Chapter 8

Articulatory Modeling of Russian Liquids

Experimental evidence presented in Chapter 7 indicates that Russian liquid consonants share the phonetic property that they are produced with a more controlled dorsum than coronal stops. In Chapter 6 it was shown that Russian liquid consonants are phonologically characterized by their shared distribution within the syllable and their tendency to interact with adjacent vowels. In this chapter, a gestural model of Russian liquids will be proposed which attempts to reconcile the most important phonetic and phonological properties of the class.

The structure of this chapter is as follows. Representations of Russian coronal consonants under an articulatory phonology framework will first be proposed, and the gestural organization of Russian coronal consonants within the syllable will be discussed. TADA simulations of liquid production will be presented, and the results compared with those of the ultrasound experiments. Finally, articulatory analyses of some of the phonological behavior of Russian liquids will be proposed, and the broader implications of the gestural model will be discussed.

8.1 Gestural Characterization of Russian Non-Palatalized Coronal Consonants

The conclusion drawn from the ultrasound study of Russian non-palatalized coronal consonants (Chapter 7) is that the liquids are characterized by the presence of a dorsal articulatory component, unlike the coronal stops, which are produced with a tongue-tip gesture alone. As in Spanish, this contrast can be modeled phonologically as the presence or absence of a tongue body gesture coupled to the tongue-tip gesture (Figure 8.1).

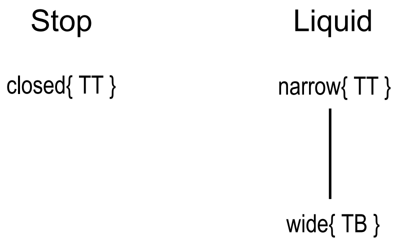


FIGURE 8.1: Contrasting coupling graphs: **Russian coronal stops and liquids**.

The data presented in Section 7.2.1 indicates that the Russian non-palatalized lateral is produced with an uvular-pharyngeal dorsal constriction, similar to that of a mid-back vowel, while the dorsal constriction of the Russian non-palatalized trill has a more anterior target, typically equivalent to that of a mid-central vowel (Fig. 7.14). A preliminary set of gestural specifications for the Russian non-palatalized coronal consonants which are consistent with these results are proposed in Table 8.1.

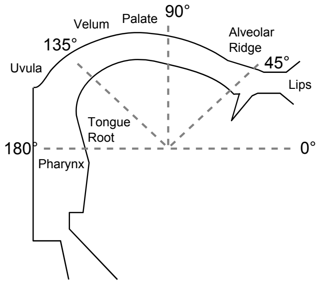
TV	/d/	/l/	/r/
TTCL	dental	alveolar	alveolar
TTCD	closed	narrow	narrow
TBCL	–	uvular-pharyngeal	velar
TBCD	–	wide	wide

TABLE 8.1: **Tract variable specifications for Russian non-palatalized coronal consonants**.

8.1.1 Modeling Russian Non-Palatalized Liquids

The phonological representations of Russian coronal consonants proposed in Table 8.1 were examined by conducting articulatory simulations using TADA. The gestural parameters used to model the two non-palatalized liquids are shown in Figure 8.2.

Comparing the articulatory representations of Russian liquids with those proposed for Spanish (Table 5.1), we can see that the essential difference between the models is the location of the dorsal constriction targets for the laterals. Unlike the open



ARPA	Organ	Osc	TV	Constrict	Target	Stiffness	Damping
L	TT	nar	TTCL	DENT	45	.	.
	TT	nar	TTCD	NAR	2	.	.
	TT	rel	TTCL	REL	24	.	.
	TT	rel	TTCD	REL	11	.	.
	TB	voc	TBCL	UVUPHAR	170	.	.
	TB	voc	TBCD	V	8	.	.
R	TT	nar	TTCL	ALVPAL	60	.	.
	TT	nar	TTCD	NAR	2	20	0.2
	TT	rel	TTCL	REL	24	.	.
	TT	rel	TTCD	REL	11	.	.
	TB	voc	TBCL	VEL	110	.	.
	TB	voc	TBCD	V	8	.	.
	Lips	voc	LA	NAR	2	.	.

FIGURE 8.2: Left: **Semi-polar coordinate system** used to specify constriction location in TADA; Right: **Gestural parameters used in TADA simulations of Russian non-palatalized liquids**.

palatal constriction of the Spanish clear lateral, the Russian non-palatalized lateral is specified for a much more retracted tongue body constriction location (TBCL = 170°, TBCD = 8 mm), consistent with the upper-pharyngeal dorsal articulation observed in the ultrasound data.

