Organization of Complex Onsets and Codas in American English: Evidence for a Competitive Coupling Model

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Abstract

This study systematically investigates the temporal organization of American English onset and coda consonant clusters on the basis of kinematic data. Results suggest that consonants in complex onsets are organized globally with respect to the following vowel (c-center organization), while consonants in complex codas are coordinated sequentially. These results support the competitive coupling model hypothesized for complex onsets, and is also consistent with the non-competitive coupling relations assumed for codas. We also observe a difference between /l/-clusters and /s/-clusters, potentially due to the particular gestural composition of American English /l/.

1. Introduction

Consonants differ systematically in their kinematic properties as a function of syllable position [5]. Further, in complex onsets different timing patterns have been observed compared to complex codas: While onset clusters have been described as being coordinated globally as an ensemble of gestures with the following vowel (the so-called c-center effect, [2]), coda consonants have been hypothesized to be coordinated locally, or left-edge, with the preceding vowel.

At the articulatory level, an underlying c-center organization, as predicted for onsets, is indicated by a shift in the timing of the rightmost onset consonant towards the vowel as more consonants are added (e.g., *cab* vs. *scab*). This will cause an increasing overlap of the rightmost consonantal gesture and the following vowel. Local gestural coordination, as hypothesized for codas, affects no such shift in timing, and consonants are expected to be added sequentially to the left edge (e.g., *bass* vs. *bask*). Therefore, increasing coda complexity will not change the overlap between the leftmost consonant gesture and the preceding vowel.

These timing patterns have been hypothesized to arise from specific coupling modes governing gestural coordination in onset and coda position [6]: Thus, onset gestures are assumed to be coupled synchronously (in-phase) with the vowel, but anti-phase with each other, resulting in competitive demands on these gestures, that cannot be fully satisfied simultaneously (i.e. onset gestures cannot at the same time be all synchronous with the vowel and sequential to each other). The c-center organization pattern, with one gesture shifting away from the vowel and the other towards the vowel represents the "compromise" pattern that best satisfies the competing demands hypothesized to be at play in onsets. On the other hand, coda gestures are coordinated in a non-competitive manner, sequentially (anti-phase) to each other (Figure 1).

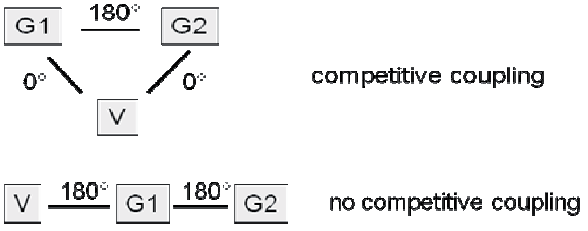

Figure 1: *Gestural organization for complex onsets (top) and for complex codas (bottom).*

While some previous empirical studies have confirmed the c-center hypothesis for onsets but not codas [1, 4], others found a c-center organization for both onset and coda consonants, at least for some speakers [3]. The limitations of these studies were that they looked at very few cluster types or did not directly compare complex onsets and complex codas. The current study uses EMA data to systematically investigate the temporal organization of American English consonant sequences in both onset and coda positions.

2. Method

EMA data (AG500, Carstens Medizinelektronik) were collected from 7 native speakers of American English, who produced the target words (cf. Table 1) embedded in a carrier phrase. Each target word included a consonantal anchor with respect to which the timing of the consonants of interest (singletons and clusters) was measured. The current analysis includes between 5 and 8 repetitions for each cluster per speaker. The utterances were designed to allow a comparison of the vowel-consonant timing between simple onsets/codas and complex onsets/codas.

Table 1. *Experimental items: relevant consonants are shown in bold face; anchor points are underlined.*

Cluster type	Onsets			Codas		
SP	**sp**ank	**p**ang	**s**ank	ga**ps**/ga**sp**	ga**p**	ga**s**
SK	**sc**ab	**c**ab	**s**ap	ba**cks**/ba**sk**	ba**ck**	ba**ss**
SM	**sm**ug	**m**ug	**s**uck	gu**ms**	gu**m**	Gu**s**
PL	**pl**ug	**p**ug	**l**ug	gu**lp**	cu**p**	gu**ll**
KL	**cl**ub	**c**up	**l**uff	bu**lk**	bu**ck**	ba**ll**

Sensors relevant for the data we report here were placed mid-sagittally on the upper and lower lips, tongue tip and tongue dorsum. Minimum Euclidean distance between upper and lower lips (Lip Aperture) was used for defining [p] and [m], maximum vertical movement of the Tongue Tip (TT) sensor was used for defining [s] and the tongue tip constriction for [l], and maximum vertical movement of the Tongue Dorsum (TD) was used for defining [k]. For each gesture, the point of maximum constriction was automatically detected using a 20% velocity threshold.

