TIMING PATTERNS OF WORD-INITIAL OBSTRUENT-SONORANT CLUSTERS IN RUSSIAN

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ABSTRACT

This study investigates intra-cluster timing patterns in Russian obstruent-sonorant clusters as a function of their segmental composition. The results confirm for Russian a velar-nasal (/kn, gn/) vs. velar-lateral (/kl, gl/) timing difference like the one reported for German [2], but this could not be extended to labial-lateral/nasal clusters (/vl, ml/ vs. /vn, mn/), which were all timed similarly. In addition, place of articulation of C1 (velar vs. labial) determined different timing patterns when C2 was a nasal (longer lags for /kn, gn/ than for /vn, mn/), but not when C2 was a lateral (/pl, bl, kl, gl/). The results support a place of articulation order effect [3] for obstruent-nasal but not for obstruent-lateral clusters. The pattern of results was robust across two speaking rates. We discuss how aerodynamic and perceptual requirements on intra-cluster timing may explain the patterns observed.

Keywords: intra-cluster timing, onset clusters, Russian

1. INTRODUCTION

It has been previously shown that the timing relationship between consonants in a cluster is significantly affected by the cluster's segmental composition. For example, the consonants in German onset cluster /kl/ have been shown to be timed closer together than those in onset /kn/ [2]. The difference between /kl/ and /kn/ onsets has been attributed to perceptual constraints: aerodynamic simulations indicated that a great degree of overlap between the nasal and the velar would attenuate the velar burst characteristics due to nasal leakage and would thus compromise perception [4]. Diachronically, this has been hypothesized to lead to relative instability of /kn/ compared to /kl/, as may have been the case for the loss of onset /kn/ in English. On the other hand, a study on Romanian /kl/ and /kn/ [8] showed no timing difference between these two clusters. Rather than invalidating the aerodynamic/perceptual explanation proposed for German, the Romanian data suggested that the lack of difference was because both /kl/ and /kn/ in this language resembled German /kn/ rather than German /kl/. This in turn suggested that language-specific timing patterns may play an important role in shaping differences between particular clusters [7].

The current study systematically analyses the timing of word-initial /Cl/, /Cn/ and /Cm/ clusters in Russian in order to further explore the relationship between clusters whose second consonant is either a lateral or a nasal. At the same time, the study tests the role of language specific timing patterns on this relationship. In addition to having a large set of such clusters in its inventory, Russian has also been shown to have a different timing pattern for its consonants compared to English (albeit across a word boundary, cf. [10]). Thus cross-word boundary clusters with the same segmental composition have been shown to be less overlapped in Russian than in English. If Russian consonants are timed with greater lags/less overlap in word-initial position as well, it may be expected that Russian will show no timing effect as a function of whether the second consonant in a cluster is a lateral or a nasal, even though data for Polish indicate that even languages with a generally low consonant overlap pattern may show a nasal-lateral asymmetry [9].

Another cluster timing effect attributed to perceptual requirements is the so-called place of articulation order effect, whereby a front-to-back stop cluster such as /bg/ would be more overlapped than a back-to-front cluster such as /gb/, as the former but not the latter would allow more overlap without fully masking the first consonant in the cluster [3]. For Russian, this place order effect has been reported for word-initial and word-medial /pt/ vs. /kt/ clusters [6]. For lateral clusters, this effect has not been robustly confirmed [2, 8], and it has been argued that it may not be relevant for clusters where the second consonant does not involve complete occlusion [2]. For nasal clusters, place order effects have not been previously addressed (due to language-specific cluster inventory limitations) and the current study provides a good opportunity in this sense, as Russian allows Cn clusters with C being either anterior or posterior to /n/ in terms of place of articulation.

As to the identity of the first consonant in a cluster, previous research [2, 8] showed that there was no robust effect on overlap patterns between this consonant being /p/ or /k/. The current data, with a larger range of variation in place of articulation and in manner and voicing of C1, allows a more systematic exploration of potential influences of identity of C1 on cluster overlap.

2. METHODS

Articulatory (EMA, AG 501) and synchronously recorded acoustic data from six native Russian speakers (one male) were recorded and analysed. The kinematic data were collected and processed using standard procedures. The stimuli were real or pseudo-words of the type CCV, with initial clusters in which the second consonant was a sonorant (/l/, /n/, /m/). The full list of clusters is evident from Figures 1-4. All target syllables were phonotactically legal sequences (for this reason, clusters /kn/ and /mn/ had to be followed by vowel /o/ rather than /a/ as the other clusters, although it was attempted to keep the following vowel constant). The target syllables were embedded in a constant carrier phrase: [gromka __ paftaril] *"(He) said __ loud"*.