Importantly, in this model, the rhotic is specified for a mid-oral tongue body constriction target (TBCL = 110°, TBCD = 8 mm, similar to that specified for the Spanish), because the data from the ultrasound study does not support the claim that the Russian trill is velarized/pharyngealized by virtue of its non-palatalized status (c.f. Halle 1959).[1]

Modeling Russian Non-Palatalized Laterals

Data from a simulation of Russian non-palatalized lateral articulation are shown in Figure 8.3. The acoustic waveform and time course of the tongue tip (TTCD) and tongue body constriction degree (TBCD) tract variables generated in a simulation of the sequence /aɫa/, using the gestural specifications in Figure 8.2, are shown on the right. Midsagittal articulation during the pre-consonantal vowel and the point of closest coronal approximation of the lateral are shown on the left.

Comparing the results of the simulation with the Spanish equivalent (Fig. 5.5), it can be seen that the fundamental difference between the clear and dark laterals of the two languages has been successfully modeled using the gestural specifications in Tables 8.1 and 5.1. Articulation of the non-palatalized Russian lateral, in

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[1] It should be noted that the labels used to specify constriction location of a tract variable do not always correspond to specifications for place of articulation with the same name used by the IPA. The primary difference is that the IPA system is essentially a horizontal specification of degree of anteriorness or posteriorness, while TADA tract variables are specified using a midsagittal semi-polar coordinate system. A schwa, for example, could be specified either in terms of tongue body displacement from the rear pharyngeal wall, or from the palate.

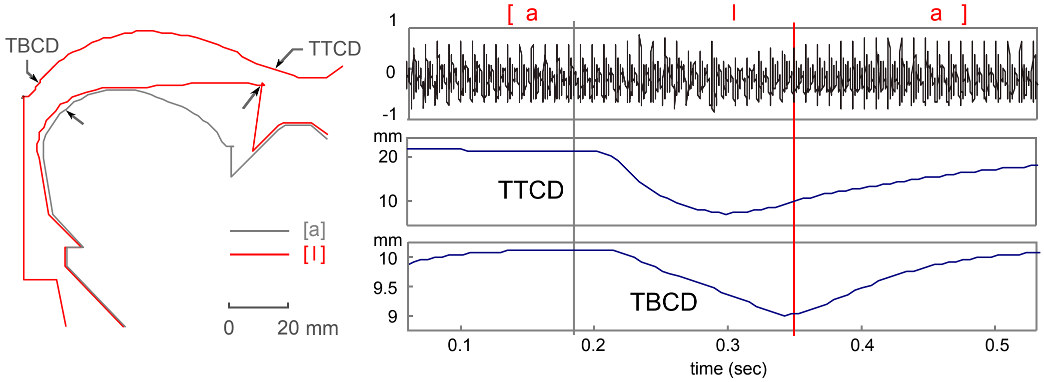


FIGURE 8.3: **TADA simulation of Russian intervocalic non-palatalized lateral articulation: [ala]**. Left: midsagittal articulation during pre-consonantal vowel and mid-consonant; Right: acoustic waveform and time course of tongue tip and tongue body constriction degree tract variables.

a low vowel context, involves dorsal retraction and raising towards the velarized tongue body constriction location, unlike the dorsal advancement observed in the production of the clear [l] in Spanish.

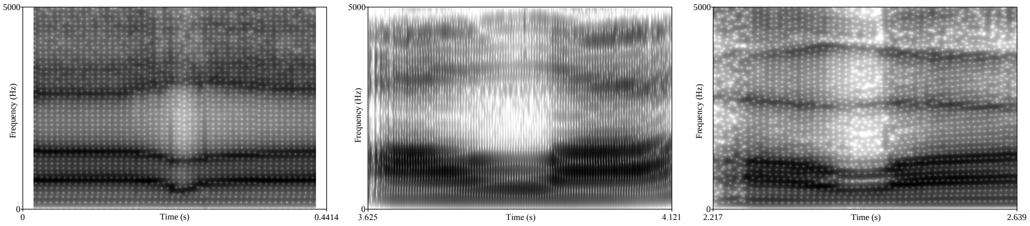


FIGURE 8.4: **Spectra of simulated and spoken Russian intervocalic non-palatalized laterals**. Left: Speech synthesized from articulatory sequence [ala] simulated in TADA; Center: [ala] spoken by female subject W2; Right: [ala] spoken by male subject M1;

The spectrogram of an intervocalic lateral synthesized from the articulatory model is shown in Figure 8.4, where it is compared to spectra of intervocalic laterals produced by female and male Russian speakers. Comparing the spectra with those of the simulated and spoken Spanish laterals (Fig. 5.7), it can be seen that the Russian lateral has been successfully synthesized as a dark [ƚ] , and that the primary acoustic difference between the laterals in the two languages is in the trajectory of F2. Unlike in the clear lateral of Spanish, where the second formant raises in a low vowel context, F2 tracks F1 during the production of the velarized lateral, lowering in the same vowel context, due to its correlation with tongue body backness.

