronic phonological and diachronic phonetic accounts are in zero-sum competition is fully pursued in the EVOLUTIONARY PHONOLOGY program (Blevins 2007). The idea presented there is that synchronic phonological grammars should only be invoked when no phonetic/typological explanation can be found. We add to the critique of this zero-sum approach (de Lacy & Kingston 2013, Anderson 2016) by relying on profound and extensive work in diachronic typology showing that specification of synchronic grammars is an essential first step in establishing the possible directions of change.

Greenberg's STATE-PROCESS model of diachronic and synchronic typology (Greenberg et al. 1963, Greenberg 1965, 1978, 1995) considers languages to exist in certain synchronic states, and diachrony describes the transitions between these states. For instance, having and not having tones are two synchronic states; therefore tonogenesis and monogenesis (the neutralization of the tonal contrast) are the possible diachronic transitions. Greenberg (1966) argued that one of the great hopes of diachronists—understanding the set of possible diachronic changes at any time during the development of a language—can be realized only when one has characterized the possible synchronic states of languages.[27] This reflects earlier insights by historical linguists such as Hoenigswald, who wrote that 'the typology of change is subordinate to the typology of existing states' (1961:31). Greenberg (1978) attempted to further develop the model to deal with possible synchronic phonological and syntactic states that are much more complex in order to deal with highly complicated diachronic transitions, where the directions of change are numerous. We believe that these attempts may have been limited by the simplicity of how synchronic states were specified, especially as they become more complex. The state-process model, born of the broadest work on typology, is incompatible with the idea fundamental to the evolutionary phonology paradigm that invokes a competition between typological and synchronic explanation, since there is no such competition if our understanding of diachronic typologies necessitates an understanding of synchronic ones.[28] A further reason for the invocation of synchronic

[27] Greenberg (1966) also argues the opposite point, that understanding of diachronic universals could help us figure out why certain synchronic phenomena are common and others not, a point we believe is equally important but has been thoroughly underappreciated by synchronic grammarians working in the shadow of the antinomy.

[28] The need for a synchronic grammar is further necessitated if we examine phonetically quite detailed recent work on sound change in progress, which has argued for a view of sound change as being IMMEDIATELY phonological in nature (Fruehwald 2013, Labov n.d.). The main idea of this work is that 'speakers choose between different phonological systems, not simply between different variable realizations of a category'

grammars is that languages can be stable for many hundreds of years. Phonetic factors that are indeed relevant for the initiation of a sound change are not sufficient to account for how the new phonological states have lasted for one thousand years. Historical transmission of the language state through learned synchronic grammars, we believe, is essential to understanding the stability of a change, once it has been initiated.

One of the most attractive things about using OT to describe sound change involving merger and contrast maintenance is that the fundamental notions of 'markedness' and 'faithfulness' take on a special meaning in that context. In the words of Prince and Smolensky (2003), '[i]f phonology is the computational link between the lexicon and phonetic form, then Markedness is the advocate of the phonetic interface, Faithfulness the agent of the lexical interface'. Therefore, the notion of markedness can be used to express the idea that languages prefer or disprefer a particular type of phonetic output. In the case of Slavic palatalization, the dispreference can be expressed as a markedness constraint *C^j (see Takatori 1997 for a similar proposal). This statement can be taken as a markedness constraint in the tradition of Trubetzkoy (1939), who defined the notion of a marked feature value to denote the less attested and more unstable element of an opposition. Of course, the notion of markedness is not unproblematic (Haspelmath 2006), but we believe that in the case of segments with secondary contrast, it is uncontroversial that the marked value for the contrast is that where the secondary feature is present, regardless of whether the dispreference is for perceptual or articulatory reasons (Kochetov 2002, Kavitskaya 2006). Framed as a constraint on the secondary-palatalization contrast, it points to which of the two members of the pair is likely to disappear if merger occurs.[29]

A faithfulness constraint balancing *C^j is IDENT(Pal) (Padgett 2003a), which expresses the identification of a lexical palatalization gesture with that same gesture in the output. This constraint is violated if the lexically specified palatalization gesture does not survive into the spoken output. We would like to note how the faithfulness to the learned lexicon of IDENT(Pal) and the functional force of change implicit in *C^j present a formalization of the two forces in diachrony mentioned by Hoenigswald (1961). Furthermore, OT allows for the parameterization of constraints; IDENT(Pal) can be parameterized as to whether the consonant it applies to is of the AA+ class or the AA− class, so we obtain two faithfulness constraints: IDENT(Pal_{AA+}) and IDENT(Pal_{AA-}). IDENT(Pal_{AA+}) favors palatalization identity when the primary contrastive gestures in combination with the articulatory-acoustic transform allow for the maximal acoustic expression of the palatalization gesture, while IDENT(Pal_{AA-}) favors palatalization when the primary contrastive gestures in combination with the articulatory-acoustic transform do not allow for the maximal acoustic expression of the palatalization gesture. Both IDENT constraints are vacuously satisfied when the consonant in the input is a member of the other set.

Several proposals have been made within OT to freeze rankings of certain constraints for cognitive and phonetic reasons. Steriade (2008) proposed one such device, the P-map, based on perceptual factors. This device is used by the present account to fix the ranking of the two faithfulness constraints IDENT(Pal_{AA+}) and IDENT(Pal_{AA-}), with the former always ranked higher than the latter, encoding the main phonetic factor dis-

(Kiparsky 2016:483). Indeed, Fruehwald (2013) provides several strong arguments for the nongradual nature of the phonologization of sound changes.