For each experimental word, the relative timing of the consonant gestures to the anchor point was calculated as the lag between the maximum constriction of the relevant consonant and maximum constriction of the anchor consonant. To compare lags of single consonants with lags in consonant clusters, relative shifts were calculated (Figure 2). For example, in the case of onset [sp], shift of [p] was calculated as the difference between [p]-lag to the anchor in "spank" and [p]-lag to the anchor in "pang". The same method was used for all other clusters, and the computations were done so that positive values indicate a shift towards the vowel, while negative values indicate a shift away from the vowel in the case of both onsets and codas.

By this measure, if a cluster shows a c-center organization, it is expected that the consonant adjacent to the vowel in that cluster will exhibit a shift towards the vowel compared to its timing as a singleton. If a cluster is locally timed (left or right edge), no such shift towards the vowel is expected. According to the c-center hypothesis, consonants adjacent to the vowel are expected to shift towards the vowel in onset but not in coda clusters.

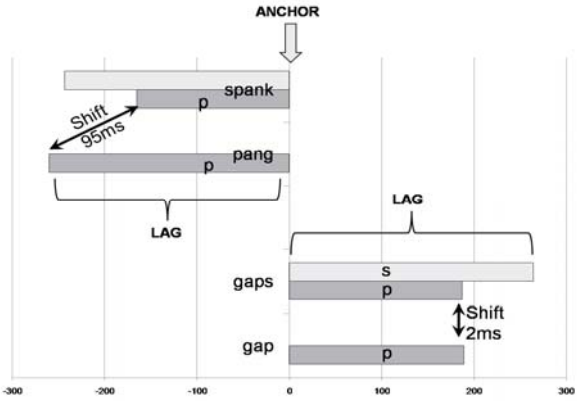

Figure 2: *Timing measurements: Lags of consonants with respect to anchor point, and shifts of consonants in clusters adjacent to the vowel with respect to singleton consonants. This example, produced by the same subject, shows a shift towards the vowel of [p] in "spank", and basically no shift of [p] in "gaps".*

3. Results

The experimental question was whether shift patterns of the consonant adjacent to the vowel in a complex cluster were significantly different dependent on their syllable affiliation – onset vs. coda, and in the direction predicted by the c-center hypothesis.

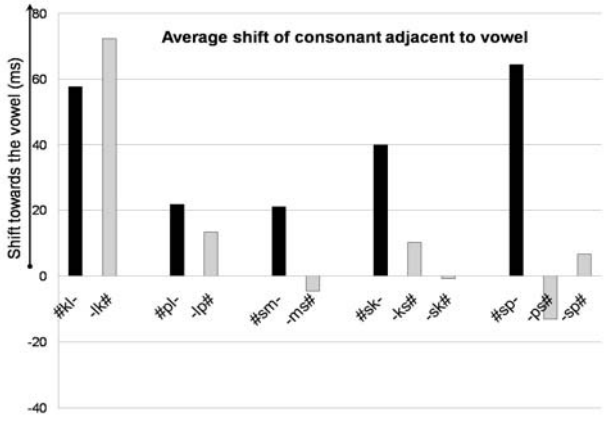

Figure 3: *Average shift of consonant adjacent to the vowel in onset and coda clusters (7 subjects for /s/-clusters, 2 subjects for /l/-clusters).*

Across-subject means (Figure 3) indicate that for all /s/-clusters, the rightmost consonant in onsets exhibits a greater shift towards the vowel than the leftmost consonant in coda, which exhibits either a relatively smaller shift towards the vowel ([-ks], [-sp]), or a small shift away from the vowel ([-ms], [-sk], [-ps]).

Because for /l/, coda cluster data were at this point available from only two subjects (because the other subjects produced mostly vocalized [l] in coda), statistical tests were limited to the /s/-clusters. A repeated measures ANOVA with the factors Syllable Position (onset or coda) and Cluster Type (SM, SK, SP) as factors, was significant for both main effects (Syllable Position: $F(1, 6) = 31.534$, $p = 0.001$; Cluster Type: $F(2, 12) = 4.069$, $p = 0.045$) and the interaction (Syllable Position*Cluster Type: $F(2, 12) = 20.248$, $p < 0.001$). Note that for SK and SP clusters, only [-ks] and [-ps] codas were included in the ANOVA. The result shows that the shift patterns observed in onsets and codas are indeed significantly different from each other with greater shifts in onsets than in codas. The main effect of cluster type also confirms that shift patterns are significantly different between each cluster type, with a larger shift in [sp-] than in [sk-] than in [sm-]. The interaction effect further indicates that the difference between onsets and codas is dependent on cluster type, a difference again largely attributable to the differences between clusters in shift magnitudes in onsets.

For the SK and SP clusters, paired samples t-tests between the two coda types (Cs/sC) turned out not significant ([-ks] vs. [-sk]: $t(6) = 1.215$, $p = 0.270$; [-ps] vs. [-sp]: $t(6) = -1.505$, $p = 0.183$).