The higher formants of the synthesized Russian lateral more closely resemble those produced by Russian speakers than in the Spanish model, demonstrating that, as in English (Browman & Goldstein 1995; Ladefoged & Maddieson 1996), a certain degree of lateralization results from the intrinsic gestural characterization of the

Russian non-palatalized segment. Because the dorsal target of the Russian lateral is even more raised and retracted than in English, and because this gesture is coordinated with a highly anterior coronal approximation (Russian laterals are typically classified as dental), the tongue is highly elongated, and side channels will form naturally from this lingual posture. The more realistic trajectories of F3 and F4 in the acoustic simulation would appear to result from the articulatory consequences of this gestural characterization in TADA.

Modeling Russian Non-Palatalized Rhotics

Data from a simulation of Russian non-palatalized rhotic articulation are shown in Figure 8.5. The acoustic waveform and time course of the tongue tip (TTCD) and tongue body constriction degree (TBCD) tract variables generated in a simulation of the sequence /ala/, using the gestural specifications in Figure 8.2, are shown on the right. Midsagittal articulation during the pre-consonantal vowel and a point during the second coronal closure of the trill are shown on the left.

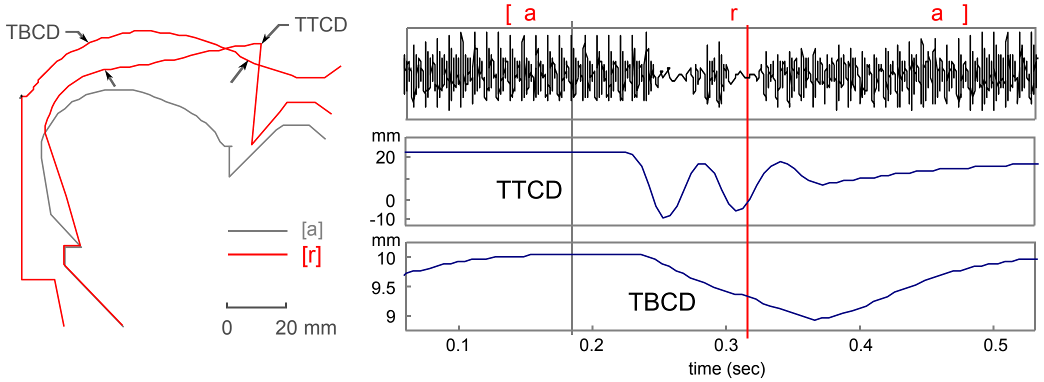


FIGURE 8.5: **TADA simulation of Russian intervocalic non-palatalized rhotic articulation: [ara]**. Left: midsagittal articulation during pre-consonantal vowel and mid-consonant; Right: acoustic waveform and time course of tongue tip and tongue body constriction degree tract variables.

The figure shows that the simulation has captured the essential properties of the Russian trill in this intervocalic context: the tongue dorsum raises and moves to a stable mid-central vowel-like posture, at the same time that the tongue tip is set into an oscillatory mode, making contact with the passive articulator in the region of the alveolar ridge. As with the Spanish rhotic simulations, the number of coronal contacts was found to be a function of consonantal duration (stiffness), tongue tip constriction degree, tongue body constriction location, and tongue tip damping specified for the rhotic tract variables.

The spectrogram of an intervocalic lateral synthesized from the articulatory model

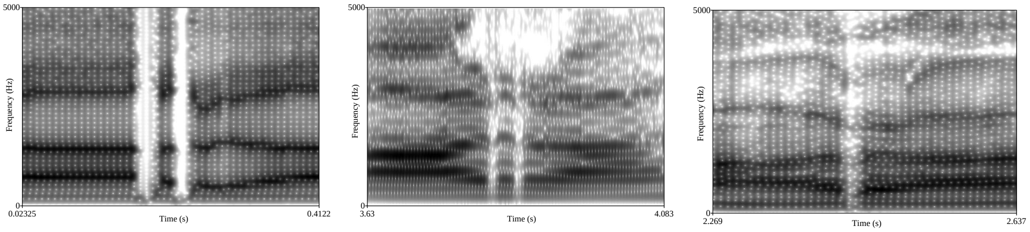


FIGURE 8.6: **Spectra of simulated and spoken Russian intervocalic non-palatalized rhotics**. Left: Speech synthesized from articulatory sequence [ara] simulated in TADA; Center: [ara] spoken by female subject W3; Right: [ara] spoken by male subject M1;

