Intra-cluster Timing in Romanian Stop-initial Onsets

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Abstract

This study investigates intra-cluster timing of Romanian onset clusters with varying segmental composition. Results show that the consonants in rhotic onsets PR, KR were timed significantly further apart than in onsets whose second consonant was a lateral (PL, KL), sibilant (PS, KS), stop (KT) or nasal (KN). Unlike in German (Bombien et al. 2013), the consonants in clusters KL and KN were timed similarly. A consonant-initial effect was only observed for the comparison PS-KS but was not easily interpretable as a place order effect (Chitoran et al. 2002). The results, while different from the pattern reported for German (Bombien et al. 2013), support the influence of aerodynamic and perceptual requirements on intra-cluster timing, while at the same time highlighting the role that language-specific timing patterns may have in shaping differences between particular clusters.

Keywords: intra-cluster timing, complex onsets, Romanian

1. Introduction

Segmental composition has been shown to significantly affect the timing relationship between the consonants within a cluster. For example, the consonants in German onset cluster KL have been shown to be timed closer together than those in onset KN, and likewise the consonants in onsets PL and KL compared to PS and KS (Bombien et al. 2013). 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 (Hoole et al. 2013). Diachronically, this has been hypothesized to lead to instability of KN, compared to KL, explaining for example the loss of onset KN in English. Likewise, the longer temporal lags in PS/KS compared to PL/KL have been attributed to perceptual and articulatory constraints (Bombien et al. 2013): a longer lag prevents the stop from being perceptually masked by the salient sibilant frication, and it also allows for the precise formation of the specific articulatory posture required for sibilant production. In the Bombien et al. (2013) study, identity of the first consonant in the cluster (/p/, /k/) did not have a robust effect.

In addition, rhotic onset clusters such as PR have been shown to be less overlapped than lateral PL clusters in German, French, Portuguese and Romanian, likely due to aerodynamic factors required in producing the uvular approximant in German and French, or the alveolar trill in Portuguese in Romanian (Cunha, 2012; Hoole et al., 2013; Marin & Pouplier, 2014).

Finally, another cluster timing effect attributed to perceptual requirements is the so-called place 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 (Chitoran et al. 2002). This effect has originally been observed for Georgian stop-stop clusters, and while various studies have attempted to generalize it to other cluster types, it has become evident that order effects are truly pertinent only to stop-stop clusters where recoverability issues play a greater role than in the case of other cluster types (cf. for example Gafos et al. 2010). In addition, Georgian clusters also exhibited a place of articulation effect, whereby clusters composed of coronal and dorsal consonants in either order were more overlapped than clusters composed of labial and coronal consonants; this effect was explained as likely due to the language-specific grammatical status of the respective clusters, where labial-coronal clusters, unlike labial-velar or coronal-velar are non-harmonic clusters (Chitoran et al. 2002).

If the previously reported differences in intra-cluster timing are due to perceptual/aerodynamic requirements, it is expected that they should hold cross-linguistically. In the present study, we investigate onset /k/- and /p/-initial clusters in Romanian, to further test how type of the second consonant in the cluster (lateral, rhotic, nasal, fricative, stop) affects intra-cluster timing. Potential order and place of articulation effects are also addressed, although as will be discussed, the Romanian data are not entirely appropriate for this purpose.

2. Methods

Articulatory (EMA) data from five native Romanian speakers were recorded and analyzed. The stimuli were real words, embedded in carrier phrases. All clusters were mono-morphemic. Six repetitions were targeted for each word.

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 (cf. for example Marin & Pouplier 2014 for further methodological details).

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: $Lag = Target_{C2} – Release_{C1}$ (Figure 1). This measure captures the temporal latency between release of the first consonant and target achievement of the second consonant, and replicates one of the measures used by Bombien et al. (2013). A larger value on this measure indicates a greater lag between the two consonants. Beside absolute lag values, normalized lag values were also computed in relation to duration of the constriction interval of the cluster, defined from achievement of target of the first consonant to release of the second consonant: $Normalized\ Lag = Lag/Release_{C2} – Target_{C1}$. This normalization indicates how much of the constriction interval is taken by the lag between release of first consonant and target achievement of the second consonant. 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 (cf. Bombien et al. 2013).

