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Syllable position effects and gestural organization: Evidence from Russian

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Syllable position effects and gestural organization: Articulatory evidence from Russian*

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Abstract

Previous articulatory studies have shown that English syllable-initial and syllable-final consonants exhibit different patterns of gestural organization. These differences – *syllable position effects* – are manifested primarily in the relative timing and magnitude of gestures. In general, syllable-initial consonants show more stable patterns of coordination and "tighter" articulatory constrictions than the same consonants in syllable-final position. This paper addresses the question of whether syllable position effects hold for other languages by examining the articulatory properties of some Russian syllable-initial and syllable final consonants: the palatal glide /j/ and labial stops /p^j/ and /p/. In general, the articulometer (EMMA) results confirm the hypothesis that the same consonants in these two positions differ with respect to their inter-gestural timing and gestural magnitude. At the same time, some predictions made based on patterns observed in English are not supported. The results thus provide evidence that, although syllable positions are characterized by different patterns of gestural organization, actual manifestations of this organization are not always the same; they may vary between gestures within a language and between similar gestures in different languages. It is further suggested that while the task-dynamics of gestural coordination is crucial to explaining syllable position effects, some non-contrastive and variable information still has to be specified – possibly by being lexically encoded.

1. Introduction: Background and predictions

While the role of the syllable as a phonological unit has been long established, attempts to find the basis of the syllable in phonetics – articulation and/or acoustics – have not been entirely successful until recently. A number of articulatory studies (Krakow 1989, Sproat and Fujimura 1993, Browman and Goldstein 1995, Byrd 1996, Fougeron and Keating 1997, Gick 2003, among others) have provided evidence for the gestural organization of the syllable in English. Specifically, it has been established that syllable-initial and syllable-final consonants tend to exhibit different patterns of gestural organization. These differences, referred to in this paper as *syllable position effects*, are manifested primarily in the relative timing of gestures, and in their magnitude, that is in the degree of constriction.

A classic example of these contextual differences involves positional allophones of the American English /l/, namely the syllable-initial *clear* [l] as in 'leap' and the syllable-final *dark* [λʃ] as in 'peel'. Investigations of these allophones using a variety of methods (Giles and Moll 1975, Sproat and Fujimura 1993, Browman and Goldstein 1995, and Gick 2003) have shown that both are produced with two articulators, a tongue tip (TT) closure at the alveolar ridge and a tongue body (TB) retraction. The difference between the dark and clear /l/ is in the timing and magnitude of these gestures. First, while the TT gesture is near-synchronous with the TB gesture syllable-initially, TT follows TB syllable-finally. Second, the relatively consistent achievement of the TT target syllable-initially contrasts with the frequent lack of complete closure syllable-finally, particularly in casual and fast speech (Giles and Moll 1975). In sum, distinct timing and magnitude patterns of the same gestures result in the two different kinds of acoustic and perceptual consequences commonly associated with the allophones [l] and [λʃ]. Similar positional effects on timing have been observed for other English consonants that involve multiple oral gestures, such as the nasal /m/ and the glide /w/. Thus, the lip aperture and velum opening gestures of syllable-initial /m/ achieve their goals synchronously. In contrast, in the production of the syllable-final /m/, the more closed articulator, the lips, lags substantially behind the more open one, the velum (Krakow 1989).

Magnitude effects, similar to the final reduction of the tongue tip of /l/, have also been documented for a number of English consonants: oral and nasal stops (Browman and Goldstein 1995, Byrd 1996, Turk 1994, Fougeron and Keating 1997), the glides /w/ and /j/, and the rhotic /r/ (Gick 2003). While exhibiting the same general pattern, individual gestures tend to vary in the degree of reduction and overall stability. For instance, it was found that the oral gestures of velar and labial stops (tongue dorsum and the lips) show a moderate reduction in magnitude in coda position, while the articulation of alveolar stops in the same position is highly variable, with TT being considerably reduced in magnitude (Browman and Goldstein 1995, Byrd 1996, among others). Although the magnitude reduction effect is commonly displayed by syllable-final consonants in English, the opposite process has been found to occur in some cases. Thus the reduction of TT in the articulation of the *dark* [l∫∫] is often accompanied by some increase in magnitude of the TB retraction gesture (Giles and Moll 1975). Similarly, the lowering of the velum of the syllable-final /m/ was found to be more extreme in final than in initial position (Krakow 1989). Yet some other consonants, for example the sibilant fricatives /s/ and /z/, do not seem to be affected by syllable position (Byrd 1996).

One question raised by the findings for English is whether they can be extended cross-linguistically, that is whether other languages also show differences between syllable-initial and syllable-final consonants in inter-gestural timing and magnitude. The few articulatory investigations of syllable effects that have been conducted on other languages have provided mixed results: while some found positional differences in gestural organization similar to English (see Krakow 1999 for a review), others reported either no consistent syllable position effect or effects somewhat different from the findings for English (see, for example, Wang 1995 on the timing and magnitude of the velum and lips in Cantonese; Gick, Campbell, Oh, and Tamburri-Watt 2003, on the magnitude and timing of tongue tip and tongue dorsum for /l/ in a number of languages).

The current work aims to contribute to the cross-linguistic study of the gestural properties of the syllable by examining positional effects in three Russian consonants: the palatalized and non-palatalized voiceless labial stops /p^j/ and /p/, and the palatal glide /j/. The first consonant, /p^j/, presents an interesting case for an articulatory study of inter-gestural timing. The consonant is a complex gestural constellation consisting of two coordinated oral gestures, Lips [bilabial, closed] and Tongue Body [palatal, narrow] (Kochetov 2002; see also Recasens and Romero 1997, Zsiga 2000 on the gestural organization of palatalized consonants). An examination of this consonant will allow us to investigate the timing of the two gestures in syllable-initial and syllable-final positions, and to compare this timing to the timing of the same gestures in combinations of the consonants /p/ and /j/, sequences /pj/ and /jp/. In addition, I will examine the magnitude and duration properties of the two gestures in the production of the syllable-initial and syllable-final consonants /p^j/, /p/, and /j/. (An examination of the velarization of the non-palatalized /p/ is beyond the scope of this paper; but see Kochetov 2002.)