[29] It needs to be pointed out that the *C^j constraint is not a shadow synchronic constraint of some related diachronic constraint, making the synchronic constraint redundant. In the account we provide, diachronic merger results from the promotion of this same *C^j constraint.

cussed in the last section: AA+ consonants give more evidence of the palatalization gesture, so maintaining that gesture in them is more appropriate than maintaining it in the AA− set. We believe that the ability of phonetics to influence phonology both in the posing of markedness constraints and in the occasional freezing of constraints is a major factor in the appropriateness of OT for thinking about diachrony. The fact that constraints are rankable, modulo fixed rankings for nongrammatical reasons, is an important part of a phonological account of diachrony. In the early days of OT, Kiparsky (1993) proposed the partially ordered theory of variability within an OT grammar (Antilla 2007, Coetzee & Pater 2011). In this theory, a language going through a stable period is characterized by a certain constraint ranking. Variability at the time of sound change is then accounted for by the loss of ranking of relevant constraints. Different subcommunities can then rank the constraints in different ways. Proto-Slavic itself, we assume, had the ranking IDENT(Pal_{AA+}), IDENT(Pal_{AA-}) >> *C^j. When the sound change commenced, that ranking was no longer in effect. What the theory is able to predict now are the possible directions of change. For three constraints, six rankings are possible. But with the articulatory-acoustically motivated (and perceptually relevant) P-map[30] (or some other mechanism to freeze constraints, such as harmonic alignment), only three rankings exist. These rankings constitute the OT account of the types of daughter languages under variability. From the point of view of Greenberg's state-process model, we could see OT as specifying the possible synchronic states.

The tableaux in 17–19 show how the predicted possible rankings of these constraints correspond to three types of modern languages: (i) those where the contrast is always maintained (as in 17 for an initial analysis of Russian, Polish, and Bulgarian); (ii) those where the contrast is maintained only in the context in which the articulatory-acoustic transform favors the acoustic expression of the palatalization gesture (as in 18 for an initial analysis of Slovak); and (iii) those where the contrast is always suppressed (as in 19 for Slovenian). In each example, the tableau for the nasal exemplifies the pattern that reflects coronal stops and the lateral, and the tableau for the sibilant shows the pattern that also reflects labials and the trill.

(17) Palatalization and contrast preservation: Russian, Polish, Bulgarian

n^j	IDENT(Pal_{AA+})	IDENT(Pal_{AA-})	*C^j
n	*!		
→ n^j			*

s^j	IDENT(Pal_{AA+})	IDENT(Pal_{AA-})	*C^j
s		*!	
→ s^j			*

[30] The P-map is likely to be relevant not only to the perceptibility of palatalization in different consonantal contexts, but also to palatalization in different prosodic positions (e.g. onset/prevocalic vs. coda/postvocalic), as presented by Steriade (2008) for [voice] and discussed by Kochetov (2002, 2004) for palatalization.

(18) Palatalization and contrast preservation: Slovak

n^j	IDENT(Pal_{AA+})	$*C^j$	IDENT(Pal_{AA-})
n	*!		
→ n^j		*	

s^j	IDENT(Pal_{AA+})	$*C^j$	IDENT(Pal_{AA-})
→ s			*
s^j		*!	

(19) Palatalization and contrast preservation: Slovenian

n^j	$*C^j$	IDENT(Pal_{AA+})	IDENT(Pal_{AA-})
→ n		*	
n^j	*!		

s^j	$*C^j$	IDENT(Pal_{AA+})	IDENT(Pal_{AA-})
→ s			*
s^j	*!		

This analysis combines phonetic and phonological factors. The phonetic factors are expressed in the phonetic motivation of the markedness constraint and in the fixing of the faithfulness constraint ranking due to phonetic considerations. The phonological factors are expressed in the following ways: (i) the free rankability and violability of the markedness constraints; (ii) the presence of faithfulness to the contrasts in the lexicon, which motivates the IDENT constraints and their violability; and (iii) the rankability of the faithfulness constraints, up to the restrictions in ranking enforced by the phonetics. The first phonological factor leads to what we would like to call the mobility of markedness, from the bottom in Russian, to a higher position in Slovak, and highest in Slovenian.[31] We believe this to be an important part of accounting for the diversity among the languages. In this light, Kiparsky's (1993) theory of variability can be seen to further Greenberg's state-process model, discussed earlier. What the latter model lacks is a notion of how to rigorously define a type of a language state. Kiparsky's (1993) theory provides exactly such a rigorous definition: the states of a language are rankings of universal constraints. The theory also sheds light on what the possible routes or processes of diachrony would take: new constraint rankings. Unfortunately, while the twentieth century saw enormous progress in both linguistic typology and the characterizing of synchronic grammars, a great deal of that work developed in the shadow of the Saussurean antinomy of synchrony and diachrony; models that developed on the two sides have therefore rarely been combined (see, however, Haspelmath 1999 and work on amphichronic explanation in phonology, in particular Kiparsky 2006, Bermúdez-Otero 2015).

[31] A referee suggests potential accounts of Slovenian that hinge either on the symmetry pressures that eliminated the one remaining palatalized sound or on a low functional load of the remaining contrast. While these accounts are in principle plausible, they do not seem to hold in the case of Slavic. For instance, Serbian and Croatian preserve the contrast only for the laterals and the coronal nasals. This may be more than one remaining contrast, but there are still only two remaining pairs, which shows that there are languages where palatalization arguably undergoes similar symmetry pressure and has functional load similar to that in Slovenian, but in which the merger did not happen.

