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# Laterals in simplex vs. complex syllable codas: a comparison of four languages

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## Abstract

*English dark /l/ in coda clusters has been shown to exhibit non-local coordination patterns (i.e., vowel shortening when going from singleton to complex codas - e.g., gull-gulp). The unpredicted organization has been attributed to the articulatory complexity and timing of the coda dark /l/. The present study further investigates this issue by analyzing coda coordination patterns as a function of /l/ darkness in Russian, English, Romanian and Georgian, four languages that differ in the gestural synergies of the coda lateral. The acoustic analysis shows that while predictions on coda coordination patterns based on the gestural composition of the /l/ are confirmed for Russian, English and Romanian, they are not confirmed in the case of Georgian.*

**Keywords:** speech production, lateral allophony, coordination patterns

## 1. Introduction

Syllable level coordination patterns, and in particular the asymmetry between onsets and codas, first described within the framework of Articulatory Phonology by Browman and Goldstein (1988) have been the focus of many studies. Within this framework, while onsets are hypothesized to have global coordination patterns, codas are timed locally. A global coordination implies that consonant gestures are synchronously timed with the following vowel gesture, triggering articulatory rearrangements with increasing phonotactic complexity. Local coordination patterns do not trigger rearrangements, the vowel and consonant gestures are sequentially timed (i.e., one gesture starts after the previous one is deactivated). Since the seminal paper of Browman and Goldstein (1988), quite a few studies have looked at cross-linguistic differences in onset coordination patterns (Honorof and Browman 1995; Brunner, Geng, and Sotiropoulou 2014; Pouplier 2012; Hermes, Grice, et al. 2008; Hermes, Ridouane, et al. 2011; Shaw et al. 2009), identifying both language- and consonant-cluster-specific patterns. Far fewer studies have looked at between-language differences of coordination patterns in codas (Marin and Pouplier 2014). One particular study, Marin and Pouplier (2010), identified a non-local organization pattern in coda position. This articulatory-acoustic study of American English onset and coda clusters revealed that in lateral coda clusters the presence of the lateral triggers a shift of the /l/ gestures towards the preceding vowel, similar to patterns found in complex onsets. Acoustically, a shortening of the vowel is observed. The authors attribute this divergent pattern to perceptual consequences of the coda /l/'s overlap with the vowel. In an acoustic study, Katz (2012) replicated and extended their finding to coda rhotics, as well. In a subsequent study, Marin and Pouplier (2014) did not find the divergent pattern for German and Romanian coda /l/, but repli-

cated it for Romanian trills. These results led the authors to amend their original hypothesis of attributing the non-local coda coordination to perceptual recoverability, suggesting that it is more likely due to the articulatory characteristics of the liquid. Coda liquids in American English (dark /l/ and rhotic) are produced with a double lingual gesture: a vocalic gesture - tongue dorsum (TD) retraction for the lateral and tongue root (TR) retraction for the rhotic - that precedes a consonantal tongue tip (TT) gesture. Similar to the English dark /l/, the rhotic trill in Romanian is also produced with a double gesture: a vocalic TR gesture that precedes and acts as an anchor for the consonantal TT trilling gesture. The English liquids and the Romanian /r/ (the cases where coda global organization was found) all involve the presence of a double lingual gesture and an earlier occurring vocalic gesture.

In this paper we therefore hypothesize that non-local organization in coda position occurs due to the presence of an earlier vocalic gesture that triggers gestural competition between the vowel nucleus and the vocalic gesture of the liquid, resulting in a reorganization of articulatory synergies in the rime.

To test this hypothesis, we focus on lateral consonants by comparing coda coordination patterns, acoustically, in four languages that differ in the gestural synergies of their coda lateral consonant: Russian (coda dark /l/ - Recasens (2012)), English (coda dark /l/ - Sproat and Fujumura (1993)), Georgian (clear - dark /l/ allophony based on vowel frontness - (Robins and Waterson 1952; Chigogidze 2011)) and Romanian (coda clear /l/ - Recasens (2012)). Robins and Waterson (1952) describe the Georgian lateral allophony as "decided "dark" velarized quality in all positions except before /e/ and /i/" (page 63), suggesting that Georgian /l/ is always dark /l/ in codas. Their study is, however, based on a single informant. The data in the present study suggests that both clear and dark /l/ varieties are present in coda position. Unlike dark /l/, clear /l/ lacks an earlier TD retraction gesture (Sproat and Fujumura 1993; Narayanan, Alwan, and Haker 1997) and is therefore not expected to trigger a non-local organization in coda position.

