The temporal coordination of Polish onset and coda clusters containing sibilants

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Abstract

Based on articulatory data of five speakers we examined the temporal coordination of Polish onset and coda clusters. Previous studies in the field of the gestural model suggest that cluster-vowel timing interacts with cluster composition – particularly in the case when sibilants form either C_1 or C_2. Thus, we investigated whether the position of a sibilant within onset/coda cluster affects the temporal organization of the cluster relative to the vowel. The results showed more cluster-vowel overlap only when the sibilants are C_1 of the onset cluster. However, the overlap pattern did not change with increasing complexity for clusters with vowel-adjacent sibilants. While we found systematic timing differences with respect to sibilant position in onset clusters, no such differences were apparent in coda clusters. We assume that cluster-vowel timing interacts with consonantal and even vowel coarticulation (resistance) and underscore that syllable timing patterns cannot be understood independently of cluster or syllable composition. Further, we provide some evidence about syllable affiliation of word-initial obstruent-obstruent clusters.

Keywords: Gestural model, articulatory timing, Polish, sibilant clusters, coarticulation, coarticulatory resistance

1. Introduction

The gestural approach of syllable organization predicts different cluster timing patterns as a function of syllable position (Browman and Goldstein 2000): onset clusters are by hypothesis globally aligned along the temporal midpoint of the consonants (the "c-center" effect) independent of onset complexity whereas coda clusters are sequentially organized. This has often been evaluated by comparing the timing of a cluster relative to a corresponding singleton onset/coda. Figure 1 (left) illustrates schematically the timing patterns of a complex onset (bottom panel) relative to the corresponding singleton onset (top panel): the vowel-adjacent consonant (indicated by the blue box) in the bottom panel starts later in time compared to the top panel. This relative rightward shift implies that the bottom /k/ in [sk̲ala] overlaps more with the vowel than the top /k/ in [k̲ala]. The dashed line in the left panel of Figure 1 indicates the temporal midpoint of the singleton (top) and cluster (bottom) onset, while the solid line indicates the constant anchor point relative to which timing of the onset consonants is evaluated. Since the temporal distance between the dashed and the solid lines is constant in the singleton and cluster condition this is described as the "c-center" effect. In contrast, Figure 1 (right) shows the predicted timing pattern for singleton (top) and complex (bottom) coda. When coda complexity increases, the vowel-remote consonant /s/ in [laks̲] is simply 'added' to the singleton coda /k/

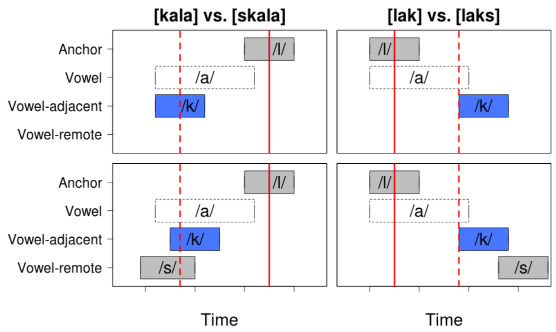

Figure 1: *Schematic representation for the predicted syllable organization. Left: "c-center" effect of onset cluster in [skala]. Right: sequential organization of coda cluster in [laks].*

in [lak̲]. The so-called sequential organization has no effect on the timing of C_1 in a VC_1C_2 sequence. This is illustrated by no temporal change between the anchor (solid line) and the vowel-adjacent /k/ (dashed line) in the bottom panel relative to the top panel.

While the predictions of the gestural model have been confirmed for several languages, previous studies have also revealed that cluster composition may interact with cluster-vowel timing in ways not accounted for by the model. This has become particularly evident in the case of clusters containing sibilants (Hermes et al. 2013, Marin 2013). Most recently a study on Romanian consonant clusters revealed "c-center" organization only for sibilant-stop onset clusters but not for stop-sibilant ones. Coda clusters, however, consistently showed sequential organization regardless of the sibilant's position (Marin 2013). Marin attributed different timing patterns in Romanian sibilant-stop and stop-sibilant onset clusters to frequency effects, but the design of her study did not allow to come to a firm conclusion. An alternative interpretation of the Marin results was mentioned by Pouplier (2012) who suggested that the coarticulatory resistance of the vowel-adjacent sibilant may have conditioned the results. A sibilant may prevent an increase in consonant-vowel overlap associated with increasing onset complexity (Figure 1) and therefore the expected c-center organization may fail to emerge. Pouplier mentioned that this interpretation cannot explain the patterning of /sk-/ since /k/ is known to be even more resistant in dorsal coarticulation than /s/. Support for the hypothesized role of coarticulatory resistance comes from previous findings that sibilants showed less coarticulatory variability than other consonants (Recasens et al. 1997, Recasens 2012). In combination with Redford's (1999) findings that syllable phonotactics interact with the mandibu-