Two speaking rates were elicited and five repetitions were targeted for each word in each rate. Rates were elicited using visual moving bars that guided the speaker on an approximate tempo for speaking the sentence. The speakers had a speaking window of 2.3 seconds in the slow rate and of 1.5 seconds in the fast rate.

Using the Matlab-based *Mview* software developed by Mark Tiede at Haskins Laboratories, kinematic events defining onset of movement, target achievement and release of consonants were determined on the basis of changes in the velocity profiles of the relevant articulatory movements. The kinematics of labial consonants were defined on the basis of lip aperture – calculated as the Euclidean distance between the sensors placed on the lower and upper lips. Alveolar and velar consonants were defined on the basis of tongue tip and respectively tongue dorsum constriction degree – calculated as the Euclidean distance between the tongue tip/tongue dorsum sensor and the hard palate.

One measure of intra-cluster timing was defined as the temporal lag between release of the first consonant in a cluster and achievement of target of the second consonant in a cluster: $Lag = Target_{C2} – Release_{C1}$. This measure captures the temporal latency between release of the first consonant and target achievement of the second consonant, and replicates other studies' methodology [2, 6, 8, 9]. A larger value on this measure indicates a greater lag between the two consonants.[1] The lag measure is relevant in terms of perceptual recoverability in that it captures whether the achievement of target of the second consonant potentially masks the release of the first one. It likely also reflects articulatory/aerodynamic constraints on how closely two constrictions may follow each other [2].

A second intra-cluster timing measure, plateau overlap, was used following the analysis of Chitoran et al. [3]. This measure indicates when movement for the second consonant begins relative to the constriction interval (plateau) of the first consonant: $Plateau\ Overlap = (Onset_{C2} – Target_{C1})/(Release_{C2} – Target_{C1})$. A negative value indicates that movement of the second consonant precedes target achievement of the first consonant, i.e. movement onset for the second consonant fully overlaps constriction interval of the first consonant. Overall, smaller values indicate increased overlap, and larger values decreasing/no overlap.

For statistical analyses, mixed linear models were computed using the *lme4* package for R, with *p*-values being determined by comparing a model including the factor/interaction of interest with a model with no fixed factor/no interaction [1]. This method circumvents the difficulty in estimating denominator degrees of freedom for mixed linear models. The data were analysed with fixed factors Cluster and Rate, and random factor Speaker. For post hoc comparisons, the *p*-values were determined using the Tukey adjusted contrast in the *multcomp* package for R [5]. Only comparisons of relevance were carried out – namely between clusters with the same C2 (e.g. Cl: /pl/, /bl/, etc.; Cn: /vn/, /mn/ etc.; Cm: /xm/, /sm/ etc.), or between clusters where C1 was the same but C2 was a lateral or nasal (e.g. /vl/ – /vn/, /ml/ – /mn/, etc.).

3. RESULTS

We start presenting our results by pointing out that our elicitation method successfully elicited a speaking rate differences for the two rate conditions. Overall, speaking tempo was of 5.46 (s.d. 0.67) syllables per second in the fast rate, and 4.51 (s.d 0.58) syllables per second in the slow rate, with the difference statistically significant between the two (mixed linear model with fixed factor: Rate and random factor: Speaker, $F = 1240$, $p < .001$).

The statistical analyses, summarized in Table 1, showed that for both measures (Lag and Plateau overlap), the factors Rate and Cluster, as well as the interaction between them were statistically significant. Overall, greater lags and a lesser degree of overlap were observed in the slow compared to the fast rate. Because the interaction of Cluster with

Rate was significant, to determine specific cluster differences, post-hoc planned comparisons were carried out separately for each speaking rate. Lag and Plateau overlap mean values as a function of cluster and rate are plotted in Figures 1-4.

Table 1: Statistical results of mixed linear models for dependent variables Lag and Plateau overlap, with fixed factors Rate, Custer, and random factor Speaker.