The general hypothesis tested in this work is that the Russian consonants in question differ syllable-initially and syllable-finally with respect to inter-gestural timing and their internal gestural properties. That is, the hypothesis predicts that the timing of the gestures of Lip Aperture (LA) and Tongue

Body (TB) of /p^j/, as well as the magnitude (and possibly duration) of these gestures in /p^j/, /p/, and /j/ differ depending on the position. Further, more specific predictions can be made about the types of differences to be observed. The timing patterns found in English suggest that we may expect the two gestures to be synchronous syllable-initially, and the more closed gesture, the lips, to follow the more open gesture, TB, syllable-finally. In addition, in all positions, the timing of the two gestures of /p^j/ in [p^ja] and [ap^j] may differ from the timing of the same gestures in the sequences of /p/ and /j/ in [pja] and [ajp], since these are lexically distinct in Russian (Avanesov 1984: 139-140, Jones and Ward 1969: 93-96). These specific predictions will be referred to as timing hypotheses A and B.

Based on the findings for the LA and TB [palatal] gestures of the English consonants /p/ and /j/, we may expect the corresponding gestures of the Russian /p/ and /j/ to be reduced syllable-finally, with more reduction for /j/ than for /p/ (the magnitude hypothesis). For the palatalized labial /p^j/, we may find the same effect for both LA and TB or, we may find a reduction of the more closed constriction, LA, and an increase in the magnitude of the more open constriction, TB (as in the English syllable-final /l/). Overall, the syllable-final consonants are expected to show more variation in timing and magnitude (the variability hypothesis). No specific predictions are made about temporal differences between initial and final gestures, or about differences between the same gestures of different consonants (LA of /p/ and /p^j/; TB of /p^j/ and /j/).

2. Experiment

Data were collected using the EMMA (Electromagnetic Midsagittal Articulometer: Perkell et al. 1992) magnetometer system at Haskins Laboratories. Four speakers of standard Russian participated in the experiment: three females (subjects AS, NT, and DK) and one male (the author, subject AK). Subjects AS and DK were originally from Moscow and subjects NT and AK were from Perm', Russia. (Some of the data, nonwords with /p/ and /p^j/ for subjects AS, NT, and AK, were used in Kochetov (2002), a study investigating the relation between articulation, perception, and phonotactics of palatalized stops.)

2.1. Materials

The stimuli included nonwords and real Russian words with the consonants /pʲ/, /p/, and /j/. Since the data for subject AK were collected earlier as part of a larger-scale exploratory study, not all of the stimuli for this subject were identical to those used later for the remaining subjects. Therefore, the stimuli used for subjects AS, NT, and DK are described here separately from the stimuli used for subject AK. The utterances used for subjects AS, NT, and DK are shown in Table 1. The utterances consisting of a sequence of nonwords and real words had the same target consonants in the same immediate environments. The stress pattern in both types of utterances was also controlled for: both test words of the utterance carried primary stress, for example, [∪ταπϑ ∪παπ⎞] or [∪γραπϑ ∪κα⏐δ↔ϖ↔].

Table 1. The nonword and real word stimuli presented to the subjects AS, NT, and DK and the analysis of these stimuli in the studies of inter-gestural timing, TB and LA magnitude and duration.

Cons.	Position	Nonword stimuli		Real word stimuli		Analysis		
		IPA	Translit.	IPA	Translit.	Timing	TB	LA
/pʲ/	onset	τα πϑαπ⎞	*ta pjapy*	♣λα πϑατ↔φ ↔	*shla pjataja*	√	√	√
		ταπ πϑα π⎞	*tap pjapy*	γραπ πϑατ↔ϖ ↔	*grab pjatogo*		√	
		τατ πϑαπ ⎞	*tat pjapy*	βρατ πϑατ↔ϖ ↔	*brat pjatogo*			√
	coda	ταπϑ απ⎞	*tap' apy*	γραπϑ ανγϑIλ ↔	*grab' angela*	√	√	√
		ταπϑ πα π⎞	*tap' papy*	γραπϑ παδ↔φ ↔	*grab' padaja*		√	
		ταπϑ ταπ ⎞	*tap' tapy*	γραπϑ τομν↔ ϖ↔	*grab' tomnogo*			√
		ταπϑ κα π⎞	*tap' kapy*	γραπϑ κα⏐δ↔ ϖ↔	*grab' každogo*			√
/p/	onset	τα παπ⎞	*ta papy*	♣λα παδ↔φ↔	*shla padaja*			√
		τατ παπ⎞	*tat papy*	βρατ παδ↔φ↔	*brat padaja*			√
		τακ παπ⎞	*tak papy*	βρακ παδ↔φ ↔	*brak padaja*			√
	coda	ταπ απ⎞	*tap apy*	γραπ ανγϑIλ↔	*grab angela*			√
		ταπ ταπ⎞	*tap tapy*	γραπ τομν↔ϖ ↔	*grab tomnogo*			√
		ταπ καπ⎞	*tap kapy*	γραπ κα⏐δ↔ϖ ↔	*grab každogo*			√
/j/	onset	τα φαπ⎞	*ta japy*				√	
		ταπ φαπ⎞	*tap japy*			√	√	
	coda	ταφ απ⎞	*taj apy*				√	
		ταφ παπ⎞	*taj papy*			√	√	

The need to control precisely for target consonants and environments took precedence over the semantic plausibility of these word combinations. (The real word utterances were verbs + noun/adjective combinations of the following Russian words: *shla* (she) 'walked,' *grab'* 'rob' (imp.), *grab* 'hornbeam,' *brat* 'brother,' *brak* 'flaw,' *pjataja* 'the fifth' (fem.), *angela* 'angel' (acc. sg.), *pjatogo* 'the fifth' (acc. sg.), *padaja* 'falling,' *tomnogo* 'fat' (acc. sg.), *každogo* 'every.') All stimuli were embedded in a carrier phrase [∪Eτ ℘ ______ ℘∪π^{φ}ατ^{φ}] 'This is ____ again' and presented in Cyrillic in alternating blocks of nonword and real word utterances. Five tokens for each nonword and each real word utterance were collected, yielding a total of 70 tokens per subject for /p^{j}/ (30 onset and 40 coda tokens), 60 tokens for /p/ (30 onset and 30 coda tokens), and 20 tokens for /j/ (10 onset and 10 coda tokens). The last three columns of the table indicate which stimuli were used in which particular study (described in Section 2.2), the studies of: inter-gestural timing (30 tokens per subject), TB magnitude and duration (60 tokens), and LA magnitude and duration (110 tokens). Note that due to errors such as false starts or certain technical problems, the number of analyzed tokens was sometimes fewer than collected; in other cases, some additional tokens were collected and analyzed. The number of tokens per subject analyzed in each particular study is given in the presentation of the results in Section 3.

