Syllabification of the /st/ cluster and vowel-to-vowel coarticulation in English

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Motivation

- V-to-V coarticulation offers insight into the (in)dependence of units of production, including internal coherence of syllables of different structure
- Articulatory Phonology [1, 2] suggests different C & V coordination for onset vs coda; while carrier models [3] suggest no difference.
- Most studies only deal with CV syllables, except [4].
- We investigate V-to-V coarticulation in English syllable sequences involving the homorganic /st/ cluster:
  - ▸ **onset /#st/** ▸ **heterosyllabic /s#t/** ▸ **coda /st#/**
  (# = syllable boundary)
- Experiments show that syllable onset and coda differ:
  - **acoustically:** onset Cs are longer and cohere more with tautosyllabic vowels than do coda Cs [5, 6].
  - **articulatorily:** onset and coda Cs coordinate differently with vowels [1, 2]; onset gestures are stronger and more distinct than coda gestures [7].
  - **typologically:** onset consonants are more frequent in the world's languages [8].
  - **perceptually:** onsets are more distinct than codas in noise [9]; VC syllables are heard as CV under some conditions [10]; adaptation is position specific [11]

→ onset is stronger and more stable than coda

Hypothesis

Since coda is more variable than onset, we predict:
Degree of V-to-V coarticulation:

coda > onset (st# > #st)

s#t ? (no clear prediction for heterosyllabic cases)

Design

Vowel sequence	Onset CV # stVC	Heterosyllabic CVs # tVC	Coda CVst # VC
ɑ ɑ	Bar Starred	Pass Tart	Past Art
ɑ i	Bar Steed	Pass Teat	Past East
ɑ u	Bar Stoop	Pass Toot	Past Ouse
i ɑ	Bee Starred	Peace Tart	Beast Art
i i	Bee Steed	Peace Teat	Beast Eat
i u	Bee Stoop	Peace Toot	Beast Ouse
u ɑ	Boo Starred	Moose Tart	Boost Art
u i	Boo Steed	Moose Teat	Boost Eat
u u	Boo Stoop	Moose Toot	Boost Ouse

Table 1. Experimental materials with /st/ clusters

- Real monosyllabic words: homorganic /st/ cluster is the only sequence allowing a full set with vowels /ɑ i u/.
- 6 native speakers of SSBE (2 male, 4 female)
- Carrier phrase: "Not a x x , but a x x again" (to induce focus stress on non-target syllables)
  - Target = vowel being measured
  - Context = vowel flanking the target
  - Carryover context: syllable 1 stressed, syllable 2 = target
  - Anticipatory context: syllable 1 = target, syllable 2 stressed

Measurements

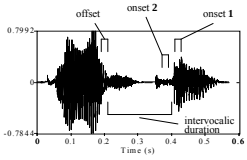

Figure 1. Examples of all measurement locations, shown using s#t sequence

- **intervocalic duration**: [s] + [t] closure + [t] burst + aspiration
- F1, F2 , F3 freq. at 3 locations (25 ms Hanning windows):
  - **offset**: centered 12.5 ms before periodicity offset
  - **onset 1**: centered 12.5 ms after periodicity onset
  - **onset 2**: 26 ms after the [t] burst, for heterosyllabic sequences only (this is a comparable place to onset 1 in terms of opening trajectory, when VOT is long)

Results

Intervocalic duration

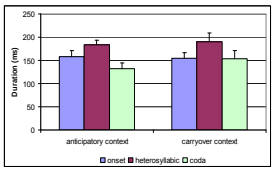

Figure 2. Intervocalic duration (ms) of the three syllable forms. anticipatory = syll. 2 stressed; carryover = syll. 1 stressed.