is shown in Figure 8.4, where it is compared to spectra of intervocalic laterals produced by female and male Russian speakers. Comparing the spectra with those of the simulated and spoken Spanish laterals (Fig. 5.7), it can be seen that the Russian lateral has been successfully synthesized as a dark [ɫ] , and that the primary acoustic difference between the laterals in the two languages is in the trajectory of F2. Unlike in the clear lateral of Spanish, where the second formant raises in a low vowel context, F2 tracks F1 during the production of the velarized lateral, lowering in the same vowel context, due to its correlation with tongue body backness.

8.2 Gestural Characterization of Russian Palatalized Coronal Consonants

Ultrasound data presented in Section 7.3 revealed that Russian palatalized coronal consonants are all produced with a vowel-like approximation in the palatal region. The same articulation was observed in the production of liquids and obstruents, which suggests that these consonants consist of a tongue body gesture with the same properties as a high front vocoid (/i/ or /j/) coupled to the gestural constellations of the non-palatalized consonantal equivalents. Under this model, the basic phonological representations of Russian palatalized stops and liquids are shown in Figure 8.7.

Building on the models proposed for Russian non-palatalized coronal consonants (Table 8.1), a preliminary set of gestural specifications for the palatalized equivalents are outlined in Table 8.2. In each case, a gesture corresponding to a high front glide has been added to the original constellation.

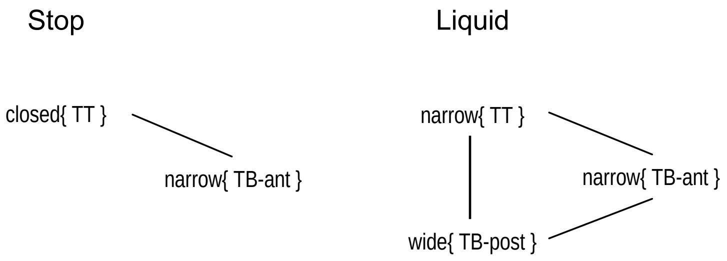


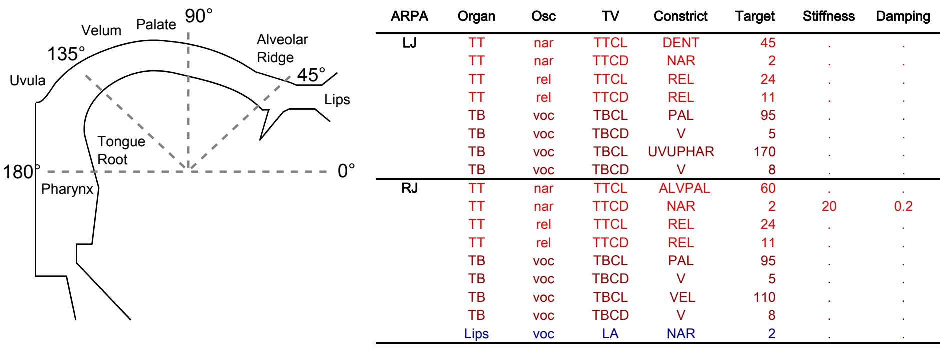
FIGURE 8.7: Coupling graphs: **Russian palatalized coronal consonants**.

TV	/dʲ/	/lʲ/	/rʲ/
TTCL	dental	alveolar	alveolar
TTCD	closed	narrow	narrow
TBCL	–	uvular-pharyngeal	velar
TBCD	–	wide	wide
TBCL	palatal	palatal	palatal
TBCD	narrow	narrow	narrow

TABLE 8.2: **Tract variable specifications for Russian palatalized coronal consonants**.

8.2.1 Modeling Russian Palatalized Liquids

The phonological representations of Russian coronal consonants proposed in Table 8.1 were examined by conducting articulatory simulations using TADA. The specific gestural parameters used to model the two palatalized liquids are shown in Figure 8.8.