Factor	Lag	Plateau overlap
Rate	F=24.46, p=.001	F=11.42, p<.001
Cluster	F=17.68, p<.001	F=18.97, p<.001
Rate * Cluster	F=11.77, p<.001	F=11.42, p<.001

Regarding cluster differences as a function of whether C2 was a lateral or nasal, post-hoc comparisons showed that the lag between consonants was greater and the overlap smaller for /kn, gn/ than for /kl, gl/, but no difference was observed between /vn/ vs. /vl/ and /mn/ vs. /ml/ clusters. In terms of plateau overlap, cluster /xl/ showed significantly more overlap than cluster /xm/, but the lag measure was not statistically significant. These results were the same for both speaking rates.

We now turn to the comparison between clusters whose C2 was /n/. In both rates and for both measures, /kn/ vs. /gn/ and /vn/ vs. /mn/ did not significantly differ in their timing, while /vn/ and /mn/ showed significantly smaller lags/more overlap than either /kn/ or /gn/. This result indicates a timing difference between Cn clusters as a function of place of articulation of the first consonant, with labials affording more overlap with a following nasal than velars.

For the comparisons where C2 was /m/, for both measures and speaking rates, the timing difference between /xm/ and /sm/ was significantly different, with more overlap/smaller lags for /sm/ than /xm/, suggesting that an alveolar affords more overlap with a following nasal than a velar. For the comparisons /xm/ – /shm/ and /sm/ – /shm/, the results differed as a function of rate: in the fast rate, /sm/ was significantly more overlapped than /shm/, and in the slow rate, /shm/ was significantly more overlapped than /xm/.

Turning to the comparisons of C1 when C2 was /l/, the results differed by speaking rate. In the slow rate, /vl/ – /kl/ and /vl/ – /gl/ had significantly different lags, while /vl/ – /kl/ and /vl/ - /xl/ had significantly different overlaps (with the labial C1 affording smaller lags/greater overlap than the velar C1). In the fast rate, /xl/ had significantly larger lags and less overlap than the other /l/ clusters.

In summary, the lateral-nasal asymmetry was confirmed for clusters where C1 was a velar but not a labial (/kn, gn/ vs. /kl, gl/, and on one measure /xm/ vs. /xl/, but not /vn, mn/ vs. /vl, ml/). There is also a clear C1 velar vs. labial/alveolar asymmetry when C2 is a nasal (/vn, mn, sm/ vs. /kn, gn, xm/), but not when C2 is a lateral (in the latter case some C1 velar clusters showed less overlap/larger lags than some C1 labial clusters, but the results varied as a function of specific cluster and speaking rate).

Figure 1: Timing lag means as a function of cluster, for the slow speaking rate.

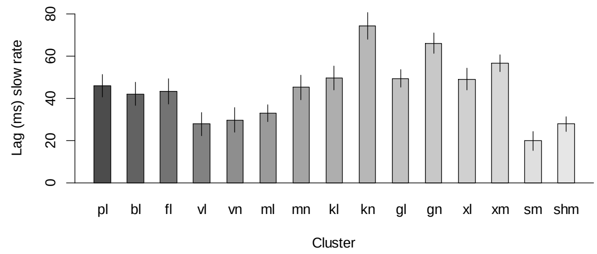


Figure 2: Timing lag means as a function of cluster, for the fast speaking rate.

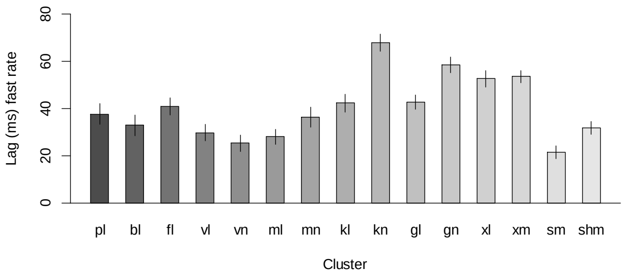


Figure 3: Plateau overlap means as a function of cluster, for the slow speaking rate.

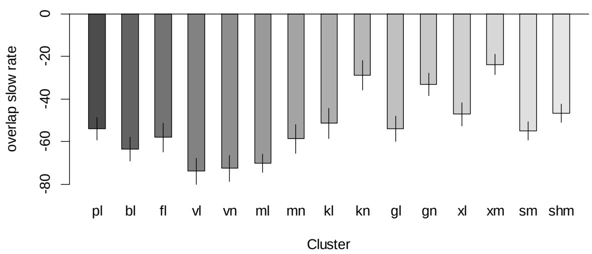
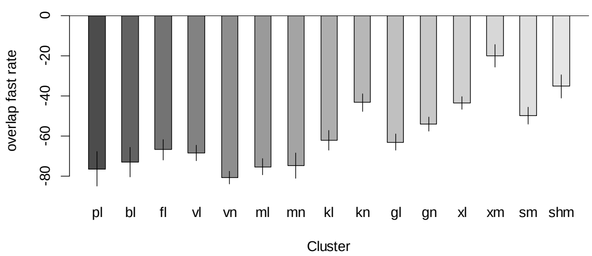


Figure 4: Plateau overlap means as a function of cluster, for the fast speaking rate.



