ONSET–VOWEL TIMING AS A FUNCTION OF COARTICULATION RESISTANCE: EVIDENCE FROM ARTICULATORY DATA

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ABSTRACT

We recorded articulatory data to investigate the influence of consonantal coarticulation resistance on consonant-vowel timing in Polish onset clusters. While recent studies found different onset-vowel timing patterns depending on the position of the sibilant within the cluster, it is widely unknown how onset-vowel timing interacts with different degrees of coarticulation resistance of the vowel-adjacent consonant. Thus we examined articulatory data of singleton and cluster onsets with different vowel-adjacent consonants varying in their coarticulation resistance. The results suggest a systematic change in CV overlap between singleton and cluster condition with most overlap for less resistant consonants /m, p, k/ and no changing overlap for most resistant consonants /s, ʃ/. Sonorants /n, l/ show intermediate CV overlap patterns. These results confirm that onset-vowel timing interacts with coarticulation resistance and strengthen the assumption that syllable organization depends on the composition of the entire syllable.

Keywords: Coarticulation resistance, onset-vowel timing, CV overlap, Polish, articulatory timing

1. INTRODUCTION

Coarticulation describes the interaction of neighboring speech sounds, conditioned by their temporal and spatial overlap. Numerous studies have revealed that the degree of coarticulation varies with the particular consonants and vowels involved, a phenomenon known as coarticulation resistance (e.g. [6], [10], [12]). Models of articulatory correlates of syllable structure do not take segmental composition of the syllable into account, yet there is some evidence that coarticulation resistance interacts with onset-vowel timing ([11]). In order to systematically investigate the possible interaction between lingual coarticulation resistance and onset-vowel timing we analyze a set of Polish onset clusters with varying vowel-adjacent consonants (henceforth C_{adja}) known to differ in their resistance in coarticulating with the vowel.

Syllable organization is often evaluated by comparing the timing of a cluster onset relative to a singleton onset. The gestural model of syllable organization ([5]) hypothesizes that onsets are globally aligned along their temporal midpoint independently of their complexity ("c-center effect"). This onset-vowel timing affords a shorter temporal lag between the C_{adja} and a constant anchor point in the cluster than in the singleton condition, i.e. increasing CV overlap with increasing onset complexity. By hypothesis, this timing pattern as a correlate of prosodic position holds independently of the segmental composition of the syllable. However, recent studies have shown diverging timing patterns as a function of different cluster compositions. For Romanian onset clusters, Marin [8] found the expected "c-center" organization only for sibilant-initial clusters while stop-initial clusters did not confirm the predictions. Pastätter and Pouplier [11] found for Polish a systematic timing difference between sibilant-initial (e.g. /ʃm-/) and sibilant-final (e.g. /mʃ-/) onset clusters: CV overlap increased with increasing onset complexity only for sibilant-initial but not for sibilant-final onsets. They hypothesized that this compositional effect could derive from different degrees of coarticulation resistance of the vowel-adjacent consonants (cf. [13]), i.e. the sibilant in /mʃ-/ is more resistant to coarticulation than the bilabial in /ʃm-/ and prevents therefore increasing CV overlap in the cluster condition necessary for c-center organization. However, while Pastätter and Pouplier [11] found a systematic difference between sibilant-initial and sibilant-final onset clusters, it remains unclear whether this effect can really be attributed to coarticulation resistance rather than to other factors such as frequency or the identity of C1, as argued by Marin [8]. In this paper, we provide further evidence that onset-vowel timing indeed interacts with coarticulation resistance.

In terms of Articulatory Phonology coarticulation of consonants and vowels results from temporally overlapping gestures ([4]). However, the degree of coarticulation with the vowel may vary between consonants (e.g. [2], [6], [10], [12]): while the articulation of bilabial consonants is highly affected by the articulation of the surrounding vowels, sibilants have been found to be by and large immune to the coarticulatory force of the adjacent vowel(s), i.e. they exhibit a high degree of coarticulation resistance. Recasens and Espinosa [12] stated that the presence of an active tongue body control during the production of consonants conditions coarticulatory resistance to the influence of adjacent segments, while consonants without tongue body contribution are quite susceptible to lingual coarticulation. Accordingly, they have proposed the hierarchy in (1) from consonants exhibiting the most coarticulatory resistance to those exhibiting the least.