We test our hypothesis using acoustic data. The acoustic effect of global coordination patterns in coda position is a shortening of the vowel in cluster tokens compared to their respective singleton counterpart.

## 2. Methods

A total of 23 native speakers - Russian (5), American English (6), Georgian (6) and Romanian (6) - were recorded producing three repetitions of target singleton-cluster pairs (C)CVL-(C)CVLC with varying front/back vowel contexts, embedded in a carrier phrase in each respective language. Target words were hand segmented and labeled in Praat (Boersma and Weenink (2022)) based on the waveform and wide-band spectrograms.

The syllable rhyme was segmented for each target word. The onset of the vowel was marked at the onset of F1. The end of the visible formant structure on the spectrogram corresponded to the end of the postvocalic /l/. Given that the boundary between vowel and lateral (especially for dark /l/) was not always robustly identifiable, two different duration measures were considered for all the data: vowel + lateral (VL) sequences, and the interval between the midpoint of the vowel and the midpoint of the lateral (V50-L50) following Durvasula (2023). Raw duration measures were normalized dividing each duration measure by the articulation rate, calculated as the number of phones per second. To measure the acoustic shortening degree in cluster vs. singleton tokens, we defined a duration ratio as the ratio between each cluster and the corresponding singleton token (e.g. for the *sill* [sɪl]- *silk* [sɪlk] pair the duration ratio is  $\frac{l\text{-duration}_{silk}}{l\text{-duration}_{sill}}$ ). Ratios close to 1 indicate lower degrees of shortening in the cluster token. To compare the degrees of shortening in clusters vs. singletons we compare each language to a hypothetical language (H) which has no shortening. Data for H was generated as a normal distribution of mean = 1 and standard deviation equal to (i) the mean standard deviation of the duration ratios found in our data, (ii) the lowest standard deviation found in our data (i.e., Russian) and (iii) the highest standard deviation found in our data (i.e., Georgian). Testing H with three different standard deviations ensures the choice of standard deviation does not bias the results.

Formant values (F1, F2, F3) were extracted at the lateral midpoint (when the vowel-lateral boundary was identifiable) or at the steady state of the lateral (when the vowel-lateral boundary wasn't robustly identifiable). The darkness degree was calculated as the difference between the F2 and F1 values ( $l\text{-darkness} = F2 - F1$ ).

### 2.1. Statistical analysis

The degree of /l/ darkness and the duration ratios between singleton and cluster tokens were used as dependent variables in linear mixed effects models (*lme4* - (Bates et al. 2015)). For all three models (/l/ darkness and two duration measures) predictors included *Language* (H (reference level), Russian, English, Georgian, Romanian), *Vowel Quality* (front, back), and *Sex* (F, M) as fixed factors and *Participant* and *Repetition* as random effects with random intercepts. An interaction term between *Language* and *Vowel Quality* was included.

### 2.2. Predictions

We expect shortening of VL and V50-L50 duration between clusters and singletons in Russian, English, and Georgian rimes with back vowels (dark /l/ in coda). No shortening is expected in Romanian and front vowel Georgian rimes (clear /l/ in coda).

## 3. Results

Results will be presented in two stages. First we compare lateral darkness across the four languages, followed by the results on acoustic shortening in the rime.

### 3.1. Coda /l/ in four languages

We first present acoustic differences of coda lateral allophones in the four languages considered: Russian, English, Georgian and Romanian. The measure of /l/ darkness is the difference between the second and first formants (F2-F1). Clear /l/ is characterized by higher, and dark /l/ by lower values of F2-F1.