lar cycle (i.e., the open-close movement of the jaw) this would imply that temporal coordination of syllables varies in a predictable fashion as a function of cluster composition.
In this study, we systematically examine Polish sibilant clusters in onset and coda aiming to understand whether the position of a sibilant within a cluster affects the temporal coordination of the cluster with the vowel. For this purpose Polish serves as an interesting test case since it provides an unusual variety of consonant sequences, among others clusters combining stops and sibilants in both orders (e.g., /ʃp/, /pʃ/) in both onset and coda position. For onsets we expect C-center organization with more onset-vowel overlap for sibilant-initial (SC) but not for sibilant-final (CS) clusters due to the coarticulation resistance of the vowel-adjacent sibilant. For codas, however, we suppose that due to generally less vowel-coda overlap there is no such interaction of sibilant position within the cluster and coda-vowel timing. There is some controversy in the literature as to whether Polish prevocalic obstruent sequences form onset clusters at all (e.g., Gussmann 2007, Rochoń 2000). Our present work will be able to shed further light on this controversy.

2. Method

2.1. Experimental setup and material

We collected EMA data (AG501, Carstens Medizinelektronik) with synchronized audio from five native speakers of Polish. We followed standard procedures for sensor calibration, placement and data postprocessing. Participants were asked to accentuate the target words (cf. Table 1) embedded in carrier phrases. The corpus contained sibilants in different syllable and cluster positions, i.e., the clusters SC={/ʃm/, /ʃp/, /sp/, /sk/} and CS={/mʃ/, /pʃ/, /ps/, /ks/} occurred in both onset and coda position. In addition we included target words with corresponding singletons as a baseline for the comparison of timing patterns under increasing onset/coda complexity, e.g., for onsets [skala] vs. [kala]; for coda [zamʃ] vs. [sam] (see Measurements). The phonemic environment was – as far as possible – kept consistent across a group of singleton and cluster onset/coda words to preserve the comparability between singleton and cluster pairs and CS and SC clusters. The complete data set comprises (up to) four repetitions per cluster and subject. Some data points are missing for the first subject due to technical issues.

Table 1: *Target words for onsets (top) and codas (bottom) grouped with respect to the sibilant position (CS, SC).*

	CS		SC	
	Cluster	Singleton	Cluster	Singleton
Onsets	mʃalik	ʃalik	ʃmata	mata
	pʃeraʑ	ʃereg	ʃperatɕ	peron
	psotɲe	sotɲa	spodɲe	podɲet
	ksero	zero	skala	kala
Codas	zamʃ	sam	naʃm	naʃ
	vjepʃ	vjep	vjeʃp	vjeʃ
	klops	glop	losp	los
	laks	lak	lask	las

We placed coils/sensors mid-sagitally on the upper and lower lip, the tongue tip and the tongue dorsum to capture the articulatory trajectories associated with labials /p, m/, coronals /t, d, n, s, ʃ, r, l/ and velar /k/, respectively. Articulatory events were identified semi-automatically on the basis of the tangential velocity profile. Due to its robustness we used for our analyses the timepoint of peak velocity (PVEL) of a gesture's closing movement (Figure 2, solid red lines). We preferred PVEL since the maximum constriction appeared to be less stable.