(1) **ɲ> ʃ > s > (dark) l > n > p**

Although Browman and Goldstein [3] assumed that "more overlap should result in greater coarticulation" (p.153) it is surprising that the consequently arising interrelation of coarticulation resistance and syllable organization has been overlooked in previous studies concerning syllable organization. For this reason we investigate the effect of coarticulation resistance and onset-vowel timing by comparing Polish singleton and cluster onsets with C_{adja} referring to different degrees of coarticulation resistance. While we expect more CV overlap in the cluster than in the singleton condition when the C_{adja} is prone to coarticulation (e.g. labial stops), CV overlap should not change when highly resistant sibilants are adjacent to the vowel (cf. [11]). In addition we expect an intermediate change in CV overlap for sonorants, however with slightly more overlap for nasals than for laterals.

2. METHOD

2.1. Experiment and corpus setup

Using electromagnetic articulography (EMA) we recorded kinematic data, synchronized with audio, from six native speakers of Polish. The target words were embedded in accented position in a carrier phrase. The stimuli comprise four sets grouped by the degree of coarticulation resistance (CR) of the C_{adja}, i.e. *CR.high* = {ks, mʃ, ps, pʃ}, *CR.mid.l* = {kl, ml, pl, vl}, *CR.mid.n* = {kn, pn} an *CR.low* = {sk, ʃm, sp, ʃp}. We grouped the C_{adja} /k, m, p/ together since /k/ and labials show a high degree of vowel coarticulation ([1], [7], [10]).

Each particular set includes a cluster and a singleton onset target word to enable the comparison of timing patterns with changing onset complexity, e.g. set sk incorporates the target words [skala] and

Table 1: Target words grouped witt respect to the degree of coarticulation resistance.

CR.high			*CR.low*		
Set	Cluster	Singleton	Set	Cluster	Singleton
mʃ	mʃalik	ʃalik	**ʃm**	ʃmata	mata
pʃ	pʃeraʑ	ʃereg	**ʃp**	ʃperatɕ	peron
ps	psotɲe	sotɲa	**sp**	spodɲe	podɲet
ks	ksero	zero	**sk**	skala	kala
CR.mid.l			*CR.mid.n*		
Set	Cluster	Singleton	Set	Cluster	Singleton
kl	klutʃɨk	ludʑik	**kn**	knurɨ	nurek
pl	platsom	latom	**pn**	pnatɕi	natɕi
ml	mlekax	lekaʃ			
vl	vlitʃɨ	litʃi			

[kala]. The sets were designed as phonemically homogeneous as possible to preserve the comparability within the sets. The complete data set comprises a maximum of four repetitions per target word and subject (n=672). However, some data points are missing due to technical issues (n=31).

The kinematic trajectories of labials, coronals and velars were determined on the basis of sensors placed mid-sagitally on the upper and lower lip, the tongue tip and the tongue dorsum, respectively. Articulatory data were labeled by means of Mark Tiede's MATLAB based mview algorithm which identified articulatory events semi-automatically on the basis of the tangential velocity profile.

2.2. Timing measurements

Our measurements were adopted from previous syllable organization studies (e.g. [3], [8], [9]). CV overlap has been determined indirectly by comparing the temporal lag between C_{adja} (e.g. /k/) and a constant anchor point (e.g. /l/) of singleton and cluster target words, e.g, the temporal distance k↔l in [kala] and [skala]. For this timing measurements we used the peak velocity (PVEL) timepoint of a gesture's closing movement due to its robustness. Then we computed lag ratios for each cluster to quantify the relative change in CV overlap between singleton and cluster condition. We averaged all lag measurements of a given singleton condition (e.g. [kala]) and compared then each occurrence of the corresponding cluster condition (e.g. [skala]) relative to the singleton mean value. Finally we centered the lag ratios to 0. Positive lag ratios represent less CV overlap in cluster than in singleton target words (i.e. longer lags in the cluster than in the singleton condition). Negative lag ratios indicate more CV overlap with increasing complexity (i.e. shorter lags in the cluster condition). Lag ratios around 0 suggest no change in cluster timing compared to the corresponding singleton.

Considering our hypothesis, we expect for *CR.low* more CV overlap in the cluster than in the singleton condition (i.e. negative lag ratios), while we assume no change in CV overlap for *CR.high*, i.e. lag ratios around zero. According to the hierarchy in (1), we expect an intermediate CV overlap change for *CR.mid.n* and *CR.mid.l* (i.e. negative lag ratios between those for *CR.low* and 0). *CR.mid.n* are expected to show more vowel overlap than *CR.mid.l* due to a higher coarticulatory resistance of laterals compared to nasals.