The descriptive analysis shows that the degree of lateral darkness is a gradient feature across languages. Russian has the darkest lateral of the four languages (overall mean $_{F2-F1}$  = 403). English has the second darkest lateral (overall mean $_{F2-F1}$  = 538). The third darkest lateral in our data (independent of vowel context) is the Georgian one (overall mean $_{F2-F1}$  = 950). Finally, as expected, Romanian has the clearest coda lateral ((overall mean $_{F2-F1}$  = 1248).

Table 1: Mean F2-F1 values of /l/ in front and back vowel context per language and participant. The absolute value of the difference between front and back vowel contexts is displayed in the rightmost column.

Language	Speaker	Front V	Back V	Δ
Russian	RU01	249	378	129
	RU02	482	247	235
	RU03	524	400	124
	RU04	440	448	8
	RU05	476	505	29
English	EN01	370	531	165
	EN02	696	531	165
	EN03	756	601	155
	EN04	670	500	170
	EN05	684	487	197
	EN06	341	331	10
Georgian	GE01	1489	808	681
	GE02	881	735	146
	GE03	649	640	9
	GE04	1275	802	473
	GE05	1203	706	497
	GE06	1528	666	862
Romanian	RO01	1018	1068	50
	RO02	1466	1459	7
	RO03	1590	1366	224
	RO04	1315	1299	16
	RO05	1107	1131	24
	RO06	1200	1073	126

A certain degree of inter-speaker and vowel context variability is observed. Table 1 shows the mean values of /l/ darkness for all participants as a function of front and back vowels. The absolute value of the difference between front and back vowel /l/ darkness measures is displayed in the rightmost column ( $\Delta = |F2-F1_{\text{front V}} - F2 - F1_{\text{back V}}|$ ). Differences in mean values of coda /l/ darkness between front and back vowel contexts are non-zero for all the languages considered, suggesting that some degree of coarticulation is present. Figure 1 illustrates the distribution of /l/ darkness measures for all languages as a function of vowel context.

The linear mixed model shows that Russian and Romanian do not exhibit a vowel context allophony. No significant difference in F2-F1 is found between front and back vowel contexts (Russian: Est.  $\sim$  31.54, t-value  $\sim$  0.63, p-value  $\sim$  0.52; Romanian: Est.  $\sim$  54.2, t-value  $\sim$  1.4, p-value  $\sim$  0.14). Both English and Georgian show significant differences in F2-F1 values depending on vowel context, with coda /l/ being clearer after a front vowel than after a back vowel. The effect is larger for Georgian than for English (Georgian: Est.  $\sim$  442, t-value  $\sim$  16.01, p-value  $<$  0.001; English: Est.  $\sim$  119, t-value  $\sim$  3.37, p-value  $<$  0.001).

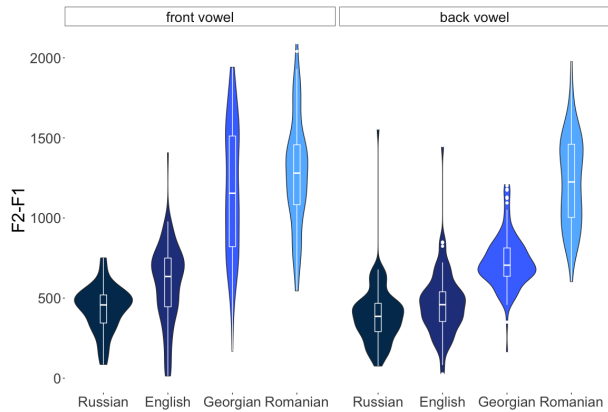


Figure 1: F2-F1 values as a function of language (Russian, English, Georgian, Romanian) and vowel quality (front vs. back).

### 3.2. Acoustic shortening in singleton-cluster pairs

In this section we present acoustic differences of vowel-lateral shortening between cluster and singleton in the four languages (Russian, English, Georgian, Romanian) compared to a hypothetical language H that has no shortening. Figure 2 illustrates the normalized VL duration ratios as a function of language and vowel quality.