A second intra-cluster timing measure, plateau overlap, was used following the analysis of Chitoran et al. (2002). This measure indicates when movement for the second consonant begins relative to the constriction interval (plateau) of the first consonant: $\textit{Plateau Overlap} = (\textit{MovementOnset}_{C2} - \textit{Target}_{C1})/(\textit{Release}_{C2} - \textit{Target}_{C1})$ (Figure 1). 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. A value between 0 and 1 indicates at what point within the first consonant's plateau movement for the second consonant begins, i.e. what percentage of the constriction interval is overlapped, with a value of 0.1 for example indicating that the second consonant begins at 10% within C1's plateau, and therefore that 90% of it is overlapped. A value over 1 indicates no overlap between movement onset of second consonant and constriction interval of the first consonant, i.e. movement for the second consonant begins after the first consonant has been released. Overall, smaller values indicate increased overlap, and larger values decreasing/no overlap.

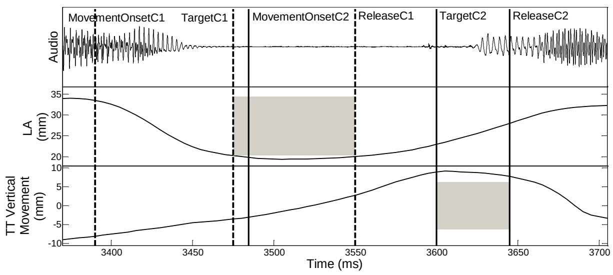

Figure 1: *Example measurement for one PL production. Dotted lines indicate the kinematic events for C1 /p/, measured on the basis of lip aperture (LA). Continuous lines indicate the kinematic events for C2 /l/, measured on the basis of tongue tip (TT) vertical movement. Shaded boxes show the constriction interval (plateau) for each consonant.*

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 (cf. Bates 2010). This method circumvents the difficulty in estimating denominator degrees of freedom for mixed linear models. For post hoc comparisons, the *p*-values were determined using the Tukey adjusted contrast in the *multcomp* package for R (Hothorn et al. 2008). The data were analyzed with fixed factors First Consonant (/p/, /k/) and Second Consonant (/l/, /r/, /s/, /t/, /n/), and random factor Speaker. On the basis of previous research, we predict a difference between lateral and rhotic clusters, lateral and sibilant clusters as well as between lateral and nasal, with no effect of first consonant in the cluster.

3. Results

Lag means as a function of cluster are plotted in Figure 2, and the normalized lag means in Figure 3. The results were qualitatively the same if absolute or normalized lag values were used as the dependent variable, so they are presented simultaneously. As shown in Table 1, the fixed factors and the interaction between them were all significant. The lags were overall greater for /p/-initial than /k/-initial clusters. Post hoc analyses for factor Second Consonant showed that the main effect was due to rhotic clusters being significantly different from all other clusters ($p<.001$), with no other types being significantly different from each other. Pairwise comparisons between clusters confirmed that the Second Consonant effect was due in both /p/-initial and /k/-initial clusters to the rhotic clusters (PR, KR) having significantly larger lags than any other clusters ($p<.001$). The interaction between factors was due to PS having significantly larger lags than KS ($p<.05$), while PL/KL and PR/KR did not differ from each other. In other words, the First Consonant effect was carried out by the PS/KS contrast, while the Second Consonant effect by the rhotic vs. lateral/nasal/fricative/stop contrast.