2.3. Tongue body position measurements

In order to determine changes in onset-vowel timing we measured for a subset of the clusters the degree of anticipatory vowel coarticulation in C_{adja}. This was done for vowel-adjacent sibilants and bilabials (i.e. *sibilant* = {mʃ, pʃ, ps} vs. *bilabial* = {ʃm, ʃp, sp}) since sibilants actively control the tongue body position while bilabials do not (e.g. [13], [15]). To analyze the articulatory variability of C_{adja} we compared the tongue body vertical position at the timepoint of the constriction maximum in singleton and cluster condition.

We expect for vowel-adjacent bilabials a significant difference in tongue body position between the cluster and singleton condition, reflecting their susceptibility to coarticulation, while tongue body position of vowel-adjacent sibilants should not be affected, reflecting their high coarticulation resistance.

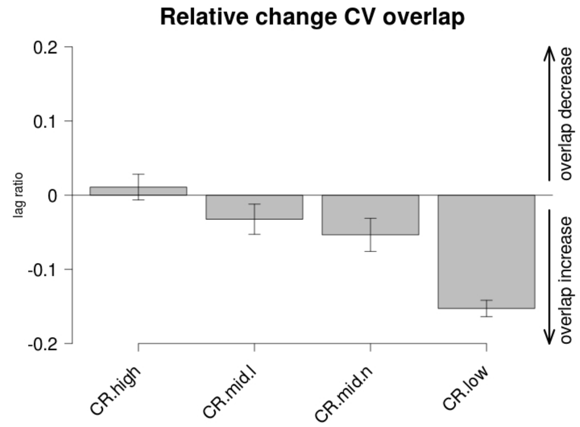
3. RESULTS

3.1. Timing measurements

Figure 1 indicates the relative change in CV overlap between the singleton and cluster condition as a function of C_{adja}. The arrangement of bars corresponds to the coarticulation resistance hierarchy suggested in (1), i.e. the group with the most resistant consonants is on the left and least resistant consonants is on the right. The trend confirms our expectations: highly coarticulation resistant sibilants (*CR.high*) show no change in CV overlap in the cluster compared to the singleton condition (i.e. ratios around 0); consonants with low coarticulation resistance (*CR.low*) show the greatest change in CV overlap between singleton and cluster conditions. The relative change in sonorant-vowel overlap indicates an intermediate pattern with nasals (*CR.mid.n*) showing slightly more overlap with the vowel than laterals (*CR.mid.l*) as syllable complexity increases.

A linear mixed model (lme4 package in R) on dependent variable Lag Ratio, with fixed factor: Group (four levels: *CR.high*, *CR.mid.l*, *CR.mid.n*, and *CR.low*) and random factors: Speaker, Word, Repetition, showed that the change of CV overlap between singleton and cluster onsets differed significantly as a function of the identity of C_{adja} ($\chi^2[3] = 10.7, p<.05$). This confirms the influence of coarticulation resistance on onset-vowel timing. Post-hoc Tukey tests revealed significant differences between *CR.low* and *CR.high* ($p<.01$) and a trend between *CR.low* and *CR.mid.l* ($p=.06$). The comparisons of the remaining pairs were not significant.

Figure 1: The relative change in CV overlap between singleton and cluster condition.



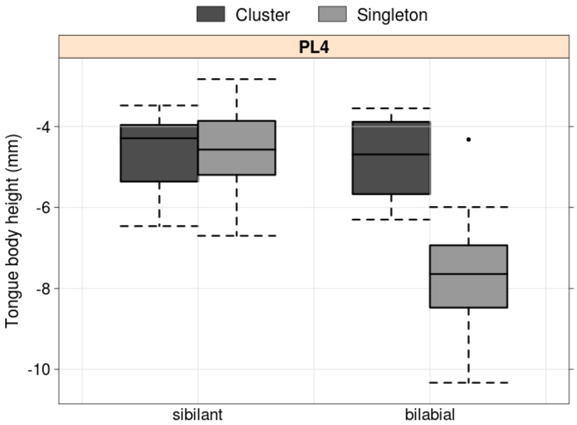
3.2. Tongue body position measurements

The interpretation of the previous results as being conditioned by coarticulation resistance hinges on the hypothesis that CV overlap increases with increasing cluster complexity. Since we use the coda consonant as constant measurement reference point, we have only provided an indirect measurement of onset-vowel overlap so far. Our second analysis therefore attemps to reveal direct articulatory evidence for increasing CV overlap with increasing onset complexity.