However, the account presented so far does not take into consideration the full range of variation in the languages. One way to account for this variation is to further parameterize the IDENT(Pal) constraints, which enables an OT account to fit the actual diachronic outcomes, but, as is discussed later, could be argued to be a form of data-fitting. The constraint IDENT(Pal_{AA+}) can be replaced with several constraints, such as IDENT(Pal_n), IDENT(Pal_T) (where T includes both coronal stops, [t] and [d]), and IDENT(Pal_l), and the constraint IDENT(Pal_{AA-}) can be replaced with IDENT(Pal_S) (where S includes both fricatives, [s] and [z]), IDENT(Pal_r), IDENT(Pal_P) (where P includes both labial stops, [p] and [b]), and IDENT(Pal_m). Table 6 presents the rankings of the constraints required to account for the phonological contrast systems of the Slavic languages discussed.

Russian, Polish, Bulgarian	IDENT(Pal_{nlT}), IDENT(Pal_{PSmr}) > $*C^j$
Belarusian	IDENT(Pal_{nlT}), IDENT(Pal_{PSm}) > $*C^j$ > IDENT(Pal_r)
Ukrainian	IDENT(Pal_{nlT}), IDENT(Pal_{rS}) > $*C^j$ > IDENT(Pal_{Pm})
Upper, Lower Sorbian	IDENT(Pal_{nlT}), IDENT(Pal_{rmP}) > $*C^j$ > IDENT(Pal_S)
Slovak	IDENT(Pal_{nlT}) > $*C^j$ > IDENT(Pal_{mrPS})
Czech	IDENT(Pal_{nT}), IDENT($Pal_{\mathbf{r}}$) > $*C^j$ > IDENT(Pal_l), IDENT(Pal_{mPS})
Macedonian, Serbian, Croatian	IDENT(Pal_{nl}) > $*C^j$ > IDENT(Pal_T), IDENT(Pal_{mrPS})
Slovenian	$*C^j$ > IDENT(Pal_{nlT}), IDENT(Pal_{mrPS})

TABLE 6. Rankings to account for the phonological contrasts of Slavic languages.

Despite the much greater complexity of the system of constraints in Table 6, as compared to those in the tableaux above, we still see an important phonological generalization. What is true of all the languages, with the exception of the Czech lateral, is that when the faithfulness constraints are ranked with respect to one another, the ones below the markedness constraint, if any, are the ones where the palatalization gesture is hidden by the articulatory-acoustic transform.

One question that we do not address in this work is how to account for the fact that the contrast is sometimes (arguably) maintained as it was in late Proto-Slavic, as in Russian [t]-[tʲ], and is sometimes changed to a different phonetic contrast, as in Polish [t]-[tɕ]. It is important to invoke enhancement theory, as we did earlier, but this still does not solve the problem of why some languages maintain the contrast almost exactly as it was, whereas others use different phonetic exponents. Even though one could construct an OT account of this variation, we believe that the phonetic instantiation of the contrast is best dealt with from the point of view of a phonetic theory that can predict the possible phonetic instantiations of a phonological contrast. Such a theory would predict why, perhaps based on gestural blending or acoustic arguments, [tʲ] is more likely to become [tɕ] or [tʃʲ] and less likely to become [tl], and even less likely to become [f], for instance. We leave this for future research.

In summary, the phonetic reasoning, by itself, predicts the situation in Slovak, whereas the embedding of this phonetic tendency into OT phonology generates the possibility of Russian and Slovenian at opposite ends of the factorial typology. We believe, however, that the phonological account we have provided has a serious shortcoming. The optimality-theoretic enterprise is based on the idea that universal grammar provides a small number of constraints, which when ordered in different ways, with the possibility of a few fixed rankings, predicts the tens or hundreds of thousands of dialects of languages that have existed. The problem is that we have had to propose novel parametrized constraints in this article to fit the observed patterns in Slavic systems. This constraint manufacturing, which is practiced by many other than the present authors, has generated many families of parametrized constraints to fit the facts of many languages, whose factorial typology is many orders of magnitude higher than the number of dialects that have ever existed. The usual approach to this problem, as it has arisen repeatedly over the last twenty-four years or so, is to treat it as a problem of temporary ignorance. But the number of parametrized constraints seems to have multiplied, instead of diminishing. Therefore, we feel that if the constraints proposed here prove to be constraints whose effects can be felt in many other languages, this account could in the future be judged to be predictive, rather than a way to fit the data.

6. CONCLUSION. The structure-history antinomy, which Weinreich and colleagues (1968) fully identified and attempted to dissipate, is still with us today, as evidenced by the division of phonology largely into synchronic and diachronic fields (despite many works that bridge these fields). We have argued here that developments in phonology, phonetics, and historical linguistics in the last fifty years or so point to new possibilities in the full development of the program for a theory of sound change. Weinreich and colleagues' vision was that the solutions to the questions/problems posed to initiate the program would establish how the social, cultural, individual, phonetic, cognitive, and phonological factors thoroughly integrate to constrain variation and change. But they pointed to the phonological theories of their time, specifically structuralism and early generative grammar, as a major obstacle to the development of a framework where nonlinguistic, physical, and linguistic factors can interact deeply. Why? Because these phonological theories had no, or extremely small, space for variation, or orderly heterogeneity, as they called it. Of course, the grammar of one language could be different from another in structuralist and early generative formalism, but the orderly heterogeneity linking different languages, or stages of languages, to each other was simply not capturable.