- longest intervocalic duration for heterosyllabic sequence in both contexts [F(2,10) = 13.04, p = 0.002]
- onset > coda in anticipatory context [t(5) = 13.66, p < 0.0001]
- onset ≈ coda in carryover context [t(5) = 0.21, p = 0.84]

Formant Frequencies†

Data Normalisation:
Context-dependent Fn
Grand mean for Fn of all target vowels

A. Analysis 1 (onset 1 and offset data)

Fig 3: Degree of V-to-V coarticulation:
▸ coda ≈ onset > heterosyllabic

F2: Syllable Form × Context [F(4,20) = 3.16, p = 0.036]

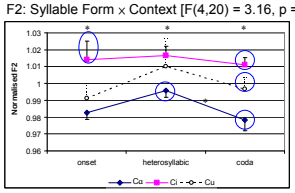

Figure 3. Normalised F2 for three vowel contexts in each syllable form.
** = p < 0.005*
biggest sig. range in F2:
onset: 0.031
hs: 0.021
coda: 0.033
sig. diff. from others in column

Fig 4: More F2 reduction after a stressed vowel (C vs A sets)
▸ except for heterosyllabic sequences

F2: Syllable Form × Direction × Target vowel [F(4,20) = 17.67, p<0.0005]

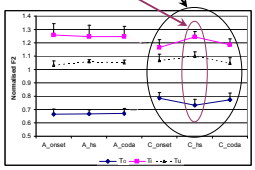

Figure 4. Normalised F2 of the three target vowels according to coarticulatory direction and syllable form.
A = anticipatory context
C = carryover context

B. Analysis 2 (onset 2 and offset data)

Possible temporal confound: [t] in heterosyllabic sequence is strongly aspirated—point corresponding to periodicity onset in tautosyllabic sequences is during aspiration

Fig 5: Similar patterns to Analysis 1 but weaker effects
Degree of V-to-V coarticulation:
▸ coda ≈ onset > heterosyllabic

F2: Syllable Form x Context [F(4,20) = 2.14, p = 0.114]

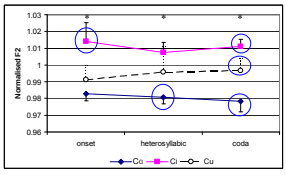

Figure 5. Normalised F2 for three vowel contexts in each syllable form.
** = p < 0.005*
biggest sig. range in F2:
onset: 0.031
hs: 0.027
coda: 0.033
sig. diff. from others in column

Fig 6: F2 of /ɑ/ is higher in the second syllable (carryover context), but no differences involving syllable structure

▸ More reduction after a stressed vowel

F2: Syllable Form × Direction × Target vowel [F(4,20) = 8.57, p<0.0005]

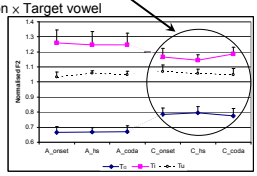

Figure 6. Normalised F2 of the three target vowels according to coarticulatory direction and syllable form.
A = anticipatory context
C = carryover context

† The data points of formant frequencies are connected for visual clarity only.

Discussion

- Contrary to expectation, only weak evidence to support the effects of syllable structure on V-to-V coarticulation:
  - ▸ coda ≈ onset > heterosyllabic

  Thus word/syllable boundaries in heterosyllabic s#t may reduce the degree of V-to-V coarticulation
- Onset and Coda conditions have similar F2 frequency, intervocalic duration and degree of V-to-V coarticulation in target vowels. Contrary to the literature. Why?
- Stressed syllables can 'attract' both onset and coda consonants [12]. Did stress placement increase similarity between onset and coda?

▸ onset 'V # stV → (ambisyllabic 'VstV) similar to coda 'Vst # V

▸ coda st # release → similar to onset V#stV

Thus, apparent syllable affiliation of onsets and codas may change in continuous speech.

- The tongue is strongly constrained in an /st/ cluster which may reduce its freedom to coarticulate [13].

Theoretical significance:

- Articulatory Phonology [1, 2] assumes gestures are timed and coordinated with respect to each other. Onset Cs are phased with the V as a unit (the C-centre effect) while only the start of a coda cluster is phased with the V. No clear prediction for V-to-V phasing across word boundaries is given, but an effect of syllable structure would be expected (coarticulation as gestural overlap).
- Öhman's [3] carrier model of coarticulation suggests that Vs form a continuous diphthongal movement with Cs being superimposed onto it → onset and coda should not affect V-to-V coarticulation differently.
- Results seem more compatible with carrier model of coarticulation, but further investigations are needed to verify this conclusion, since C V coordination patterns are presumably language-specific [14].

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Acknowledgements

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