Table 2. Real word stimuli presented to subject AK. (Nonword stimuli for /p^{j}/ and /p/ were the same as for the other subjects).

Cons.	Position	Real word stimuli
/p^{j}/	onset	πϑατ *pjat,* πϑατϑ *pjat',* κραπ □πϑατ↔ϖ↔ *krab pjatogo,* βρατ πϑατ↔ϖ↔ *brat pjatogo*
	coda	γραπϑ αδΥ *grab' Adu,* γραπϑ παδ↔φ↔ *grab' padaja,* γραπϑ ταντσ⎞ *grab' tancy,* γραπϑ καδ↔τΣνϑΙκ↔ *grab' kadočnika*
/p/	onset	πατ *pat,* βρατ παδ↔φ↔ *brat padaja,* βρακ παδ↔φ↔ *brak padaja*
	coda	κραπ αδ⎞ *krab Ady,* κραπ ταντσ↔ *krab tanca,* κραπ καδ↔τΣνϑΙκ↔ *krab kadočnika*
/j/	onset	πφαν⎞φ *pjjanyj*
	coda	βαφτ *bajt,* ϖοφν *vojn*

For subject AK, the nonsense utterances for the labial stops /p^{j}/ and /p/ were exactly the same as for the other three subjects, while no nonsense items for /j/ were collected. The real word stimuli used for subject AK are shown in Table 2. Five tokens for each nonword and four tokens for each real word utterance were collected from the subject, giving a total of 67 tokens for /p^{j}/ (31 onset and 36 coda tokens), 54 tokens for /p/ (27 onset and 27 coda tokens), and 12 tokens for /j/ (4 onset and 8 coda tokens). The presentation of the stimuli and the analysis were the same as for the other subjects, except for certain cases discussed in each particular study.

2.2. Procedure and analysis

Receivers for the articulometer were placed at the following midsagittal points: *upper lip* and *lower lip* (UL and LL; placed at the border of vermillion), lower incisors (as an estimate of jaw movement), and four points on the tongue. One of the tongue receivers was positioned about 5 mm from the *tongue tip* (TT); another receiver was attached as far back on the tongue as was possible, roughly on the *tongue dorsum* (TD). The other two receivers, *tongue body 1* (TB1, more anterior) and *tongue body 2* (TB2, more posterior), were placed between these first two receivers at approximately equal distances from TT and TD respectively, and from each other. The movement data were collected at a sampling rate of 500 Hz and the acoustic data at 20 kHz. The kinematic data were converted from voltage to distance, calibrated, and corrected for head movement and for any possible shifts of the receivers relative to the transmitters. Some malfunctions of the receiver coil for UL for subject AS resulted in a defective set of data for the corresponding articulator. For this subject the analysis of lip movements was based on the LL trajectories only.

The analysis of the articulatory data collected involved a number of measured variables: The distance between the lower and upper lip trajectories – the *lip aperture* (LA) – was taken as an indicator of the formation and release of the lip gesture of /p/ and /p^j/. Since the UL data were missing for one of the speakers (subject AS), the LL raising movement was also compared across the subjects. The position of the receiver on the tongue that showed the maximum amplitude of raising and fronting movement during the articulation of /j/ and /p^j/ was taken as an indicator of the palatal gesture of these consonants. For subjects NT and AK, this receiver was TB2, while for subjects AS and DK it was TD. For consistency of presentation, I will refer to the variables analyzed as the "lip aperture" (LA) and the "tongue body (position)" (TB).

Tangential velocity minima for all receivers were automatically calculated, based on the velocity in the x- and y-coordinates of these receivers (see Chitoran, Goldstein, and Byrd 2002). The velocity minima obtained were used to determine temporal articulatory landmarks – the beginning of the closing movement, the achievement of the target, and the release from the target. The beginning of the closing movement and the release from the target were located when the velocity for a given receiver exceeded a threshold of 20% above the mean for all utterances (zero velocity). The achievement of the target was located when the velocity for a given receiver fell below the 20% threshold. Positional maxima and minima (*peaks* and *valleys*) for LA, LL, and TB were also obtained automatically. These were used in determining the magnitude of gestures.

Two measurements of inter-gestural timing were used in the study: *achievement lag* and *release lag*. The first measurement was defined as a period of time between the achievement of two constrictions, the lips (LA or LL) and TB; the second measurement was defined as a period of time between the release of these constrictions. The lag was considered positive if the achievement or release of the TB followed the corresponding landmarks of the lips; it was considered negative if the achievement or release of the TB preceded the corresponding landmarks of the lips. These measurements were limited to the minimally contrastive nonword and real word utterances with a single /p^j/ (in syllable onset and coda) and the word-boundary sequences of /p/ and /j/ (/pj/ and /jp/; see Table 1).

The gestural magnitude measurements were based on the vertical and horizontal peak values of the TB constriction and the vertical peak values of LL, as well as on the minimum values of LA. Gestural duration was obtained based on the same articulatory landmarks as the analysis of inter-gestural timing. It involved the measurements of the duration of the *closing movement* (the time from the onset of movement towards a constriction to the achievement of this constriction and *plateau* (the distance between the achievement of the constriction and the beginning of the movement away from this constriction. The TB measurements were done for /p^j/ and /j/; the LL raising and LA measurements were done for /p^j/ and /p/ (see Table 1).

The results of all measurements were further tested in a number of Analyses of Variance (ANOVAs), separately for each subject. Each test involved three between-item factors: Consonant (/p/, /p^j/, and /j/), Position (syllable onset vs. syllable coda), and Type of stimuli (nonwords vs. real words). In each case, Tukey HSD post-hoc tests were performed to investigate significant interactions.