ARPA	Organ	Osc	TV	Constrict	Target	Stiffness	Damping
LJ	TT	nar	TTCL	DENT	45	.	.
	TT	nar	TTCD	NAR	2	.	.
	TT	rel	TTCL	REL	24	.	.
	TT	rel	TTCD	REL	11	.	.
	TB	voc	TBCL	PAL	95	.	.
	TB	voc	TBCD	V	5	.	.
	TB	voc	TBCL	UVUPHAR	170	.	.
	TB	voc	TBCD	V	8	.	.
RJ	TT	nar	TTCL	ALVPAL	60	.	.
	TT	nar	TTCD	NAR	2	20	0.2
	TT	rel	TTCL	REL	24	.	.
	TT	rel	TTCD	REL	11	.	.
	TB	voc	TBCL	PAL	95	.	.
	TB	voc	TBCD	V	5	.	.
	TB	voc	TBCL	VEL	110	.	.
	TB	voc	TBCD	V	8	.	.
	Lips	voc	LA	NAR	2	.	.

FIGURE 8.8: Left: **Semi-polar coordinate system** used to specify constriction location in TADA; Right: **Gestural parameters used in TADA simulations of Russian palatalized liquids**.

Modeling Russian Palatalized Laterals

Data from a simulation of Russian intervocalic palatalized lateral production are shown in Figure 8.9. The acoustic waveform and time course of the tongue tip (TTCD) and tongue body constriction degree (TBCD) tract variables generated in a simulation of the sequence /alʲa/ are shown on the right. Midsagittal articulation during the pre-consonantal vowel, the point of closest coronal approximation, and the point of closest palatal approximation of the lateral are shown on the left.

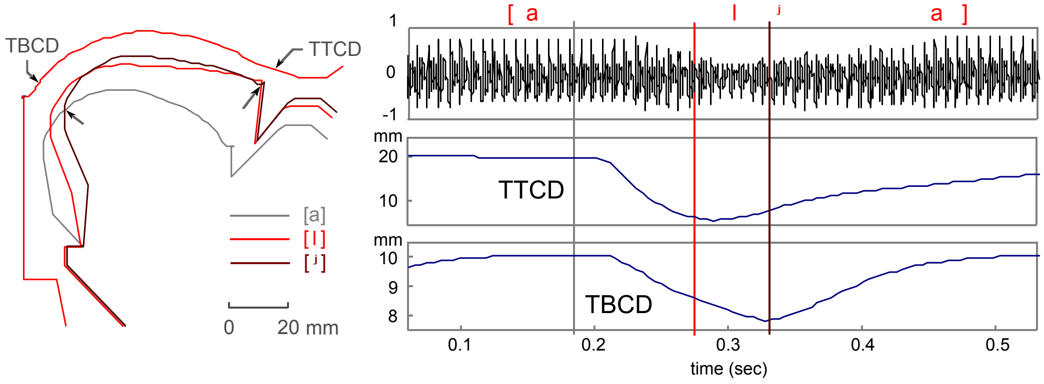


FIGURE 8.9: **TADA simulation of Russian intervocalic palatalized lateral articulation: [alʲa]**. Left: midsagittal articulation during pre-consonantal vowel; mid-consonant; and late in consonantal production (corresponding to the point of maximal palatalization); Right: acoustic waveform and timecourse of tongue tip and tongue body constriction degree tract variables.

The spectrogram of an intervocalic palatalized lateral synthesized from the articulatory model is shown in Figure 8.10, where it is compared to spectra of intervocalic laterals produced by female and male Russian speakers. The data show that the articulatory model has successfully emulated the trajectories of the lower two formants, producing the characteristic rise in F2 late in consonant production in the low vowel context. As with the non-palatalized lateral, the primary difference between the synthesized and spoken speech is in the higher formants.

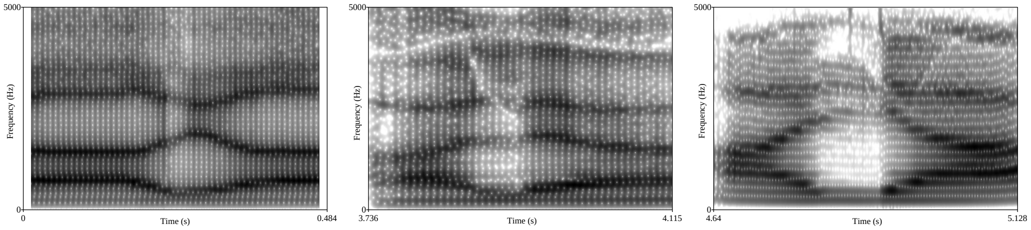


FIGURE 8.10: **Spectra of simulated and spoken Russian intervocalic palatalized laterals**. Left: Speech synthesized from articulatory sequence [alʲa] simulated in TADA; Center: [alʲa] spoken by female subject W2; Right: [alʲa] spoken by male subject M1;

Modeling Russian Palatalized Rhotics

Data from a simulation of Russian palatalized rhotic articulation are shown in Figure 8.11. The acoustic waveform and time course of the tongue tip (TTCD) and tongue body constriction degree (TBCD) tract variables generated in a simulation of the sequence /arʲa/, using the gestural specifications in Figure 8.8, are shown on the right. Midsagittal articulation during the pre-consonantal vowel, the point of maximal coronal constriction during the second closure, and the point of closest palatal approximation of the trill are shown on the left.