Table 1. *Statistical results of mixed linear models for dependent variables Lag and Normalized Lag, with fixed factors First Consonant, Second Consonant, and random factor Speaker.*

Factor	Lag	Normalized Lag
First Consonant	F=10.88, *p*=.001	F=9.34, *p*=.003
Second Consonant	F=38.85, *p*<.001	F=32.94, *p*<.001
First Consonant * Second Consonant	F=26.58, *p*<.001	F=20.25, *p*<.001

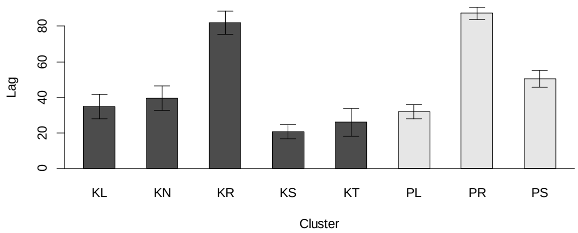

Figure 2: *Mean (+/- 1SE) lag values (ms) between release of the first consonant and achievement of target of the second consonant in a cluster.*

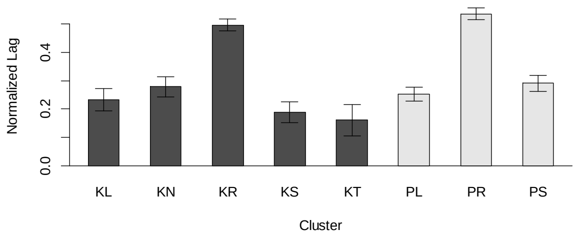

Figure 3: *Mean (+/- 1SE) lag values (ms) between release of the first consonant and achievement of target of the second consonant in a cluster normalized by constriction interval.*

Table 2. *Statistical results of mixed linear models for dependent variable Plateau Overlap, with fixed factors First Consonant, Second Consonant, and random factor Speaker.*

Factor	Plateau Overlap
First Consonant	F<1, *p*>.05
Second Consonant	F=44.53, *p*<.001
First Consonant * Second Consonant	F=27.32, *p*<.001

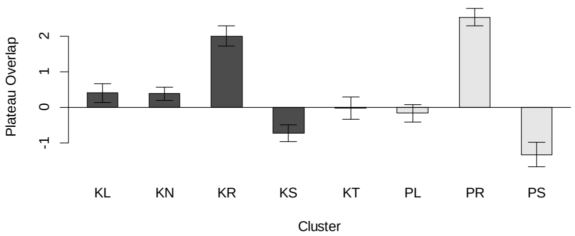

Figure 4: *Mean (+/- 1SE) plateau overlap values (ms) indicating when movement for the second consonant begins relative to the constriction interval of the first consonant.*

The results for the plateau overlap measure were qualitatively similar to those of the lag measures, with one exception being sibilant clusters. Plateau overlap means are shown in Figure 4, and the statistical results are summarized in Table 2. No overall effect as a function of first consonant identity was observed, while factor Second Consonant and its interaction with First Consonant were significant. Post hoc analyses showed that for factor Second Consonant, the main effect was due to rhotic clusters being less overlapped (*p*<.001) and sibilant clusters being more overlapped (*p*<.01) than all other cluster types. Pairwise comparisons between clusters confirmed that the Second Consonant effect was due in both /p/-initial and /k/-initial clusters to the rhotic clusters (PR, KR) being significantly less overlapped than any other clusters (*p*<.001), and to sibilant clusters (PS, KS) being significantly more overlapped (*p*<.05) than lateral clusters (PL, KL). For matched comparisons (PL-KL, PR-KR, PS-KS), no effect of First Consonant was observed (*p*>.05).

4. Discussion

The results confirmed a very robust rhotic effect, corroborating the patterns previously reported (Cunha 2012, Hoole et al. 2013, Marin & Pouplier 2014), but not a lateral vs. nasal difference (KL vs. KN), or a lateral vs. sibilant difference (PL/KL vs. PS/KS), contrary to the pattern reported for German (Bombien et al. 2013).[1] At first sight, the lack of a KL-KN difference, as well as the lack of a difference between lateral and sibilant clusters, seems to speak against a perceptual basis for the asymmetry in German. However, comparing the Romanian target-release lags with those reported for German, it becomes evident that Romanian KL and KN lag values are in the range for German KN (around 30ms) rather than for German KL (around 10ms). Indeed, Bombien at al. (2013) highlight the extremely short lags of the lateral clusters (especially KL) in comparison to the other clusters they examined. This suggests that the KN lag in Romanian may be large enough so that nasal leakage would not mask the velar burst. Likewise, PS/KS lags in Romanian, comparable to those in German (20-25ms), are large enough to meet both perceptual and articulatory requirements. Rather, the current results suggest that Romanian lateral clusters are less overlapped than German lateral clusters, pointing to the possibility that Romanian clusters may overall be less overlapped than German ones.