3. Results

3.1. Inter-gestural timing

The results for achievement lag are presented in Figure 1. Here the values for the lag in sequences /pj/ and /jp/ are given at the bottom and the values for /p^j/ at the top. Significant effects and interactions for both lag measurements are shown in Table 3. Overall, the values for the lag measurements were lower in coda position than in onset position, indicating that, syllable-finally, the TB constriction was both achieved and released earlier with respect to the LA constriction than was the case in initial position. There was, however, a significant Consonant X Position interaction for all subjects, pointing to considerable differences in the effect of position between the sequences of /p/ and /j/ on the one hand and the consonant /p^j/ on the other. In addition, there was a main effect of Consonant for some of the subjects.

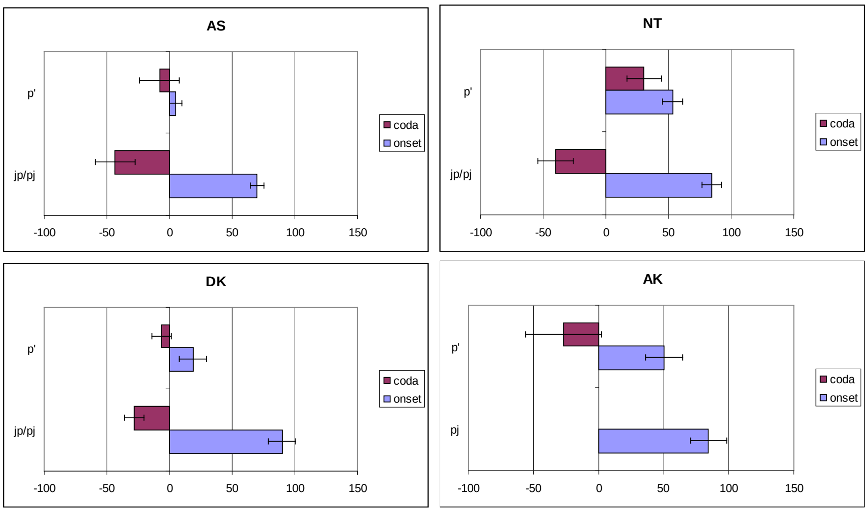

Figure 1. Mean values for achievement lag for /p^j/ in a#_a (onset) and a_#a (coda) in nonwords and real words and for the sequences /pj/ (onset) and /jp/ (coda) in nonwords (in ms) for four subjects.

Table.3. A summary of significant main effects and interactions for achievement lag (a) and release lag (b) for four subjects.

		AS	NT	DK	AK
a.	Position	F(1,26) = 70.153, p < 0.001	F(1,28) = 233.683, p < 0.001	F(1,28) = 203.432, p < 0.001	F(1,25) = 101.314, p < 0.001
	Consonant	Not significant	F(1,28) = 18.419, p < 0.001	F(1,28) = 12.874, p < 0.01	F(1,25) = 10.135, p < 0.01
	Position X Consonant	F(1,26) = 46.809, p < 0.001	F(1,28) = 121.579, p < 0.001	F(1,28) = 92.228, p < 0.001	not available
b.	Position	F(1,26) = 32.469, p < 0.001	F(1,28) = 159.748, p < 0.001	F(1,28) = 475.753, p < 0.001	F(1,25) = 43.818, p < 0.001
	Consonant	Not significant	F(1,28) = 5.867, p < 0.05	F(1,28) = 10.785, p < 0.01	not significant
	Position X Consonant	F(1,26) = 15.498, p < 0.01	F(1,28) = 205.975, p < 0.001	F(1,28) = 309.290, p < 0.001	not available

Sequences of /p/ and /j/

The results for the sequences for the first three subjects (AS, NT, and DK) are considered separately from those for subject AK, because of certain differences in the stimuli. We can see from Figure 1 that the positional differences in achievement lag between the sequences /pj/ and /jp/ for subjects AS, NT, and DK were substantial: For /pj/, the achievement of TB followed the achievement of LA by about 70–90 ms on average – a positive lag. For /jp/, the achievement of TB preceded the achievement of LA by about 30–45 ms – a negative lag. The positional differences in release lag were similar: for /pj/, TB followed LA by about 65–100 ms; for /jp/, TB preceded LA by about 50–75 ms. Overall, the lag values indicate that the constrictions of the two gestures were timed sequentially, as one might expect for sequences of two consonants; yet there was less lag in the articulation of /jp/ than for /pj/.

The timing observed for subject AK in the word-internal sequence /pj/ was similar to the timing for the other subjects (where /pj/ was a word-boundary sequence): there was a substantial positive achievement and release lag (about 85 and 75 ms respectively). An additional examination of the timing of TB and TT in the word-internal clusters /jt/ and /jn/ available for this subject (see Table 2) showed negative achievement and release lag (about 25 and 30 ms), but of a somewhat lesser degree than the TB-LA lag found for the other subjects.

The consonant /p^j/

We can see from Figure 1 (the upper bars) that the positional differences in achievement lag between the onset and coda /p^j/ were much smaller than between the two sequences: For the syllable-initial /p^j/, the achievement of

TB followed the achievement of LA by about 5–55 ms (mean values). For the syllable-final /p^j/, the lag values were more variable: the achievement of TB preceded the achievement of LA for subjects AS, DK, and AK (by about 5–25 ms), while the achievement of TB followed the achievement of LA for subject NT (by about 30 ms). All subjects, however, showed a significant difference in lag values between the onset and coda /p^j/, which varied from about 15 to 75 ms ($p < 0.001$–0.01). The positional differences in release lag were similar: a positive lag of about 5–55 ms for the syllable-initial /p^j/ and either negative or positive lag ranging from -30 to 40 ms for the syllable-final /p^j/. Three out of four subjects showed significant differences in lag values between the onset and coda /p^j/ (AS, DK, AK: $p <$ 0.001–0.05); these difference, however, varied substantially, from about 20 ms for subject AS to about 70 ms for subject AK.

Overall, the two constrictions in the production of the consonant /p^j/ were timed relatively simultaneously, yet the positional differences in timing were in the same direction as the differences between sequences of consonants: a positive lag for the onset /p^j/ comparable to the substantial positive lag for the sequence /pj/, and a zero-to-negative lag for the coda /p^j/ in some cases comparable to the negative lag for the sequence /jp/. The difference between /p^j/ and the sequences of /p/ and /j/ in timing was always maintained: the onset /p^j/ and the sequence /pj/ differed in about 30–70 ms in achievement lag and in about 10–85 ms in release lag; the coda /p^j/ and the sequence /jp/ differed in about 20–70 ms in achievement lag and in about 60–90 ms in release lag. An informal examination of standard deviations suggested slightly higher variability for the coda /p^j/ for at least some subjects (AS, NT, AK; see error bars in Figure 1).