4. DISCUSSION

The current results confirm for Russian an velar-nasal vs. velar-lateral timing difference like the one first reported for German /kl/ - /kn/ [2]. Like in German, the consonants in Russian /kn, gn/ clusters (and on one measure /xm/) were less overlapped than in clusters /kl, gl/ (and /xl/). This difference could not however be observed for labial-sonorant clusters (/vl, ml/ vs. /vn, mn/). The consonantal lags for Russian lateral clusters even in the fast rate were similar to those of German /kn/ (around 30ms), and still, Russian /kn, gn/ were even less overlapped (lags over 50 ms). This is in accordance with the patterns for Polish [9], but contrasts with the pattern observed for Romanian [8], where both /kl/ and /kn/ had similar timing lags of around 35 ms.

To further understand the Russian pattern, one needs to take into account place of articulation order effects. Our results showed an order effect, but only when the second consonant was a nasal, not a lateral (this effect could alternatively be described as place of articulation – velar vs. labial/alveolar effect, if /sm/ vs. /xm/ asymmetries are also to be taken into account).[2] Thus, back-to-front /kn, gn/ clusters were less overlapped than front-to-back clusters /vn, mn/, but no consistent difference was observed for lateral clusters. Not finding it for lateral clusters is not surprising, as recoverability is likely less of a problem with lateral clusters than with stop-stop clusters, and this finding is consistent with other previous research [2, 8]. The current Russian data allowed us to confirm that this order effect is pertinent for nasal clusters (in addition to stop-stop /pt/ vs. /kt/ clusters, cf. [6]). The difference between /kl, gl/ - /kn, gn/ and the lack of difference between /vl, ml/ - /vn, mn/ may reflect this order effect. The lags typical for lateral clusters may be enough to assure recoverability of a labial followed by a nasal, but not of a velar followed by a nasal.

Nevertheless, the difference between the current data set and the pattern of results observed for Romanian and German, which suggest that lags of about 30ms allow a perceptual recovery of the velar in /kn/, suggests that language-specific factors may as well play a role in shaping Russian intra-cluster timing. Lateral clusters in Russian exhibit consistently larger timing lags than lateral clusters in the other languages for which comparable data exist (30-50ms depending on rate in Russian vs. 10ms in German, and 30ms in Romanian). A base-line timing difference for clusters among languages may shape perceptual expectations, and for this reason, Russian listeners may need larger lags to correctly perceive velars before nasals. This may be especially important given that Russian, unlike standard German or Romanian, phonologically contrasts several obstruent-nasal clusters and therefore correctly perceiving place of articulation of the consonant preceding the nasal may be functionally important. This hypothesis will need to be tested in future work.

Additionally, Russian qualitatively differs from Romanian in terms of its plateau overlap pattern: while in Romanian obstruent-sonorant clusters mostly exhibited positive plateau overlap values [8], indicating that the second consonant started after the first consonant reached its target, Russian clusters consistently showed negative overlap values, indicating that the second consonant in a cluster was initiated well before the first reached its target. This suggests a very different temporal organization of clusters in the two languages, which may contribute to the different patterns of contrast observed between them. The exact implications for production and perception of the relationship between plateau overlap and target-release lag, and the possible cross-linguistic timing typologies, remain to be explored in the future.

As to speaking rate, in the current study, few cluster specific effects were rate-dependent. The sporadic differences observed may reflect different variability/stability patterns in the two rates, which in turn resulted in statistical (non)-significance in one condition but not the other. On the other hand, the similar main findings across rates suggest the robustness of the uncovered timing patterns, reflecting an interaction between place of articulation order effects and lateral vs. nasal effects.

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[1] Normalized lag values were also computed and analysed, but because there was no qualitative difference between them and raw lag values, they are not reported here.

[2] The fact that SM patterns with front-to-back clusters may also be explained by the high perceptual salience of the sibilant, which – like front-articulated labials, is less likely to be masked by a following overlapping consonant.