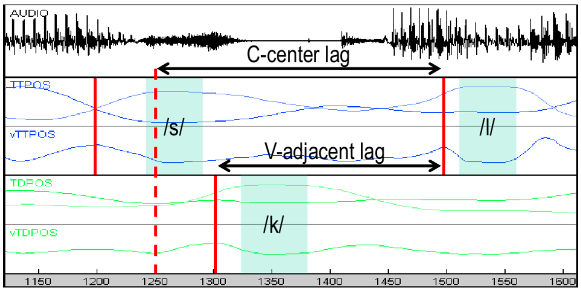

Figure 2: *Articulatory labeling and lag measurements.*

2.2. Measurements

For each singleton and cluster target word we measured the temporal lags between onset/coda constituents and a constant anchor point. The anchor point was the consonant following and preceding the vowel in onsets and coda clusters, respectively (e.g., /l/ in onset target word [skala]; /z/ in coda target word [zamʃ]). In keeping with previous work (Browman and Goldstein 1988, Marin and Pouplier 2010) we indirectly determined the cluster-vowel timing as follows: for onset/coda cluster words we measured the distance between the vowel-adjacent consonant and the anchor point (henceforth V-adjacent lag; e.g., for onset: k↔l in [skala]; for coda: z↔m in [zamʃ]); further we measured the distance between the temporal midpoint of the consonant(s) and the anchor point (henceforth C-center lag; e.g., for onset: sk↔l in [skala], k↔l in [kala]; for codas: z↔mʃ in [zamʃ], s↔m in [sam]). Figure 2 exemplifies for the /sk/ cluster in [skala] the measurement points for of the V-adjacent and C-center lags.
To quantify the relative timing differences between singleton and cluster words, we computed lag ratios for each cluster as follows: we averaged all lag measurements of a given singleton condition (e.g., [kala]); then we compared each occurrence of the corresponding cluster condition (e.g., [skala]) relative to the singleton mean value; finally we centered the lag ratios to 0. This was done for V-adjacent and C-center lags alike. Positive lag ratios represent a lag increase between singleton and cluster, i.e., less overlap with the vowel in cluster than in singleton target words. Negative lag ratios indicate a shift towards the anchor, i.e., more consonant-vowel overlap with increasing complexity. Lag ratios around 0 suggest no change in timing compared to the corresponding singleton.
For onsets, the gestural model predicts a negative lag ratio for the V-adjacent measure and a lag ratio around 0 for the C-center measure (Figure 1 left). For codas, the V-adjacent measure should not be affected by coda complexity while the C-center measure should be positive (sequential organization; Figure 1 right). If, as we predict, coarticulation resistance prevents increasing onset-vowel overlap in the case of vowel-adjacent sibilants, there would be an interaction of these measures with sibilant position: for SC clusters there should be a negative V-adjacent lag ratio and a C-center lag ratio around 0; for CS clusters, however, a V-adjacent lag ratio around 0 and a positive C-center lag ratio are expected. For codas we predict no difference in lag ratios as a function of sibilant position. We

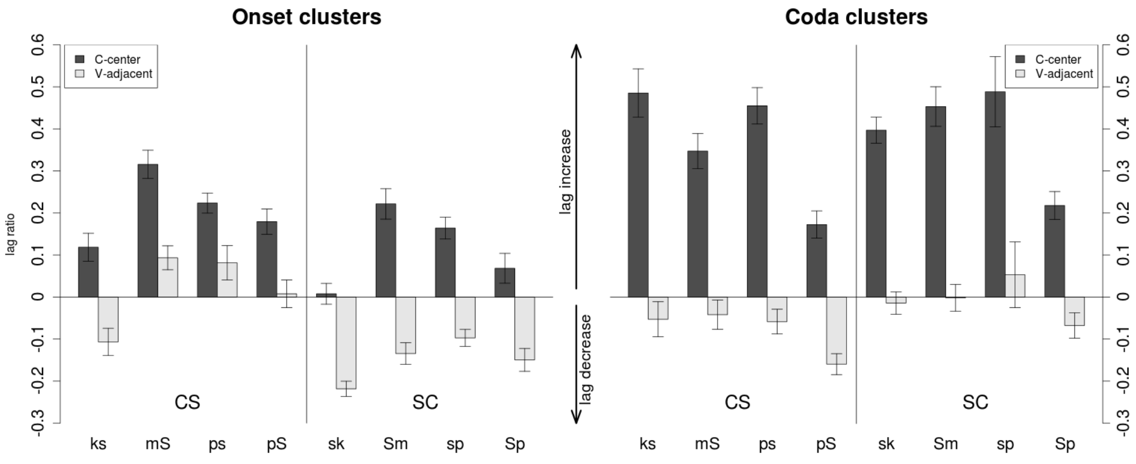

Figure 3: *Temporal lag ratios for onset (left) and coda (right) clusters.*

expect for both cluster types V-adjacent lag ratios around 0 and clearly positive C-center lag ratios.