3.2. Magnitude and duration of Tongue Body

Magnitude

The magnitude results for maximum TB height, with respect to the upper teeth (a) and TB fronting (b) are presented in Table 4. The values for syllable-initial and syllable-final /p^j/ are presented on the left and those for /j/ in the same positions are given on the right.

Table 4. Mean values of tongue body height (a) and tongue body fronting (b) for /p^j/ and /j/ in syllable onset (a#_a, p#_a) and syllable coda (a_#a, a_#p) in nonwords and real words (for /p^j/ only) for four subjects.

		AS (N=59)		NT (N=59)		DK (N=60)		AK (N=51)	
a.	onset /p^j/	4.18	(1.06)	10.07	(0.82)	3.22	(1.10)	4.27	(1.24)
	coda /p^j/	3.27	(0.89)	8.04	(1.54)	2.92	(1.42)	2.12	(1.81)
	onset /j/	10.52	(1.02)	13.07	(0.73)	7.43	(0.69)	7.81	(1.44)
	coda /j/	9.19	(2.13)	9.63	(1.12)	3.27	(1.78)	3.45	(1.27)
b.	onset /p^j/	37.77	(2.16)	33.91	(1.00)	27.58	(0.83)	30.16	(1.19)
	coda /p^j/	37.93	(1.89)	33.91	(1.55)	27.49	(1.35)	35.13	(1.95)
	onset /j/	37.63	(1.13)	33.56	(0.61)	25.53	(1.02)	28.54	(1.04)
	coda /j/	37.48	(1.63)	35.61	(0.89)	28.60	(2.33)	31.61	(1.12)

The results for TB height (see Table 4a) indicate that there was a main effect of Position for all four subjects [AS: $F(1, 58) = 12.806$, $p < 0.01$; NT: $F(1, 58) = 68.244$, $p < 0.001$; DK: $F(1, 59) = 22.902$, $p < 0.001$; AK: $F(1, 50) = 44.931$, $p < 0.001$]: TB was significantly lower in coda position than in onset position. There was a main effect of Consonant for all subjects [AS: $F(1, 58) = 170.784$ $p < 0.001$; NT: $F(1, 58) = 37.860$, $p < 0.001$; DK: $F(1, 59) = 26.035$, $p < 0.001$; AK: $F(1, 50) = 27.133$, $p < 0.001$]: TB during /j/ was substantially higher than during /p^j/. For one subject there was a significant Consonant X Position interaction [DK: $F(1, 59) = 16.216$, $p < 0.001$]: the factor Position was significant for /j/ only. Overall, syllable-final /j/ showed more reduction (on average by about 1.5 to 4 mm) than syllable-final /p^j/ (about 0.5 to 2 mm). The reduction of the TB for /j/ was also more consistent across subjects than the reduction of the same gesture for /p^j/. As a result, the TB raising difference between the two consonants – rather substantial in onset position (3 to 6.5 mm) – was less apparent in coda position (0.5 to 6 mm).

For TB fronting (see Table 4b), there was a main effect of Position for three subjects [NT: $F(1, 58) = 9.777$, $p < 0.01$; DK: $F(1, 59) = 8.439$, $p < 0.01$; AK: $F(1, 50) = 106.478$, $p < 0.001$]: For all of them, TB in coda position was less front (i.e., reduced) than in onset position. There was a main effect of Consonant for three subjects [AS: $F(1, 58) = 5.116$, $p < 0.05$; NT: $F(1, 58) = 15.131$, $p < 0.001$; AK: $F(1, 50) = 50.928$, $p < 0.001$]: For two of these subjects the TB gesture for /j/ was slightly more front than for /p^j/ (AS and AK); for the other subject (NT), the TB position for /j/ was more to the back than /p^j/. There was a significant Consonant X Position interaction for three subjects [NT: $F(1, 58) = 14.007$, $p < 0.001$; DK: $F(1, 59) =$

10.615, $p < 0.01$; AK: $F(1, 50) = 7.929$, $p < 0.01$]: For the first two speakers /j/ was more susceptible to reduction than /p^j/; for the third speaker the reverse was observed. Overall, the results of TB fronting showed high inter-speaker variability. The positional differences were limited primarily to the TB for /j/ (three subjects), which was moderately reduced in coda.

There were no consistent differences in TB raising or fronting between more specific contexts: the post-vocalic vs. post-consonantal onset (a#_a vs. p#_a) and the prevocalic vs. preconsonantal coda (a_#a vs. a_#p). An examination of standard deviations (see Table 4) suggested that the TB raising and fronting values for the coda consonants, and particularly for the coda /j/, were more variable than those for the same consonants in onset position, at least for some speakers (AS, NT, and DK). For example, standard deviations for the syllable-initial /j/ of subject DK were 0.69 mm for TB height and 1.02 mm for TB fronting, while standard deviations for the syllable-final /j/ were substantially higher: 1.78 mm and 2.33 mm respectively (See Table 4).

Duration

The results for the closing movement (a) and the plateau (b) duration of the TB raising gesture are presented in Table 5.

Table 5. Mean duration of the closing movement (a) and plateau (b) of the tongue body raising gesture for /p^j/ and /j/ in syllable onset (a#_a, p#_a) and syllable coda (a_#a, a_#p) in nonwords and real words (for /p^j/ only) for four subjects.

