24.964

Phonetic Realization

Articulatory Phonology

Readings for next time

- We will continue to talk about articulatory phonology, moving on to the broader issue of the phonetics and phonology of consonant releases.
- Review Gafos (2002), Steriade (1997), Jun (2002).
- I’ll also post Zsiga (2000) on overlap in consonant clusters in Russian and English and Chitoran et al (2002) on Georgian.

Duration compensation

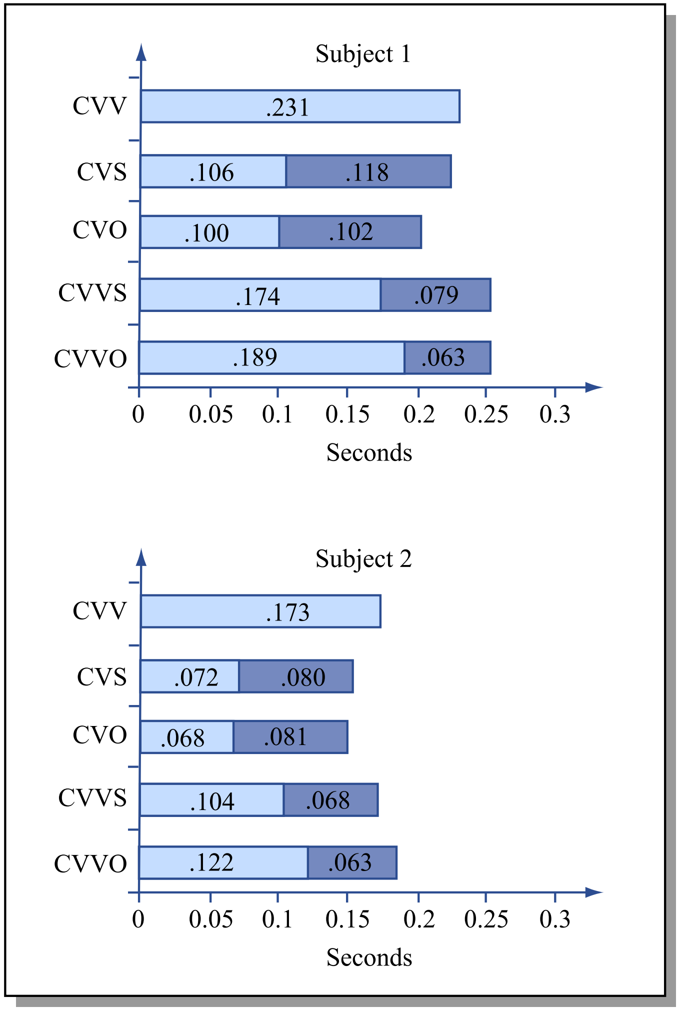
- The ‘weighted constraints’ approach to modeling phonetic realization is particularly well suited to situations in which realization is analyzed as a compromise between conflicting requirements.
  - e.g. F2 transitions as a compromise between realizing targets and minimzing movement.
- In principle allows for the influences of multiple factors on the final outcome.
- Patterns of duration show both properties - many factors affect segment duration, and resulting durations often seem to involve compromise between these demands.
- Role of conflict and compromise is particularly clear in duration compensation.

Duration compensation in Thai

- Data from Morén and Zsiga (2006). Similar patterns in Zhang(2004).

Compensation between V and coda:

- Codas are longer where V is short
- Long V is shorter in closed syllable.
- Net effect: all rhyme types are quite similar in duration in spite of large differences in V durations.



Cantonese (Gordon 1998)

- Again: nasal coda is longer after short V, closed syllable V shortening. Also pre-obstruent shortening. (cf. Zee 2002).