2.3. Statistics

To test the global differences between sibilant-initial (SC) and sibilant-final (CS) clusters statistically we applied two linear mixed models, one with the C-center lag, the other with the V-adjacent lag as the dependent variable. Sibilant Position (two levels: SC and CS) and onset/coda Complexity (two levels: singleton and cluster) were fixed factors; Speaker and Set (pairs of singleton and cluster target words) were random factors. P-values were obtained by comparing, for example, one model with and one without the interaction of the fixed factors.
Based on our hypotheses we predict for onsets a significant interaction of sibilant position and complexity for both lag ratios. For codas on the other hand we expect no significant difference in vowel-coda timing between SC and CS clusters.

3. Results

3.1. Temporal coordination of onset clusters

Results for onsets are given in the left plot of Figure 3. For SC clusters, we found as predicted a "c-center" organization with more consonant-vowel overlap in clusters than in the corresponding singletons. This is evident by consistent negative V-adjacent lag ratios for those clusters (light gray bars). In the case of CS clusters, the V-adjacent lag ratios are predominantly above or around 0, indicating no change in consonant-vowel overlap in clusters compared to singletons. Confirming our predictions, the interaction of Sibilant Position and Complexity was significant ($\chi^2[1] = 25.8$, $p<.001$), i.e., the V-adjacent lag ratios differed significantly between CS and SC clusters. The light gray bars suggest that within the CS and SC groups, not all clusters behave the same. We therefore ran two additional mixed models, separately for CS and SC clusters in order to determine whether the clusters within these two groups differed significantly from each other (dependent variable: V-adjacent lags; fixed factors: Set and Complexity; random factor: Subject). Results revealed a significant interaction of Complexity and CS sets ($\chi^2[3] = 16.5$, $p<.001$), i.e., the V-adjacent lag ratios differed between CS sets. Post-hoc Tukey tests revealed that consonant-vowel overlap increased significantly only for set /ks/ ($p<.05$), i.e., the vowel-adjacent consonant /s/ in [ksero] shifted towards the vowel and, thus, overlapped more with the following vowel than in the singleton condition [zero]. This is the pattern that we generally found for SC clusters and that is predicted for a "c-center" onset coordination. For the remaining CS clusters (/mʃ/, /ps/ and /pʃ/) consonant-vowel overlap did not change significantly between singleton and cluster condition. Similarly, the effect of complexity on V-adjacent lags differed significantly between SC cluster sets (Complexity × Set interaction; $\chi^2[3] = 11.8$, $p<.01$). All sets showed more consonant-vowel overlap in clusters than in singletons. Post-hoc Tukey tests revealed complexity effects for /sk/ ($p<.001$), /ʃm/ ($p<.01$) and /ʃp/ ($p<.001$) but not for /sp/.
Onset C-center lag ratios (dark gray bars, Figure 3 left) patterned more homogeneously showing consistently positive values for CS and SC clusters. Statistically, the C-center lag ratios differed significantly between SC and CS clusters ($\chi^2[1] = 13.4$, $p<.001$), i.e., there was an overall bigger C-center lag ratio for CS clusters compared to SC clusters. In analogy to the V-adjacent lag measurements, we conducted follow-up mixed models for the C-center lags since the dark gray bars suggest set-dependent variability (dependent variable: C-center lags; fixed factors: Set and Complexity; random factor: Subject). Considering sibilant position, we found that C-center lag ratios differed between CS sets ($\chi^2[3] = 9.9$, $p<.05$). Post-hoc Tukey test revealed a global shift away from the vowel in the cluster relative to the singleton condition for /mʃ/ ($p<.001$), /ps/ ($p<.001$) and /pʃ/ ($p<.01$). However, /ks/ showed "c-center" organization since the C-center lag did not increase significantly with complexity. The differences between sets were also significant for SC ($\chi^2[3] = 14.0$, $p<.01$). Post-hoc Tukey test ascertained that clusters /sk/ and /ʃp/ show "c-center" organization, since C-center lags did not change significantly between singleton and cluster condition. In contrast the remaining clusters shifted globally away from the vowel, i.e., no global alignment (/ʃm/: $p<.001$; /sp/: $p<.01$).