		AS (N=54)		NT (N=59)		DK (N=60)		AK (N=51)	
a.	onset /p^j/	65.70	(26.02)	142.35	(37.19)	107.64	(19.51)	111.19	(42.50)
	coda /p^j/	62.00	(30.76)	122.26	(58.23)	77.65	(29.82)	88.94	(33.75)
	onset /j/	111.00	(40.37)	105.40	(42.12)	120.50	(17.30)	148.00	(20.59)
	coda /j/	110.00	(29.00)	150.20	(29.94)	93.50	(20.30)	100.25	(25.76)
b.	onset /p^j/	89.70	(37.03)	44.80	(16.89)	36.36	(9.65)	54.14	(26.58)
	coda /p^j/	111.05	(44.06)	49.95	(25.09)	46.75	(20.62)	54.67	(26.03)
	onset /j/	63.33	(16.28)	40.40	(19.16)	22.75	(13.52)	59.00	(17.63)
	coda /j/	41.20	(25.63)	30.20	(10.78)	17.80	(5.45)	18.00	(3.55)

The ANOVA results for the closing movement indicate that two subjects showed a main effect of Position [DK: $F(1, 59) = 28.378$, $p < 0.001$; AK: $F(1, 49) = 18.993$, $p < 0.001$]: this movement was significantly shorter in coda position (e.g., about 20% shorter for subject AK). There was a main effect of Consonant for three subjects [AS: $F(1, 53) = 18.567$, $p < 0.001$; NT: $F(1, 58) = 12.412$, $p < 0.001$; AK: $F(1, 49) = 22.928$, $p < 0.001$], although, in different directions: the closing movement was longer either for /j/ (AS, AK) or for /p^j/ (NT). There was no significant Consonant X Position interaction for any of the speakers.

For the plateau duration, there was no main effect of Position for any of the subjects. The factor Consonant was significant for two subjects [AS: $F(1, 54) = 26.351$, $p < 0.001$; DK: $F(1, 59) = 13.090$, $p < 0.01$; AK: $F(1, 50) = 14.204$, $p < 0.001$], showing longer plateaus for /p^j/ than for /j/. It should be noted, however, that the longer plateaus of /p^j/ for these speakers were often accompanied by relatively short closing periods; there were no significant differences between the two consonants in the total duration of the gesture (closing movement + plateau). There was a significant Consonant X Position interaction for one subject only [AK: $F(1, 50) = 6.023$, $p < 0.05$], indicating that the reduction in duration in coda position affected /j/ but not /p^j/. Note that this may be due to the difference in the stimuli used for this subject. A comparison of standard deviations for the duration measurements in syllable-initial and syllable-final positions revealed somewhat higher variation in syllable-final /p^j/, at least for some speakers (AS, NT, DK). Overall, the duration for /p^j/ and /j/ varied substantially in both positions. In terms of the type of stimuli, there were some significant differences between nonword and real word utterances: For real words, the closing movement of the TB gesture was shorter (NT, DK, and AK), while the TB plateau was longer for all subjects. The TB gesture in the real words was less front (AS, NT, and AK) than in the nonwords.

3.3. Magnitude and duration of Lip Aperture

Magnitude

The results for the lip gesture, based on the measurements of maximum lower lip height (a) and lip aperture (b) are summarized in Table 6.

Table 6. Mean magnitude of the lower lip height (a) and lip aperture (b) for /p/ and /p^j/ in syllable onset (a#_a, t#_a, k#_a) and syllable coda (a_#a, a_#t, a_#k) in nonwords and real words for four subjects.

		AS (N=113)		NT (N=108)		DK (N=112)		AK (N=88)	
a.	onset /p/	-15.93	(1.40)	-10.56	(1.56)	-12.97	(0.60)	-21.30	(1.88)
	coda /p/	-15.86	(1.02)	-10.50	(1.10)	-12.81	(0.42)	-20.40	(1.50)
	onset /p^j/	-15.83	(1.22)	-10.03	(1.25)	-12.69	(0.48)	-21.09	(1.60)
	coda /p^j/	-16.03	(0.86)	-10.24	(1.20)	-12.73	(0.53)	-20.69	(1.55)
b.	onset /p/	not available		3.83	(1.88)	9.23	(0.40)	18.64	(1.58)
	coda /p/	not available		3.76	(1.88)	9.00	(0.38)	17.32	(1.14)
	onset /p^j/	not available		3.58	(1.65)	9.11	(0.45)	18.18	(1.55)
	coda /p^j/	not available		3.71	(1.80)	8.84	(0.43)	17.49	(1.07)

In terms of the magnitude of LL, there were neither significant effects of Position and Consonant, nor significant Consonant X Position interaction for any of the subjects. This means that the magnitude of this gesture did not differ significantly between the consonants, /p^j/ vs. /p/, or between positions (onset vs. coda). For LA, there was a main effect of Position for two of the three subjects [DK: $F(1, 111) = 11.265$, $p < 0.01$; AK: $F(1, 87) = 14.039$, $p < 0.001$; no data for AS]: These speakers showed smaller LA values (i.e., a narrower constriction) in coda position than in onset position. There was no main effect of Consonant for any of the subjects and there was no significant Consonant X Position interaction. An informal examination of the standard deviations of the results (see Table 6) suggests that the LL magnitude was somewhat more variable in onset position than in coda position.

Duration

The closing movement and plateau duration results for the four subjects are shown in Figure 2. The productions for syllable-initial and syllable-final /p^j/ (at the top) and /p/ (at the bottom) are aligned in time by the achievement of the target, the onset of the plateau.

For the closing movement, there was a main effect of Position for three out of four subjects [AS: $F(1, 111) = 41.940$, $p < 0.001$; NT: $F(1, 106) = 7.658$, $p < 0.001$; DK: $F(1, 111) = 53.170$, $p < 0.001$], indicating that the closing movement was substantially shorter for coda consonants: This reduction in duration amounted to as much as 30% of the duration of the movement in onset position (see Figure 2). There was a main effect of Consonant for one subject only [NT: $F(1, 106) = 9.978$, $p < 0.05$], pointing to a slightly longer movement to the constriction of /p/ than to that of /p^j/.

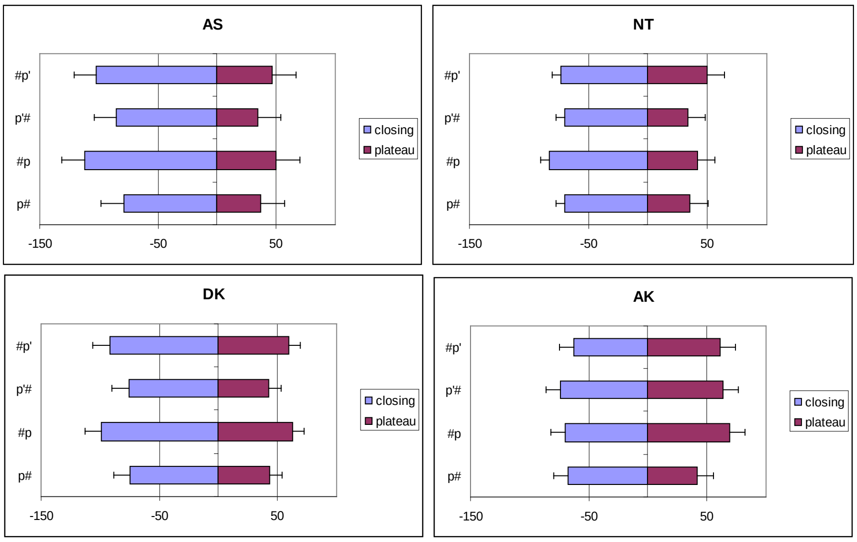

Figure 2. Mean duration of the closing movement and plateau of the lower lip gesture during the articulation of for /p/ and /p^j/ in syllable onset (a#_a, t#_a, k#_a) and syllable coda (a_#a, a_#t, a_#k) in nonwords and real words (in ms) for 4 subjects.