OT, however, is based on an attempt to account for crosslinguistic variation and could therefore serve as a foundation for a theory of orderly heterogeneity. By basing itself on the fundamental concepts of rankability, violability, and emergent factorial typology, OT can describe heterogeneity and order simultaneously. As we have seen in the development of STRATAL OT (Kiparsky 2000, Bermúdez-Otero 2003), for example, these concepts have been used successfully to account for how the grammar changes from one stage of a language to another. In addition, the equivalence of grammars in which some constraints are not ranked with respect to each other in the language as a whole, allowing for synchronic grammatical variability, has fruitfully been used to account for within-language variability (Anttila 2007). Furthermore, gradient forms of OT (Pater 2009, Smolensky et al. 2014), developments allowing for stochastic variation (Boersma 1997)[32] and phonetic grammars (Flemming 2002) and phonetic constraining of grammars (Steriade 2008), possibly point the way for future theories that integrate social, grammatical, and physical variation into a single approach. This is the basis for our hope that the structure-history antinomy will soon give way to richer theories that investigate sound change, variation, and synchronic phonology from one perspective.

[32] Based on the work of Escudero and Boersma (2003), Boersma and Hamann (2008), and Boersma (2009), among others, we believe that it is possible to construct an OT-type grammar using cue weighting, which would also bring in the role of the speaker.

Appendix: Experimental items

CONSONANT	WORD-INITIAL		INTERVOCALIC	
p	ˈpapə	‘father’	paˈpa	‘priest.GEN.SG’
pʲ	ˈpʲatkə	‘heel’	oˈpʲat	‘honey mushroom.GEN.PL’
b	ˈbabə	‘woman’ (colloq.)	raˈba	‘slave.GEN.SG’
bʲ	ˈbʲakə	‘bad thing’ (colloq.)	aˈbʲazən	‘obliged’
m	ˈmamə	‘mother’	saˈma	‘self.F’
mʲ	ˈmʲatə	‘mint’	paˈmʲat	‘crumpled’
t	ˈtapka	‘slipper.GEN.SG’	kaˈta	‘cat.GEN.SG’
tʲ	ˈtʲapkə	‘hoe’	kaˈtʲat	‘kitten.GEN.PL’
d	ˈdamə	‘dame’	vaˈda	‘water’
dʲ	ˈdʲamə	nickname	fxaˈdʲa	‘entering’
s	ˈsam	‘self’	aˈsa	‘wasp’
sʲ	ˈsʲam	‘here’	kaˈsʲak	‘door jamb’
z	ˈzamə	‘vice.GEN.SG’	kaˈza	‘goat’
zʲ	ˈzʲamə	nickname	raˈzʲa	‘striking’
n	ˈnam	‘to us’	aˈna	‘she’
nʲ	ˈnʲam	‘tasty’ (colloq.)	kaˈnʲa	‘horse.GEN.SG’
l	ˈlapə	‘paw’	staˈla	‘table.GEN.SG’
lʲ	ˈlʲapə	‘mistake.GEN.SG’ (colloq.)	paˈlʲa	‘field.PL’
r	ˈradə	‘glad.FEM’	paˈrat	‘parade’
rʲ	ˈrʲadəm	‘close; next to’	paˈrʲat	‘soar.3PL’

REFERENCES

AGRESTI, ALAN. 2012. *Categorical data analysis*. 3rd edn. Oxford: Wiley.

ANDERSON, STEPHEN R. 2016. Synchronic versus diachronic explanation and the nature of the language faculty. *Annual Review of Linguistics* 2.11–31. DOI: 10.1146/annurev-linguistics-011415-040735.

ANTTILA, ARTO. 2007. Variation and optionality. *The Cambridge handbook of phonology*, ed. by Paul de Lacy, 519–36. Cambridge: Cambridge University Press.

BAJEC, ANTON; RUDOLF KOLARIČ; and MIRKO RUPEL. 1956. *Slovenska Slovnica*. Ljubljana: Državna Založba Slovenije.

BAKRAN, JURAJ. 1996. *Zvučna slika hrvatskoga govora*. Zagreb: Ibis Grafika.

BARNES, JONATHAN, and DARYA KAVITSKAYA. 2001. Compensatory lengthening without moras: A study in phonologization. *Berkeley Linguistics Society* 26.17–26. DOI: 10.3765/bls.v26i1.1134.

BATEMAN, NICOLETA. 2007. *A crosslinguistic investigation of palatalization*. San Diego: University of California, San Diego dissertation.

BELLMAN, RICHARD E. 1957. *Dynamic programming*. Princeton, NJ: Princeton University Press.

BERMÚDEZ-OTERO, RICARDO. 2003. The acquisition of phonological opacity. *Proceedings of the Stockholm Workshop on Variation within Optimality Theory*, ed. by Jennifer Spenader, Anders Eriksson, and Östen Dahl, 25–36.

BERMÚDEZ-OTERO, RICARDO. 2015. Amphichronic explanation and the life cycle of phonological processes. *The Oxford handbook of historical phonology*, ed. by Patrick Honeybone and Joseph C. Salmons, 374–99. Oxford: Oxford University Press.

BISHOP, CHRISTOPHER M. 2006. *Pattern recognition and machine learning*. Dordrecht: Springer.

BLEVINS, JULIETTE. 2007. The importance of typology in explaining recurrent sound patterns. *Linguistic Typology* 11.107–13. DOI: 10.1515/LINGTY.2007.009.