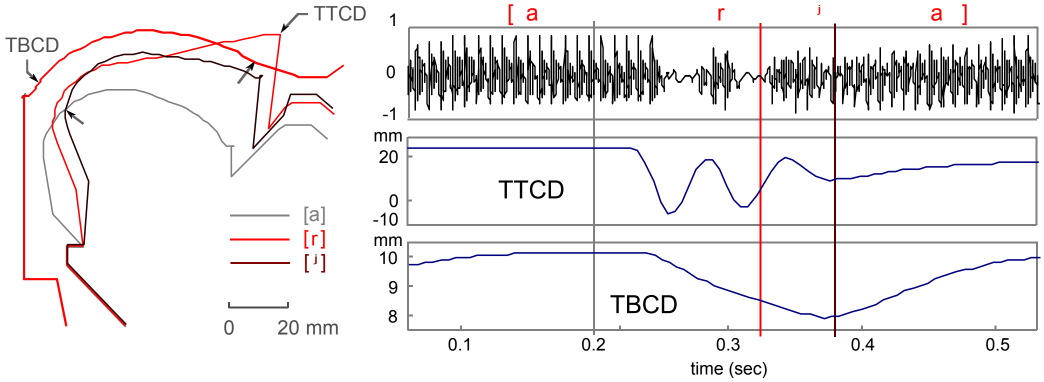


FIGURE 8.11: **TADA simulation of Russian intervocalic palatalized rhotic articulation: [arʲa]**. Left: midsagittal articulation during pre-consonantal vowel, mid-consonant and immediately post consonant; Right: acoustic waveform and time course of tongue tip and tongue body constriction degree tract variables.

The spectrogram of an intervocalic palatalized rhotic synthesized from the articulatory model is shown in Figure 8.10, where it is compared to spectra of intervocalic laterals produced by female and male Russian speakers. The data show that the articulatory model has successfully emulated the trajectories of the lower two formants, producing the characteristic rise in F2 late in consonant production in the low vowel context. As with the non-palatalized lateral, the primary difference between the synthesized and spoken speech is in the higher formants: F3 does not raise during lateral production in this context, and F4 remains too low.

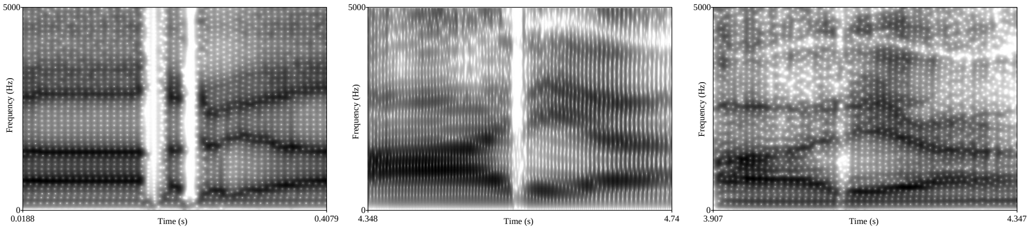


FIGURE 8.12: **Spectra of simulated and spoken Russian intervocalic palatalized rhotics**. Left: Speech synthesized from articulatory sequence [arʲa] simulated in TADA; Center: [arʲa] spoken by female subject W2; Right: [arʲa] spoken by male subject M1;

8.2.2 Summary: Gestural Modeling of Russian Liquid Consonants

In this section, phonological representations have been proposed for Russian coronal consonants. Non-palatalized liquids have been modeled as coordinated structures of tongue tip and tongue body gestures. Palatalized liquids are argued to consist of an additional tongue body approximation gesture coordinated with the gestural constellation corresponding to the paired non-palatalized consonant.

TADA simulations have been used to examine the validity of these phonological representations, and have demonstrated that a multi-gestural model is capable of capturing the essential articulatory properties of the four Russian liquids, consistent with the articulatory data obtained from the ultrasound experiment. In contrast to Spanish, where the dorsal target of the lateral is anterior to that of the rhotics, the Russian lateral was modeled using a more retracted tongue body constriction location, consistent with its characterization as a dark lateral.