For the duration of the plateau, there was a main effect of Position for all subjects [AS: $F(1, 111) = 17.133$, $p < 0.001$; NT: $F(1, 106) = 9.788$, $p < 0.01$; DK: $F(1, 111) = 96.304$, $p < 0.001$; AK: $F(1, 85) = 14.192$, $p < 0.001$]: The plateaus were consistently shorter in coda position than in onset position, with the reduction amounting to as much as 40% of the duration of the syllable-initial plateau. There was no main effect of Consonant for any of the subjects. There was a significant Consonant X Position interaction for two subjects [NT: $F(1, 106) = 4.146$, $p < 0.05$; AK: $F(1, 85) = 20.586$, $p < 0.001$]: These speakers showed shorter plateaus for the syllable-final /p/ but not for the syllable-final /p^j/. In terms of variability (based on standard deviations; see error bars in Figure 2), the duration of the closing movement in onset position was more variable than in coda position. In terms of the type of stimuli, none of the significant differences in magnitude and duration were consistent across all four subjects.

4. Discussion

In this section I discuss the results of the EMMA experiment with respect to the general and specific hypotheses made in Section 1. The results of our experiment largely confirm the general hypothesis: we do find substantial differences between the same consonants in different syllable positions. The syllable effects are manifested primarily in: (a) the timing of the lips and tongue body for the onset and coda /p^j/, which follows the general pattern of timing in the sequences /pj/ and /jp/; (b) the magnitude of the TB raising gesture for /p^j/ and /j/; and (c) the duration of the LA gesture for /p^j/ and /p/. The differences in the magnitude of TB fronting, in the duration of TB raising, and in the magnitude of LA are less consistent, being found only for certain speakers. All these differences are discussed in detail below.

With respect to the timing hypothesis, our findings (see Section 3.1) indicate that the gestures of TB and LA for the Russian /p^j/ show more lag (are more sequential) in onset position and less lag (are more synchronous) in coda position. The lag for the onset /p^j/ is always positive; that is, the more open gesture, TB, is delayed with respect to the more closed gesture, LA. The lag for the coda /p^j/ is either positive or negative: in the latter pattern, the more open gesture (TB) slightly precedes the more closed gesture (LA). The observed timing pattern is not fully consistent with the first prediction made with regard to timing (timing hypothesis A): no lag in onset and a substantial negative lag in coda. Recall that this prediction was based on the pattern observed for the positional variants of the English /l/. While it differs from the timing pattern for the English /l/ (especially in onset), the pattern for the Russian /p^j/ is similar to the one observed for the English /w/ (Gick 2003): For this consonant, LA for the syllable-initial /w/ were found to precede the equally open TB backing gesture in the syllable onset, while the two were near-synchronous in the syllable coda.

The timing of gestures found for the initial /p^j/ is likely influenced by perceptual factors (see Mattingly 1981 and Silverman 1997 on gestural timing and recoverability). Specifically, a somewhat later achievement of the TB target compared to the LA target results in the relatively long and perceptually salient CV transitions characteristic of palatalized consonants in general (mainly high F2; see, for example, Ladefoged and Maddieson 1996: 364; see Kavitskaya, this volume; Kochetov 2002). In addition, this timing results in a high frequency noise burst of /p^j/, which is perceptually different from the weak burst of the non-palatalized /p/. In addition, the timing pattern for the onset /p^j/ (and to some degree for the coda /p^j/) is consistent with sonority generalizations about inter-gestural timing (Sproat and Fujimura 1993, Gick 2003): the more open, more sonorous, TB gesture is timed closer to the syllable peak, than the more closed, less sonorous, LA gesture.

Another important finding of the current study is that the timing of gestures for the onset /p^j/ is similar to those for the word-boundary or within-word sequence /pj/, showing a substantial delay of the TB gesture (a positive lag). Also, the timing of gestures for the coda /p^j/ tends to be in the same direction as the timing in the sequence /jp/. Yet, the timing patterns for the single consonants are distinct from those for the sequences, thus confirming our second prediction about inter-gestural timing (timing hypothesis B). Perceptual factors are likely at play here again: A delay of the TB for the onset /p^j/ by more than 50–60 ms would cause a confusion of the palatalized consonant with the sequence /pj/; similarly, a lead of the TB for the coda /p^j/ by more than 20–30 ms may cause a confusion of the palatalized consonant with the sequence /jp/. Note also that a completely simultaneous production of the two gestures may obscure the acoustic transitions characteristic for a lip closure leading to the percepts [t^j] or [t] (see Kochetov 2002). Thus, the timing patterns found for tongue body and lips in Russian seem to be optimal in a sense that they allow to maintain multiple lexical distinctions that rely on timing of these gestures, and ensure that these gestures (and the corresponding phonological categories) are reliably recovered by listeners.

With respect to the magnitude hypothesis, the current results (see Section 3.2) confirm our prediction about the coda reduction of the TB gesture of /j/ (single and in sequences) in magnitude, primarily in TB raising. The reduction in magnitude of the TB gesture was in some cases accompanied by a reduction in duration. The results are consistent overall with the findings for the English /j/, which shows consistent reduction in TB magnitude (both raising and fronting: Gick 2003). The reduction of the TB gesture in coda was also observed for the palatalized stop /p^j/, thus confirming the first version of the magnitude hypothesis for this consonant (See Section 1). This finding for Russian, however, contrasts with the lack of reduction and some expansion of the secondary velar articulation of the English /l/. Thus, our alternative prediction about the TB magnitude of effects for /p^j/ is not supported. The robust TB magnitude differences between syllable-initial and syllable-final /p^j/ (as well as the timing differences) appear to correlate with significant differences in the perception of these positional variants. In a perceptual study in Kochetov (to appear) both native and non-native listeners showed substantially longer reaction time and lower rate of correct identification of /p^j/ syllable-finally than syllable-initially.