BOERSMA, PAUL. 1997. How we learn variation, optionality, and probability. *Proceedings of the Institute of Phonetic Sciences* 21.43–58. Online: http://www.fon.hum.uva.nl/paul/papers/learningVariation.pdf.

BOERSMA, PAUL. 2009. Cue constraints and their interactions in phonological perception and production. *Phonology in perception*, ed. by Paul Boersma and Silke Hamann, 55–110. Berlin: Mouton de Gruyter.

BOERSMA, PAUL, and SILKE HAMANN. 2008. The evolution of auditory dispersion in bidirectional constraint grammars. *Phonology* 25.217–70. DOI: 10.1017/S0952675708001474.

Boersma, Paul, and David Weenink. 2015. Praat: Doing phonetics by computer. Online: http://www.praat.org/.
Bolla, Kalman. 1981. *A conspectus of Russian speech sounds*. Cologne: Bölau.
Bondarko, L. V. 1977. *Zvukovoi stroi sovremennogo russkogo iazyka*. Moscow: Proveshchenie.
Bratkowsky, Joan G. 1980. The predictability of palatalization in Russian. *Russian Linguistics* 4.329–36. Online: http://www.jstor.org/stable/40159942.
Browne, Wayles. 1993. Serbo-Croat. In Comrie & Corbett, 306–87.
Carlton, Terence R. 1991. *Introduction to the phonological history of the Slavic languages*. Bloomington, IN: Slavica.
Chistovich, Ludmilla A., and Valentina V. Lublinskaja. 1979. The 'center of gravity' effect in vowel spectra and critical distance between the formants: Psychoacoustical study of the perception of vowel-like stimuli. *Hearing Research* 1.185–95. DOI: 10.1016/0378-5955(79)90012-1.
Chomsky, Noam, and Morris Halle. 1968. *The sound pattern of English*. New York: Harper & Row.
Coetzee, Andries W., and Joe Pater. 2011. The place of variation in phonological theory. *The handbook of phonological theory*, 2nd edn., ed. by John Goldsmith, Jason Riggle, and Alan C. L. Yu, 401–31. Oxford: Blackwell.
Cohen, Jacob 1992. A power primer. *Psychological Bulletin* 112.155–59. DOI: 10.1037/0033-2909.112.1.155.
Comrie, Bernard, and Greville G. Corbett (eds.) 1993. *The Slavonic languages*. London: Routledge.
Davidson, Lisa. 2006. Comparing tongue shapes from ultrasound imaging using smoothing spline analysis of variance. *The Journal of the Acoustical Society of America* 120.407–15. DOI: 10.1121/1.2205133.
de Bray, Reginald G. A. 1980. *Guide to the Slavonic languages*. Bloomington, IN: Slavica.
de Lacy, Paul, and John Kingston. 2013. Synchronic explanation. *Natural Language and Linguistic Theory* 31.287–355. DOI: 10.1007/s11049-013-9191-y.
Escudero, Paola, and Paul Boersma. 2003. Modelling the perceptual development of phonological contrasts with optimality theory and the gradual learning algorithm. *University of Pennsylvania Working Papers in Linguistics (Proceedings of the 25th annual Penn Linguistics Colloquium)* 8.71–85. Online: http://repository.upenn.edu/pwpl/vol8/iss1/7.
Fant, Gunnar. 1960. *Acoustic theory of speech production*. The Hague: Mouton.
Farina, Donna Marie. 1991. *Palatalization and jers in Modern Russian phonology: An underspecification approach*. Urbana-Champaign: University of Illinois dissertation.
Flemming, Edward. 2002. *Auditory representations in phonology*. London: Routledge.
Friedman, Victor A. 1993. Macedonian. In Comrie & Corbett, 249–305.
Fruehwald, Josef. 2013. *Phonological involvement in phonetic change*. Philadelphia: University of Pennsylvania dissertation.
Fujimura, Osamu. 1962. Analysis of nasal consonants. *The Journal of the Acoustical Society of America* 34.1865–75. DOI: 10.1121/1.1909142.
Garrett, Andrew, and Keith Johnson. 2013. Phonetic bias in sound change. *Origins of sound change: Approaches to phonologization*, ed. by Alan C. L. Yu, 51–97. Oxford: Oxford University Press.
Goldsmith, John A. 1990. *Autosegmental and metrical phonology*. Oxford: Blackwell.
Gould, Stephen Jay. 2002. *The structure of evolutionary theory*. Cambridge, MA: Belknap.
Greenberg, Joseph H. 1965. Some generalizations concerning initial and final consonant sequences. *Linguistics* 18.5–34. DOI: 10.1515/ling.1965.3.18.5.
Greenberg, Joseph H. 1966. Synchronic and diachronic universals in phonology. *Language* 42.508–17. DOI: 10.2307/411706.
Greenberg, Joseph H. 1978. Diachrony, synchrony and language universals. *Universals of human language, vol. 1: Method and theory*, ed. by Joseph H. Greenberg, Charles A. Ferguson, and Edith A. Moravcsik, 61–92. Stanford, CA: Stanford University Press.
Greenberg, Joseph H. 1995. The diachronic typological approach to language. *Approaches to language typology*, ed. by Masayoshi Shibatani and Theodora Bynon, 145–66. Oxford: Clarendon.

Greenberg, Joseph H.; Charles E. Osgood; and James J. Jenkins. 1963. Memorandum concerning language universals. *Universals of language*, ed. by Joseph Greenberg, xv–xxvii. Cambridge, MA: MIT Press.