An overall initial-consonant effect was observed on the target-release lag measure, with larger lags for /p/-initial than /k/-initial clusters, but matched comparisons indicated that this effect was carried out by clusters PS and KS alone. From a perceptual point of view, one would expect, if anything, that PS would allow shorter lags than KS, since in front-to-back clusters such as PS, the first consonant with a more anterior constriction is less likely to be masked by the more posterior constriction of the second consonant. Also from a production perspective, one would expect the same pattern: since /p/ has been shown to be less resistant to co-articulation than /k/ (Recasens et al. 1997), the sibilant would be expected, if anything, to encroach the labial more than the velar and not vice versa. It is not entirely clear therefore what factor(s) determine the Romanian PS/KS pattern. Chitoran et al. (2002) have observed for Georgian that labial-coronal stop clusters were less overlapped than velar-coronal ones, but this difference was likely due to the language-specific grammatical status of labial-coronal (non-homorganic) vs. velar-coronal (homorganic) Georgian clusters, so it is not clear to what extent this would apply to a cluster in a different language.

An order effect could not be systematically tested using the current data. Firstly, the available onset clusters conflate order with place of articulation: thus, if all effects reported for Georgian (Chitoran et al. 2002) are generalizable, then /p/-initial clusters are expected to be more overlapped than /k/-initial clusters as an order effect, but less overlapped as a place of articulation effect. Second, and perhaps more importantly, as mentioned in the introduction, order effects are hypothesized to play a role in shaping stop-stop intra-cluster timing, rather than apply to any cluster types. Since only one cluster (KT) in the current data meets this description, no comparisons could be carried out. Given that KT is a back-to-front stop-stop cluster, it may seem at first surprising that it exhibits a similar timing pattern to KL (or PL), but it must be emphasized that the second consonant in the cluster achieved its target at least 20 ms after release of the first consonant, which for perceptual purposes may be enough regardless of cluster composition.

The consistently much larger target-release lag in the case of rhotic clusters is determined not by perception, but by the aerodynamic requirements for producing a trill, whereby the trilling tongue tip articulation (which is the articulation measured here for the trill) must be synergistically supported by a preceding tongue dorsum retraction (cf. Solé 2002, for a discussion of the aerodynamic parameters required to initiate a trill).

Finally, regarding the plateau overlap measure, the one exception to the target-release lag measure pattern pertained to sibilant clusters. Thus, by this measure PS and KS showed significantly more plateau overlap than PL/KL, and did not differ in overlap degree from each other. The results thus indicate that the sibilant in the PS/KS clusters starts earlier than the lateral in PL/KL relative to the constriction interval of /p/-/k/. Nonetheless, in relation to release of /p/-/k/, the sibilant reaches its target at a time comparable to the lateral in PL/KL. Also, although the sibilant starts at the same time relative to

[1] The sibilant-lateral difference, observed in the current study on the plateau overlap measure only, is in the opposite direction from the pattern reported for German.

the constriction interval of either /p/ or /k/, it reaches its target later when following /p/ than when following /k/. This further suggests that the PS/KS lag asymmetry may be due to particular (perhaps word/language-specific) constraints or perhaps measuring artifacts, an issue that remains to be explored in future research.

In conclusion, the current data do not contradict previous perceptual/aerodynamic accounts of differing overlap patterns as a function of cluster composition. Particular intra-cluster lag differences are however not generalizable in the absence of knowledge of overall timing patterns of a language. Thus, larger intra-cluster timing lags for KN compared to KL, or for PS/KS compared to PL/KL cannot be automatically predicted on the basis of the German pattern, without first knowing how the consonants in onset PL/KL are timed in the respective language. The diachronic asymmetry between KL and KN may therefore not hold for languages that exhibit overall greater intra-cluster lags. The results overall highlight the importance of direct comparisons between clusters in a variety of languages so that cross-linguistic patterns could be separated from language-specific ones.

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