As to the /l/-clusters, visual inspection of Figure 3 shows that the onset-coda asymmetry differs in /l/-clusters compared to /s/-clusters: For PL, there is a shift of [l] towards the vowel in both onset [pl-] and coda [-lp], with a difference between the two shifts of less than 14ms. KL is even more different from the pattern observed for /s/-clusters in that [l] shifts towards the vowel more in the coda than in the onset. Looking in more detail at the individual subjects' data (Figure 4), it becomes evident that for KL, subjects uniformly show quite a big shift of /l/ towards the vowel in both onset [kl-] and coda [-lk]. The subjects for whom both onset and coda conditions are available show a trend for greater shifts in codas compared to onsets. For PL, shifts towards the vowel are relatively smaller for both onsets and codas compared to KL. One of the subjects for whom onset and coda can be compared shows some shift towards the vowel in onset but not in coda, yet the other subject shows a pattern similar to that observed for KL (i.e. a shift towards the vowel in both onset and coda positions), albeit smaller in magnitude. Data from more subjects will be needed in order to confirm the patterning of KL and PL clusters.

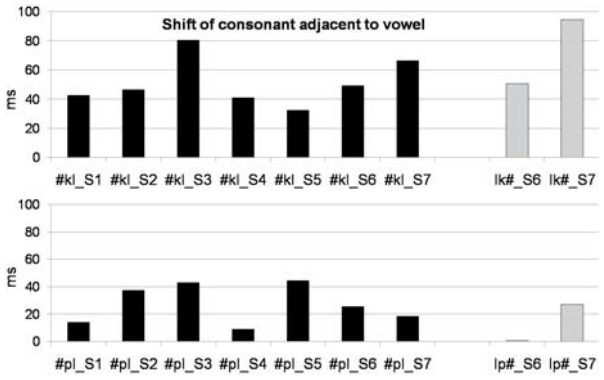

Figure 4: *Individual shifts in /l/-clusters.*

4. Discussion

Overall, for /s/-clusters, results from seven speakers show a significant difference in shift patterns in onsets and codas: the consonant adjacent to the vowel shifts towards the vowel significantly more in onsets than in codas. This pattern is the predicted one if a c-center organization is at play in onsets, while a sequential organization is at play in codas. These results thus confirm the competitive coupling structure hypothesized for complex onsets but not for complex codas. Competing demands on the onset consonantal gestures – by hypothesis coupled in phase with the vowel and sequentially with each other – result in a tight temporal organization; the observed c-center effect is the temporal organization that emerges from this competition. On the other hand, gestures in a complex coda have been hypothesized to be coupled serially to the vowel, and this is indeed the temporal pattern observed in [sC] codas, where the consonant closest to the vowel has a tendency to preserve its timing regardless of whether it is part of a complex coda or not.

For /l/-clusters, the results diverge from the hypothesized pattern. Subjects show an organization similar to that of a c-center in both complex onsets and complex codas for /l/-clusters (with shifts of greater magnitude in KL than PL clusters), indicated by a shift towards the vowel of the consonant in the cluster adjacent to the vowel.

Conceivably, the difference observed in /l/-clusters may be due to the nature of American English /l/ – involving both a tongue tip (consonantal) gesture and a tongue body retraction (vocalic) gesture [7]. The observed tongue tip shift towards the vowel in [lC] codas may then be due to /l/'s multiple coupling relations compared to obstruents, and/or to the perceptual consequences of /l/'s overlap with the vowel. Thus, the temporal shift

into the vowel may be a possible organization pattern for coda consonants when an increasing overlap of the vowel and the postvocalic gestures does not obscure the vowel itself perceptually, as is the case with /l/ but not with obstruent coda clusters. Under this assumption, the difference between /l/-clusters and other clusters does not stem from a different underlying phonological organization of /l/ and /s/-clusters, but rather from the gestural composition of /l/ and the multiple coupling relations it involves, as well as from additional recoverability demands. To shed further light on this issue, we plan to examine in further research the timing pattern of the tongue dorsum retraction during /l/ in complex onsets and especially codas, as well as the timing of the gesture further away from the vowel.

In addition to the differences observed between /l/-clusters and /s/-clusters (i.e. a different shift pattern between onsets and codas for /s/-clusters, but not for /l/-clusters), we also observed quantitative cluster-specific differences in shift magnitudes, in that there were larger shifts in onset [sp-] than onset [sm-], or larger shifts overall for KL than for PL. Such differences may be due to different coarticulation demands, or to differences in articulator tracking and measuring, an issue worth pursuing in future research.

Overall, our results are consistent with the hypothesis that gestures in complex onsets and codas exhibit distinct organization patterns: a c-center organization for onset clusters, and sequential organization for /s/-coda clusters. The c-center-like pattern we observe for /l/-clusters is conceivably due to the gestural composition of American English /l/.

5. Acknowledgements

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