Greenberg, Marc L. 2000. *A historical phonology of the Slovene language*. (Historical phonology of the Slavic languages 13.) Heidelberg: Winter.

Grepl, Miroslav; Zdeňka Hladká; Milan Jelínek; Petr Karlík; Marie Krčmová; Marek Nekula; and Zdenka Rusínová. 1995. *Přiruční mluvnice češtiny*. Praha: Nakladatelství Lidové Noviny.

Gu, Chong. 1992. Diagnostics for nonparametric regression models with additive terms. *Journal of the American Statistical Association* 87.1051–58. DOI: 10.2307/2290642.

Gu, Chong. 2002. *Smoothing spline ANOVA models*. (Springer series in statistics.) New York: Springer.

Hall, Kathleen Currie; Elizabeth Hume; T. Florian Jaeger; and Andrew Wedel. 2016. The message shapes phonology. Vancouver: University of British Columbia, ms.

Haspelmath, Martin. 1999. Optimality and diachronic adaptation. *Zeitschrift für Sprachwissenschaft* 18.180–205. DOI: 10.1515/zfsw.1999.18.2.180.

Haspelmath, Martin. 2006. Against markedness (and what to replace it with). *Journal of Linguistics* 42.25–70. DOI: 10.1017/S0022226705003683.

Hayes, Bruce. 2009. *Introductory phonology*. Malden, MA: Wiley-Blackwell.

Hock, Hans Henrich. 2006. *[+labial, +palatalized]. *Anuario del Seminario de Filologia Vasca 'Julio de Urquijo'* 40.437–48.

Hoenigswald, Henry M. 1960. *Language change and linguistic reconstruction*. Chicago: University of Chicago Press.

Hoenigswald, Henry M. 1961. Are there universals of linguistic change? *Universals of language: Report of a conference held at Dobbs Ferry*, New York, April 13–15, 1961, ed. by Joseph H. Greenberg, 23–41. Cambridge, MA: MIT Press.

Howe, M. S., and Richard S. McGowan. 2005. Aeroacoustics of [s]. *Proceedings of the Royal Society A* 461.1005–28. DOI: 10.1098/rspa.2004.1405.

Howson, Phil; Alexei Kochetov; and Pascal van Lieshout. 2015. Examination of the grooving patterns of the Czech trill-fricative. *Journal of Phonetics* 49.117–29. DOI: 10.1016/j.wocn.2015.01.002.

Howson, Phil; Ekaterina Komova; and Bryan Gick. 2014. Czech trills revisited: An ultrasound EGG and acoustic study. *Journal of the International Phonetic Association* 44.115–32. DOI: 10.1017/S0025100313000339.

Iskarous, Khalil; Carol A. Fowler; and Douglas H. Whalen. 2010. Locus equations are an acoustic expression of articulator synergy. *The Journal of the Acoustical Society of America* 128.2021–32. DOI: 10.1121/1.3479538.

Iskarous, Khalil, and Darya Kavitskaya. 2010. The interaction between contrast, prosody, and coarticulation in structuring phonetic variability. *Journal of Phonetics* 38.625–39. DOI: 10.1016/j.wocn.2010.09.004.

Iskarous, Khalil; Christine H. Shadle; and Michael I. Proctor. 2011. Articulatory-acoustic kinematics: The production of American English /s/. *The Journal of the Acoustical Society of America* 129.944–54. DOI: 10.1121/1.3514537.

Jespersen, Otto. 1922. *Language: Its nature, development, and origin*. London: G. Allen and Unwin.

Johnson, Keith. 1997. Speech perception without speaker normalization: An exemplar model. *Talker variability in speech processing*, ed. by Keith Johnson and John W. Mullennix, 145–65. San Diego: Academic Press.

Kavitskaya, Darya. 2006. Perceptual salience and palatalization in Russian. *Laboratory phonology 8*, ed. by Louis Goldstein, D. H. Whalen, and Catherine T. Best, 589–610. Berlin: Mouton de Gruyter.

Kedrova, Galina Y.; Nikolay V. Anisimov; Leonid M. Zaharov; and Yurij A. Pirogov. 2008. Magnetic resonance investigation of palatalized stop consonants and spirants in Russian. *The Journal of the Acoustical Society of America* 123.3325. DOI: 10.1121/1.2933814.

Keyser, Samuel Jay, and Kenneth N. Stevens. 2006. Enhancement and overlap in the speech chain. *Language* 82.33–63. Online: http://www.jstor.org/stable/4490084.

Kharlamov, Viktor. 2014. Incomplete neutralization of the voicing contrast in word-final obstruents in Russian: Phonological, lexical, and methodological influences. *Journal of Phonetics* 43.47–56. DOI: 10.1016/j.wocn.2014.02.002.

Kiparsky, Paul. 1993. An OT approach to phonological variation. Handout of a paper presented at the Rutgers Optimality Workshop.

Kiparsky, Paul. 2000. Opacity and cyclicity. *The Linguistic Review* 17.351–65. DOI: 10.1515/tlir.2000.17.2-4.351.

Kiparsky, Paul. 2006. The amphichronic program vs. evolutionary phonology. *Theoretical Linguistics* 32.217–36. DOI: 10.1515/TL.2006.015.

Kiparsky, Paul. 2016. Labov, sound change, and phonological theory. *Journal of Sociolinguistics* 20.464–88. DOI: 10.1111/josl.12196.

Kochetov, Alexei. 2002. *Production, perception, and emergent phonotactic patterns: A case of contrastive palatalization*. New York: Routledge.