Conforming to our hypotheses, we observed that a vowel-adjacent sibilant has a very similar tongue body position in singleton and cluster, i.e. the degree of anticipatory vowel coarticulation remains unchanged with increasing cluster complexity. For vowel-adjacent bilabials, however, the tongue body was significantly higher in the complex than in the singleton condition, i.e. the tongue body height of the bilabial is conditioned by the coarticulatory aggressive sibilant rather than by the vowel. This clearly confirms the coarticulatory variability of bilabials on the one hand, and the coarticulation resistance of the sibilants on the other.

A linear mixed model on dependent variable: Tongue body vertical position, with fixed factors: Group (two levels: *sibilant*, *bilabial*) and Onset Complexity (two levels: singleton, cluster), and with random factors: Speaker, Word, Repetition, showed that tongue body height was significantly affected by onset complexity ($\chi^2[1] = 4.57$, $p<.05$), while factor Group was not significant. The interaction between factors was significant ($\chi^2[1] = 5.92$, $p<.05$), and a Post-hoc Tukey test indicated that tongue body was significantly higher when a sibilant was added before a bilabial ($p<.001$). However, tongue body height during sibilants was not affected by increasing onset complexity. These different coarticulation patterns are exemplified for a single representative speaker (PL4) in Figure 2.

Figure 2: Tongue body height for vowel-adjacent *sibilants* (left) and *bilabials* (right) as a function of onset complexity for speaker PL4.



4. DISCUSSION

In this study we hypothesized that onset-specific timing patterns (i.e. temporal changes due to increasing onset complexity as hypothesized by a c-center organization) are influenced by onset composition and specifically by the degree of coarticulation resistance of the C_{adja}. Lag ratios which quantify the relative change in CV overlap between singleton and cluster onsets confirmed this hypothesis. We found no change in CV overlap for *CR.high* (sibilants) but the largest CV overlap for *CR.low* (/m, p, k/). This replicates the systematic difference of syllable organization found for sibilant-initial and sibilant-final onset clusters ([8], [11]). In addition, we observed an intermediate change in CV overlap for *CR.mid.l* and *CR.mid.n*. In sum, conforming our hypothesis the relative CV overlap gradually increased with decreasing coarticulation resistance of C_{adja} (cf. [12]). Relative CV overlap did not significantly differ between vowel-adjacent sonorants and sibilants (*CR.high*, *CR.mid.l* and *CR.mid.n*).

With the tongue body position measurements which serve as a measure of consonant-vowel coarticulation we further corroborated our hypothesis that coarticulation resistance interacts with onset-vowel timing. For vowel-adjacent bilabials the tongue body was significantly higher in the complex than in the singleton condition. In a gestural perspective this suggests that in the singleton condition the bilabial overlaps with the vowel while in the cluster condition even the preceding sibilant and thus the entire onset overlaps with the vowel, i.e increasing onset-vowel overlap with increasing onset complexity (cf. *CR.low* in Figure 1). Since the tongue body gesture of the sibilant (which determines coarticulation resistance (cf. [13], [15]) and the vowel are simultaneously activated, this leads to competing demands on the same articulator. Since the sibilant is coarticulatorily even more aggressive than the vowel the tongue body height during the bilabial is dominated by the sibilant ([14]). This results in a tongue body height similar to that of singleton sibilants (see *sibilant* in Figure 2). If there was no overlap of sibilant and the vowel (i.e. constant onset-vowel timing in singleton and cluster condition) we would expect a lower tongue body position. On the other hand vowel-adjacent sibilants had similar tongue body heights in both singleton and cluster condition. In combination with the temporal measurements (cf. *CR.high* in Figure 1) this suggests that the coarticulatory resistant sibilant controls both the tongue body height and conditions a particular pattern of onset-vowel timing. Accordingly, it is not mandatory that the tongue body position and sibilant-vowel timing changes with increasing onset complexity. In summary the tongue body position measurements provided for a subset of the clusters direct articulatory evidence for the interaction between lingual coarticulation resistance and onset-vowel timing. How the effect of different degrees of coarticulation resistance on onset-vowel organization is to be represented from a gestural perspective, remains to be investigated in future research.

5. ACKNOWLEDGEMENTS

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