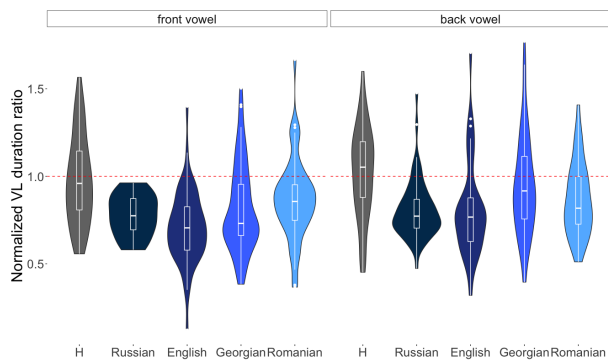


Figure 2: Normalized ratios of vowel-lateral (VL) duration as a function of language (H, Russian, English, Georgian, Romanian) and vowel quality (front vs. back). The red horizontal line indicates a ratio of 1 (i.e., VL duration in singleton = VL duration in cluster token)

Results of the linear mixed models only partially confirm our prediction, and cross-measure differences (VL vs. V50-L50) are found. The VL duration ratio results show that, as expected, Russian and English both have significantly higher degrees of shortening, while Romanian shows no differences in shortening compared to language H in either front or back vowel contexts. Going against our predictions, Georgian exhibits significant shortening in the front vowel context (clear /l/s) and no shortening for back vowel contexts (dark /l/s). Results for the VL duration ratio are summarized in Table 2.

The V50-L50 results show the same patterns, as well as an additional unpredicted significant shortening for Romanian in front vowel context (i.e., Romanian has significant shortening when compared to the non-shortening language H only in front vowel contexts). The V50-L50 measure is, however, the less

reliable one in our case because of the difficulty of identifying a precise acoustic boundary between the vowel and the lateral coda, especially in back vowel - dark /l/ and front vowel - clear /l/ sequences.

Table 2: Model results of VL duration ratios as a function of Language and Vowel Context. The reference level for language is the hypothetical language H (normal distribution of mean=1 and standard deviation equal to the mean standard deviation found in our data).

Lang.	Front V			Back V		
	Est.	t	p.	Est.	t	p
RU	-0.21	-2.5	< 0.01	-0.23	-3.27	< 0.01
EN	-0.26	-3.9	< 0.001	-0.20	-2.91	< 0.01
GE	-0.17	-2.65	< 0.05	-0.09	-1.4	0.16
RO	-0.10	-1.45	0.15	-0.15	-1.9	0.05

## 4. Discussion and conclusion

The present study set out to test the hypothesis that global coordination patterns in coda position are triggered by the earlier occurring vocalic gesture present in the production of dark /l/, by comparing four languages that differ in their type of coda lateral. Predictions were confirmed for all languages except Georgian, which shows the reverse pattern from the one predicted. One possible explanation for the unexpected pattern is that the degree of darkness could play a role. In our data, Georgian dark /l/ is significantly less dark than Russian and English dark /l/.

An effect of vowel context was found for both English and Georgian. We expected it for Georgian, which has a reported vowel context allophony in onsets. Previous literature on Georgian suggested dark /l/ in codas, but our data reveals much more variability. Data from additional speakers, as well as an analysis of individual speaker data, may reveal whether this difference can be attributed to coarticulatory effects, or to allophony.

Depending on duration measure (VL vs. V50-L50), significance levels change. Given the difficulty of robustly identifying the boundary between vowel and lateral in some cases, we used a proxy measure consisting of the vowel-lateral (VL) sequences. We acknowledge that other changes may occur within this VL interval, which require further careful acoustic and articulatory investigation. At the same time, V50-L50 is not a robust measure. While it works well for obstruents, it is less efficient for sonorants, since vowels are less easily separable from sonorants acoustically.

The present study relies only on acoustic data to confirm predictions derived from theoretical articulatory characteristics of laterals. In order to better understand the relationship between /l/ darkness and coda coordination patterns, articulatory data will be collected to precisely compare the timing of the articulatory gestures in the lateral coda rime.

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