Kochetov, Alexei. 2004. Perception of place and secondary articulation contrasts in different syllable positions: Language-particular and language-independent asymmetries. *Language and Speech* 47.351–82. DOI: 10.1177/00238309040470040201.

Kochetov, Alexei. 2006. Testing licensing by cue: A case of Russian palatalized coronals. *Phonetica* 63.113–48. DOI: 10.1159/000095305.

Koneski, Blaže. 1983. *A historical phonology of the Macedonian language*. Heidelberg: Winter.

Krajčovič, Rudolf. 1975. *A historical phonology of the Slovak language*. Heidelberg: Winter.

Labov, William. n.d. The regularity of regular sound change. Philadelphia: University of Pennsylvania, ms. Online: http://www.ling.upenn.edu/~wlabov/Papers/RRSC.pdf.

Lehmann, Winfred P. 1968. Saussure's dichotomy between descriptive and historical linguistics. *Directions for historical linguistics: A symposium*, ed. by Winfred P. Lehmann and Yakov Malkiel, 3–20. Austin: University of Texas Press.

Litvin, Natallia. 2014. An ultrasound investigation of secondary velarization in Russian. Victoria: University of Victoria master's thesis.

Martinet, André. 1952. Function, structure, and sound change. *Word* 8.1–32. DOI: 10.1080/00437956.1952.11659416.

Mayo, Peter. 1993. Belorussian. In Comrie & Corbett, 887–946.

McCarthy, John J., and Alan Prince. 1993. Generalized alignment. *Yearbook of Morphology* 1993.79–153. DOI: 10.1007/978-94-017-3712-8_4.

McGowan, Richard S. 1992. Tongue-tip trills and vocal-tract wall compliance. *The Journal of the Acoustical Society of America* 91.2903–10. DOI: 10.1121/1.402927.

Nance, Claire. 2014. Phonetic variation in Scottish Gaelic laterals. *Journal of Phonetics* 47.1–17. DOI: 10.1016/j.wocn.2014.07.005.

Narayanan, Shrikanth S., and Abeer A. Alwan. 1995. An articulatory study of fricative consonants using magnetic resonance imaging. *The Journal of the Acoustical Society of America* 98.1325–47. DOI: 10.1121/1.413469.

Ohala, John J. 1981. The listener as a source of sound change. *Chicago Linguistic Society (Parasession on language and behavior)* 17(2).178–203.

Ohala, John. 1983. The origin of sound patterns in vocal tract constraints. *The production of speech*, ed. by Peter F. MacNeilage, 189–216. New York: Springer.

Ohala, John. 1989. Sound change is drawn from a pool of synchronic variation. *Language change: Contributions to the study of its causes*, ed. by Leiv Egil Breivik and Ernst Håkon Jahr, 173–98. Berlin: Mouton de Gruyter.

Ohala, John. 1992. What's cognitive, what's not, in sound change. *Lingua e Stile* 27.321–62.

Padgett, Jaye. 2001. Contrast dispersion and Russian palatalization. *The role of speech perception in phonology*, ed. by Elizabeth Hume and Keith Johnson, 187–218. San Diego: Academic Press.

Padgett, Jaye. 2003a. Contrast and post-velar fronting in Russian. *Natural Language and Linguistic Theory* 21.39–87. DOI: 10.1023/A:1021879906505.

Padgett, Jaye. 2003b. The emergence of contrastive palatalization in Russian. *Optimality theory and language change*, ed. by D. Eric Holt, 307–35. Dordrecht: Kluwer.

Padgett, Jaye, and Marzena Żygis. 2007. The evolution of sibilants in Polish and Russian. *Journal of Slavic Linguistics* 15.291–324. Online: http://www.jstor.org/stable/24599670.

Pater, Joe. 2009. Weighted constraints in generative linguistics. *Cognitive Science* 33.999–1035. DOI: 10.1111/j.1551-6709.2009.01047.x.

Priestly, T. M. S. 1993. Slovene. In Comrie & Corbett, 388–454.

Prince, Alan, and Paul Smolensky. 2003. Optimality theory in phonology. *International encyclopedia of linguistics*, vol. 3, 2nd edn., ed. by William Frawley, 212–22. Oxford: Oxford University Press.

Prince, Alan, and Paul Smolensky. 2004 [1993]. *Optimality theory: Constraint interaction in generative grammar*. Oxford: Blackwell. [Revision of 1993 technical report, Rutgers University Center for Cognitive Science.]

Pritchard, Sonia. 2012. *A cross-language study of the production and perception of palatalized consonants*. Ottawa: University of Ottawa dissertation.

Reformatskii, Aleksandr A. 1958. O korreliatsii 'tverdykh' i 'miagkikh' soglasnykh (v sovremennom russkom literaturnom iazyke). *Melanges linguistiques offerts a Emil Petrovici par ses amis etrangers a l'occasion de son soixantieme anniversaire*, 494–99. Bucharest: Editura Academiei Republicii Populare Romine.

Rothstein, Robert A. 1993. Polish. In Comrie & Corbett, 686–758.

Rubach, Jerzy. 1984. *Cyclic and lexical phonology: The structure of Polish*. Dordrecht: Foris.

Rubach, Jerzy. 1993. *The lexical phonology of Slovak*. Oxford: Oxford University Press.

Rubach, Jerzy. 2003. Duke-of-York derivations in Polish. *Linguistic Inquiry* 34.601–29. DOI: 10.1162/002438903322520160.