3.2. Temporal coordination of coda clusters

The lag ratios for coda clusters are shown in Figure 3 (right). Similarly to the results of the sibilant-initial (SC) onset clusters the V-adjacent lag ratios showed for sibilant-final (CS) clusters consistently negative values (Fig 3 right, light grey bars). This indicates a slightly decreasing lag between the anchor point and the vowel-adjacent consonant and, thus, more consonant-vowel overlap in the cluster compared to the singleton condition. The V-adjacent lag ratios of SC coda clusters, however fall around 0, i.e., there is no change in vowel-consonant timing relative to the singleton condition. Since differences concerning consonant-vowel overlap (indicated by V-adjacent measure) was small between CS and SC coda clusters, sibilant position and complexity interacted only at trend level ($\chi^2[1] = 3.1$, $p<.1$). However, there was no interaction of Set and Complexity in the follow-up mixed models, Post-hoc Tukey tests revealed that vowel adjacent consonant of /-pʃ/ shifted towards the preceding vowel as the /ʃ/ was added ($p<.01$). Concerning consonant-vowel overlap in SC clusters, we found no set-specific differences. Finally, both CS and SC clusters shifted globally away from the vowel, i.e., the C-center lag increased with coda complexity for CS and SC alike. In sum, with the only exception /-pʃ/, CS and SC clusters showed sequential organization.

4. Discussion and conclusion

We hypothesized that syllable organization of onset clusters should be affected by the sibilant's position within the cluster since more onset-vowel overlap is expected for sibilant-initial than sibilant-final clusters. For coda clusters, however, we expected no such effect due to generally less consonant-vowel overlap. The results confirm our predictions. We found more consonant-vowel overlap when sibilants are C_1 in a C_1C_2 onset cluster (i.e., SC). In contrast the vowel-adjacent sibilant overlapped less with the vowel in CS onset clusters. Further, our results showed no differences in vowel-consonant timing in CS and SC coda clusters. This means that our findings deviate to some extent from the predictions made by the gestural model (Browman and Goldstein 1988, 2000): concerning the V-adjacent measures, CS onset clusters showed sequential alignment instead of "c-center" organization; further, CS and SC onset clusters showed a significant complexity effect for the C-center lag measure. The gestural organization of coda clusters is, however, predominantly in line with the gestural model. The timing patterns observed in our data agree with recent results of Marin (2013) who found "c-center" organization only in sibilant-stop but not in stop-sibilant onset clusters for Romanian. That coda clusters are not affected by sibilant position in the current data is also consistent with Marin's findings. These results can be interpreted in terms of coarticulatory resistance and aggressiveness of consonants since sibilants were found to coarticulate less and – at the same time – to trigger more coarticulation than other consonants (Recasens et al. 1997, 2012). This may account for why onset clusters with a vowel-adjacent sibilant showed generally less consonant-vowel overlap compared to clusters in which sibilants formed the edge of the target word. In sum, the timing patterns generally support the assumption that cluster-vowel timing interacts with coarticulation resistance and underscore that syllable timing patterns cannot be understood independently of cluster composition.

We also found differing timing patterns between CS sets: while /mʃ-, ps-, pʃ-/ predominantly showed V-adjacent lag ratios above or around 0 (i.e., increasing or unaltered timing patterns with increased complexity), /ks-/ showed a significant increase in consonant-vowel overlap compared to the singleton condition. Another set-dependent timing pattern concerns the coda cluster /-pʃ/: we found a significant shift of the vowel-adjacent consonant towards the preceding vowel. Interestingly, both clusters differ from the other stimuli used in the experiment in terms of vowel context, i.e., /ks-/ and /-pʃ/ precede/follow the front vowel /e/ while the other clusters are adjacent to back vowels /a, o/. This suggests that also vowel identity may affect syllable timing.

In this respect the jaw could play a decisive role (cf. Redford 1999). It is possible that consonant-vowel overlap in onset /ks-/ and even in coda /-pʃ/ can be achieved since the target position of the jaw is relatively similar for both the vowel-adjacent consonant and the vowel /e/. This would be in accordance with Redford (1999) who observed a positive displacement-duration relationship for the open-close movement of the jaw. However, whether and to what extent the syllable timing patterns is affected by jaw position constraints remains for future research.

Finally, our results provide some new aspects to the controversy whether initial/final obstruent sequences are complex onsets/codas in Polish or not. From an articulatory point of view we found evidence for syllabic organization since our results showed systematic differences in terms of sibilant position and vowel context. However, the complex interaction of gestural overlap, jaw movement and coarticulation in Polish syllable organization remains a topic for further investigation.

5. Acknowledgements

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