Speech synthesized from dynamic simulations of intervocalic consonants was recognizable as each of the four liquids, and broadly consistent with the acoustic recordings of the same utterances produced by Russian speakers. In particular, the gestural models were highly successful at modeling the trajectories of the lower two formants, suggesting that the specifications of tongue body gestures are broadly correct.

As in the Spanish experiments, the acoustic simulations were less successful at modeling the behavior of F4, suggesting once more that a strictly midsagittal model of liquid articulation might be too reductive. F3 trajectories, on the other hand, were more accurate in the synthesized Russian non-palatalized lateral and palatalized liquids than in the Spanish liquid simulations, suggesting that the limitations of the midsagittal model are more problematic in languages which use clearer liquids in which the tongue body is more advanced.

8.3 Gestural Analysis of Phonological Processess involving Russian Liquids

Having characterized the Russian liquids using the phonological representations proposed above, we now consider how a gestural model might be able to account for some phonological processes involving liquid consonants in Russian.

8.3.1 Articulatory Analysis of Liquid Metathesis

Historically, as discussed in Section 6.3.2, liquids have been involved in a disproportionate number of metathesis phenomena in Russian. The most common of these processes involved the interchange of coda liquids with their preceding nuclear vowels (Table 6.6) in the development of Proto-Slavic.

It is noteworthy that the vowel which participated in this processes was the mid-back vowel /o/. It was shown in Chapter 7 that the dorsal gestures of the Russian (non-palatalized) liquids have constriction locations resembling those of the mid-back and mid-central vowels. Under the gestural analysis being proposed here, metathesis of the type *#oLC → *#LoC can be modeled as the result of a change in the coupling relationships between the nucleus and its associated consonantal gestures.

Cubberley (2002) cites the example of Proto-Slavic */olkotı/ *'elbow'* developing into Modern Russian /lok(o)tʲ/. A comparison of the gestural organization at the beginning of the two words (Tables 8.3 and 8.4) shows that there is no difference in gestural *constituency* in the first syllable: both words begin a prolonged uvular-pharyngeal vocalic gesture coordinated with a tongue tip closure gesture. The contrast results from the difference in timing relationships between these gestures: tongue-tip closure is synchronous with the tongue body gesture when the lateral is in the onset /lo/, and delayed with respect to the start of the dorsal constriction when the lateral appears in the coda /ol/. We can model these timing differences at the planning level using the coupling graphs contrasted in Figure 8.13.

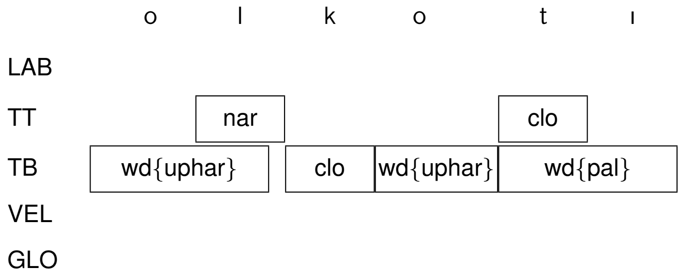


TABLE 8.3: Gestural Score: Late Common Slavonic **/olkotı/**.

Under this model, diachronic CV metathesis results from a change in the phasing relationships between the constellation of gestures which constitute a syllable. Given a preference for in-phase coordination, the model predicts that historical metatheses of this type would be more likely to proceed in the direction #VC → #CV than the reverse – an account which is consistent both with the historical evidence from Slavic and typological preferences for open syllables.

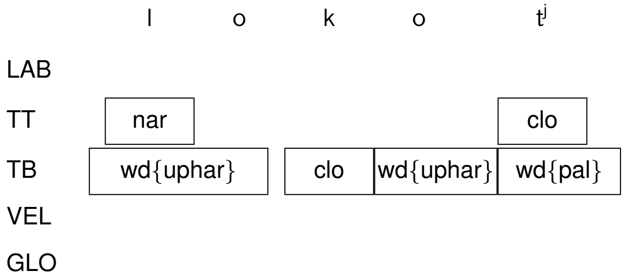


TABLE 8.4: Gestural Score: Modern Russian **/lokotʲ/**.