Rubach, Jerzy. 2007. Feature geometry from the perspective of Polish, Russian, and Ukrainian. *Linguistic Inquiry* 38.85–138. DOI: 10.1162/ling.2007.38.1.85.

Rubach, Jerzy. 2008. Palatal nasal decomposition in Slovene, Upper Sorbian and Polish. *Journal of Linguistics* 44.169–204. DOI: 10.1017/S0022226707004987.

Rubach, Jerzy. 2011. Slavic palatalization. *The Blackwell companion to phonology*, ed. by Marc van Oostendorp, Colin Ewen, Elizabeth Hume, and Keren Rice, 2908–35. Oxford: Wiley-Blackwell.

Sagey, Elizabeth. 1986. *The representation of features and relations in non-linear phonology*. Cambridge, MA: MIT dissertation.

Scatton, Ernest A. 1993. Bulgarian. In Comrie & Corbett, 188–248.

Schaarschmidt, Gunter. 1997. *The historical phonology of the Upper and Lower Sorbian*. Heidelberg: Winter.

Schaarschmidt, Gunter. 2002. *Upper Sorbian*. Munich: LINCOM Europa.

Schenker, Alexander M. 1995. *The dawn of Slavic: An introduction to Slavic philology*. New Haven, CT: Yale University Press.

Schuster-Šewc, Heinz. 1996. *Grammar of the Upper Sorbian language: Phonology and morphology*. Munich: LINCOM Europa.

Shadle, Christine H. 1985. *The acoustics of fricative consonants*. Cambridge, MA: MIT dissertation.

Shevelov, George Y. 1965. *A prehistory of Slavic: The historical phonology of Common Slavic*. New York: Columbia University Press.

Shevelov, George Y. 1979. *A historical phonology of the Ukrainian language*. Heidelberg: Winter.

Shevelov, George Y. 1993. Ukrainian. In Comrie & Corbett, 947–98.

Short, David. 1993a. Czech. In Comrie & Corbett, 455–532.

Short, David. 1993b. Slovak. In Comrie & Corbett, 533–92.

Singer, Judith D., and John B. Willett. 2003. *Applied longitudinal data analysis: Modeling change and event occurrence*. Oxford: Oxford University Press.

Smolensky, Paul; Matthew Goldrick; and Donald Mathis. 2014. Optimization and quantization in gradient symbol systems: A framework for integrating the continuous and the discrete in cognition. *Cognitive Science* 38.1102–38. DOI: 10.1111/cogs.12047.

Steriade, Donca. 2008. The phonology of perceptibility effects: The P-map and its consequences for constraint organization. *The nature of the word: Studies in honor of Paul Kiparsky*, ed. by Kristin Hanson and Sharon Inkelas, 151–80. Cambridge, MA: MIT Press. [Originally circulated in 2001.]

Stevens, Kenneth N. 1971. Airflow and turbulence noise for fricative and stop consonants: Static considerations. *The Journal of the Acoustical Society of America* 50.1180–92. DOI: 10.1121/1.1912751.

Stevens, Kenneth N. 1998. *Acoustic phonetics*. Cambridge, MA: MIT Press.

Stevens, Kenneth N., and Samuel Jay Keyser. 1989. Primary features and their enhancement in consonants. *Language* 65.81–106. DOI: 10.2307/414843.

Stevens, Kenneth N., and Samuel Jay Keyser. 2010. Quantal theory, enhancement and overlap. *Journal of Phonetics* 38.10–19. DOI: 10.1016/j.wocn.2008.10.004.

Stieber, Zdzisław. 1973. *A historical phonology of the Polish language*. Heidelberg: Winter.

Stone, Gerald. 1993. Sorbian. In Comrie & Corbett, 593–685.

Takatori, Yuki. 1997. *A study of constraint interaction in Slavic phonology*. New Haven, CT: Yale University dissertation.

Timberlake, Alan. 2004. *A reference grammar of Russian*. Cambridge: Cambridge University Press.

Townsend, C. E. 1990. *A description of spoken Prague Czech*. Bloomington, IN: Slavica.

Trubetzkoy, Nikolay S. 1939. *Grundzüge der Phonologie*. (Travaux du Cercle Linguistique de Prague 7.) [English translation: *Principles of phonology*. Berkeley: University of California Press, 1969.]

Weinreich, Uriel; William Labov; and Marvin I. Herzog. 1968. Empirical foundations for a theory of language change. *Directions for historical linguistics: A symposium*, ed. by Winfred P. Lehmann and Yakov Malkiel, 97–195. Austin: University of Texas Press.

Wexler, Paul. 1977. *A historical phonology of the Belorussian language*. Heidelberg: Winter.

Wieling, Martijn; Simonetta Montemagni; John Nerbonne; and R. Harald Baayen. 2014. Lexical differences between Tuscan dialects and standard Italian: Accounting for geographic and sociodemographic variation using generalized additive mixed modeling. *Language* 90.669–92. DOI: 10.1353/lan.2014.0064.

Wierzchowska, Bożena. 1971. *Wymowa polska*. Warsaw: Państwowe Zakłady Wydawnictw Szkolnych.

Wierzchowska, Bożena. 1980. *Fonetyka i fonologia języka polskiego*. Warsaw: Zaklad Narodowy im. Ossoliriskich, Wydawnictwo Polskiej Akademii Nauk.

Żygis, Marzena, and Jaye Padgett. 2010. A perceptual study of Polish fricatives, and its implication for historical sound change. *Journal of Phonetics* 38.207–26. DOI: 10.1016/j.wocn.2009.10.003.

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