Another interesting finding is that the TB gestures for /p^j/ and for /j/ (including for /j/ in the sequences /pj/ and /jp/) were significantly different in the degree of TB raising and, for some speakers, in TB fronting and duration. The TB of /j/ was higher than that of /p^j/ and was often characterized by a shorter plateau. The two consonants also differed in the degree of gestural reduction and variation, with /j/ being more affected by the position. This suggests that the TB gesture of /p^j/ is a distinct articulatory structure, with different target parameters than those of /j/ (either as a single consonant or in a sequence with /p/). Thus, the consonant /p^j/ and the sequences of /p/ and /j/ in Russian differ not only in the timing of the gestures LA and TB, but also in the magnitude of the TB gesture (especially for the onset /p^j/ and the sequence /pj/).

While our predictions about the reduction of the TB gesture are fully confirmed, the predictions about the magnitude reduction of the lip gesture are not supported (see Section 3.3). None of the subjects showed any reduction of this gesture in coda; in fact, two speakers showed a tighter lip constriction (i.e., expansion in LA) in coda. In addition, our results show no syllable-final LA reduction for the palatalized /p^j/, disconfirming both versions of the magnitude hypothesis for this consonant. Interestingly, however, the lip gesture for both /p/ and /p^j/ in coda was substantially reduced in duration. These results are not consistent with certain findings for English, where labial stops in coda have been reported to be reduced in magnitude, although to a lesser degree than coronals and dorsals (Browman and Goldstein 1995). At the same time, our results for Russian labials are fully consistent with the behavior of Russian stops in general, which do not show reduction in magnitude, but show consistent reduction in duration (Kochetov and Goldstein, in preparation; cf. the results of an EPG study of the Russian /n/ in Barry 1991). It is possible that the differences between Russian and English in reduction patterns of the LA gesture (and other oral gestures in stops) are related to the considerable differences in the degree of overlap in stop sequences in the two languages, as well as to differences in the proportion of coda stops that are audibly released in clusters and before a pause (Zsiga 2000, Kochetov 2002).

With respect to the variability hypothesis, informal observations of the results suggested that the consonants in coda position were somewhat more variable in terms of inter-gestural timing, TB magnitude, and TB duration (for /p^j/ only). The opposite effect – higher variability in onset – seemed to hold for some lip magnitude and duration measurements. Based on these preliminary observations, the variability hypothesis is only partly confirmed.

5. Summary and conclusions

While providing evidence for the general hypothesis and some of our specific predictions, the results of our experiment challenge some other predictions and, placed in the context of other studies, raise a number of questions: First, why do we observe syllable position effects in the first place? What are the underlying reasons for the phenomenon? Second, how can we explain the observations that only some gestures show syllable position effects and that the actual manifestations of these effects differ from gesture to gesture? Finally, and most importantly for the current study, how can we account for both the similarities and the differences in the degrees and kinds of reduction of similar gestures in different languages?

The discussion of various manifestations of syllable position effects and of their possible underlying causes is well beyond the scope of this paper; however, it is worth outlining a possible direction to follow in explaining the attested patterns. One approach within the framework of Articulatory Phonology (Browman and Goldstein 1989, et seq.) has been seeking to account for syllable position effects attested in English by reference to the dynamics of coordinated articulatory gestures modeled as coupled oscillators (Nam and Saltzman 2003; Browman and Goldstein, in prep.; see Saltzman and Byrd 2000 on the task-dynamics of phasing using oscillator coupling). In particular, the *dynamic approach* assumes two basic types of coordination relations between gestures: in-phase coordination of gestures in syllable-initial position and out-of-phase coordination of gestures in syllable-final position. The first coupling mode is presumed to result in dynamically stable patterns that exhibit high amplitude oscillations of the corresponding gestures; the second mode renders the gestures dynamically unstable, with lower amplitude oscillations. The actual consequences for individual gestures are expected to vary according to differences in their dynamic properties.

While the dynamic account represents a promising direction to follow in identifying and explaining the general mechanism behind the syllable position effects, it is not yet clear whether application of general, language-independent task-dynamics is sufficient to account for the differences in the kinds and degrees of gestural reduction in different languages. It appears that a more plausible (although less parsimonious) alternative is to combine the dynamic approach within Articulatory Phonology with phonetically richer and intrinsically variable exemplar-based lexical representations (Pierrehumbert 2001). In this view, not all manifestations of syllable position effects are direct consequences of gestural dynamics: Some of them may reflect listener-based interpretation of the variable input, stored as detailed gestural structures (see Browman and Goldstein 1995). These structures would encode phasing of gestures and their magnitude parameters for each lexical item, with the values potentially differing in syllable onset and coda. Moreover, a single semantic representation for a lexical item may be associated with a number of alternative gestural structures, or exemplar memories. Weights for the competing structures, as well as values for phasing and other gestural parameters for each particular representation are constantly updated based on an individual's perception/production experience. Crucially, the differences in reduction patterns between various gestures within a language result not only from the dynamic properties of these gestures, but also from how well these units can be recovered by a listener given the variable output of production in various contexts (see, e.g., Surprenant and Goldstein 1998, Chitoran, Goldstein, and Byrd 2002). Differences between languages in types and degrees of reduction of otherwise similar gestures are likely to arise from language-particular gestural coordination patterns (e.g., degree of gestural overlap), more specifically, from essentially random differences the way these patterns are recovered and stored by speakers/listeners. Thus, no one-to-one correspondence between dynamic properties of gestures and realizations of syllable-final reduction is expected; nor should we expect similar gestures in different languages to pattern identically with respect to the reduction process. This approach could potentially capture the general relation between dynamic properties of gestural coordination and syllable position effects, while at the same time accounting for variation in effects within and across languages.

To conclude, more empirical research is needed to identify the range of possible syllable-position effects cross-linguistically. In addition, more theoretical modeling work is necessary to provide new insights into the nature of these effects, and ultimately, into the underlying relation between the microscopic properties of gestural organization and the macroscopic category of the syllable.

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