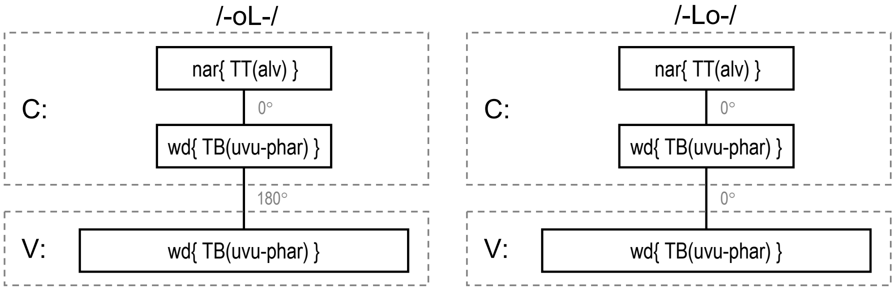


FIGURE 8.13: **Russian -oL- metathesis** resulting from changes in C-V phasing relationships.

8.3.2 Articulatory Analysis of Russian Jer Preservation

Another phonological process involving Russian liquids which warrants consideration under an articulatory framework is the preservation of medial jers. As noted in Section 6.3.2, in the development out of LCS, medial jers tended to be preserved when they occurred adjacent to a liquid in the Eastern Slavic languages, while the same sequence resulted in a syllabic liquid in the Southern Slavic languages (Tables 6.4–6.5).

Considering the phonological representation of a LCS word such as */vɪlkʊ/ *'wolf'*, the gestural organization would resemble that indicated in the gestural score in Table 8.5.

The development of this etymon into the forms found in the daughter languages: /vl̩k/ (Czech) and /volk/ (Russian) can be modeled in terms of changes in coupling and timing relationships between the same constituent gestures (as well as the changes in specification of tongue body constriction location which would accompany the changes in vowel quality). The gestural organization in the Modern Russian word /volk/, for example, is shown in Table 8.6: the loss of the final jer has led to the reorganization of the velar stop in coda position: asynchronously coupled to the preceding vowel.

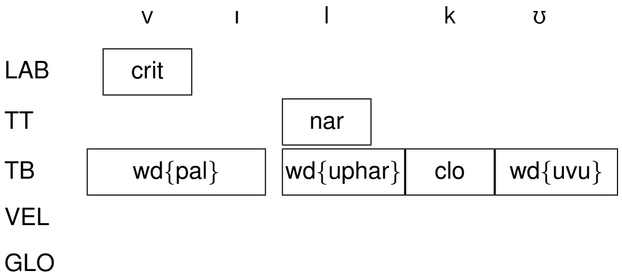


TABLE 8.5: Gestural Score: Late Common Slavonic **/vɪlkʊ/**.

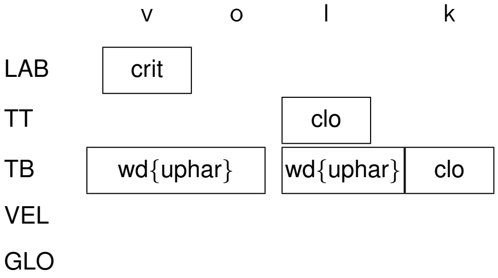


TABLE 8.6: Gestural Score: Russian **/volk/**.

Daughter forms of Common Slavic words in which jer-liquid sequences became syllabic may be seen as the consequence of further gestural reorganization whereby the tongue tip and tongue body gestures of the coda liquid became nucelic; i.e. became the gestures to which all other ambisyllabic gestures become coupled. The phonological representation of the Modern Czech word */vl̩k/ *'wolf'*, for example, is indicated in the gestural score in Table 8.7.

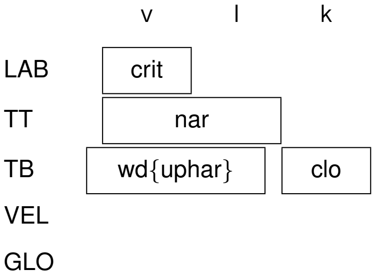


TABLE 8.7: Gestural Score: Czech **/vl̩k/**.

8.4 Summary

In this chapter, phonological models of Russian coronal consonants have been proposed. As for Spanish, and consistent with the central hypothesis of this dissertation, the non-palatalized coronal liquid consonants are argued to differ from the obstruents in that they are intrinsically comprised of coordinated tongue tip and tongue body gestures. Phonological representations have been proposed for Russian palatalized consonants in which an additional tongue body approximation gesture is coordinated with the non-palatalized gestural constellations.

Vowel-liquid metathesis has been analyzed as resulting from the reorganization of coupling relationships between tongue body gestures corresponding to adjacent vowels and liquids – an account which is consistent with the identity of the vowel most commonly involved in this process in the dichronic phonology of Slavic. Jer preservation and development of syllabic liquids in Slavic are argued to result from the interaction and syllabic reorganization of adjacent vowel and liquid tongue body gestures.