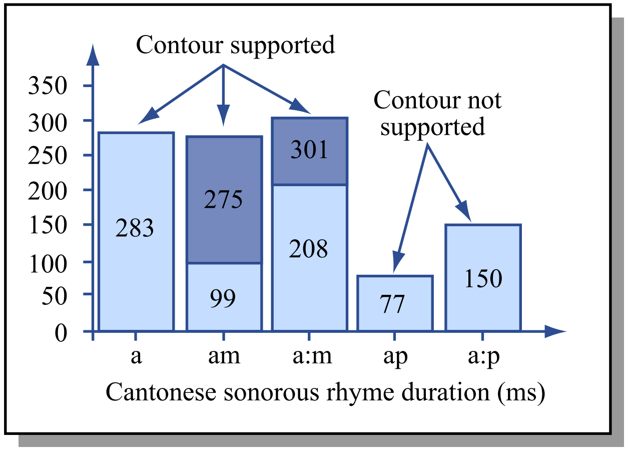


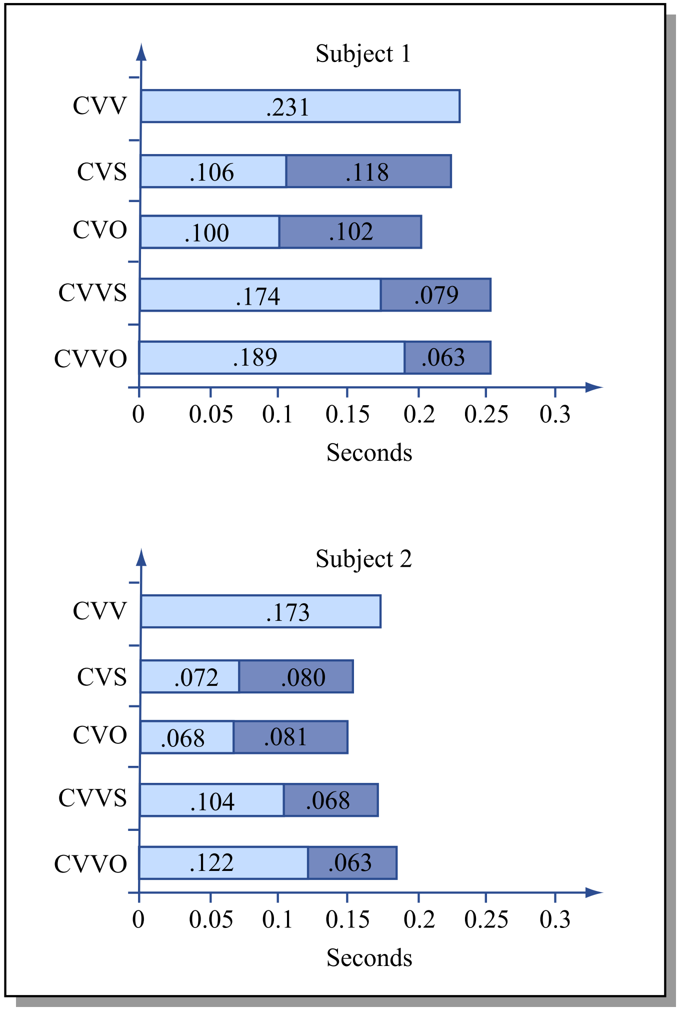
Image by MIT OpenCourseWare. Adapted from Zhang, Jie. "The Role of Contrast-Specific and Language-Specific Phonetics in Contour Tone Distribution." *Phonetically-Based Phonology*. Edited by Robert Kirchner, Bruce Hayes, and Donca Steriade. New York, NY: Cambridge University Press, 2004.

Duration compensation

- Longstanding idea: compensation between the duration of segments within the same constituent (syllable, foot, word).
- In the simplest case, the duration of the constituent is constant, so adding or lengthening a segment must be compensated by equal shortening of other segments.
- Total compensation is rare. More typical is the situation observed in Thai - partial compensation:
  - Coda C is longer after a short V, shorter after a long V, but V:C is still longer than VC.
  - Difference in coda durations does not equal difference between V and V:

Duration compensation

- Further compensatory relationships within the rhyme:
  - V: is shorter in closed syllables
  - V: is longer before shorter C (O vs. S) (significant?)
- Mutual compensation between V and coda C has been observed in English monosyllables (Munhall et al 1992).



Modeling duration compensation

- Duration compensation requires complex rules if duration is assigned to segments by context-dependent rules (e.g. Klatt 1979) due to interdependence of segment durations.
- Some researchers have proposed top-down models to account for duration compensation: duration is assigned to syllables then divided up between segments (e.g. Kohler 1986, Campbell 1992).
  - Partial compensation is problematic.
- In a constraint-based model it is possible to assign targets to individual segments and to larger constituents.
  - With weighted constraints, segment durations are a compromise between segment and constituent requirements.
  - Partial compensation.

Modeling duration compensation

- Simple example: Rhyme compensation
  - Targets for vowel, T_V, coda, T_C, Rhyme, T_R.
  - Actual durations: D_V, D_T, D_R.
  - Constraint: $D_i = T_i$ cost: $w_i(D_i - T_i)^2$
  - Total cost for VC rhyme:

    $w_V(D_V - T_V)^2 + w_C(D_C - T_C)^2 + w_R(D_R - T_R)^2$

- Conflict arises if $T_v + T_C \neq T_R$.
- Implementation using Excel solver.

- Additional constraints are required. E.g. pre-obstruent shortening in Cantonese.
- Compensation can be observed across syllable boundaries.

Additional applications: VOT

- Port and Rotunno (1979) found that in English VOT increases with duration of the following vowel,
  - but VOT is not a fixed proportion of the vowel.
- Could be targets for VOT, voiced vowel duration and total vowel duration.
  - but intercept is different for tense vowels.

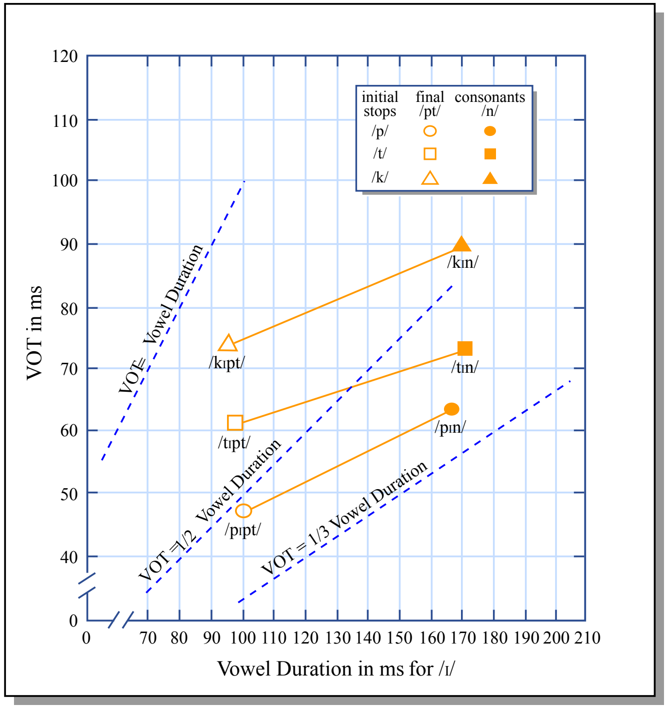


Image by MIT OpenCourseWare. Adapted from Port, Robert F., and Rosemarie Rotunno."Relation Between Voice-Onset Time and Vowel Duration." *The Journal of the Acoustical Society of America* 66, no. 3 (September 1979): 654-662.

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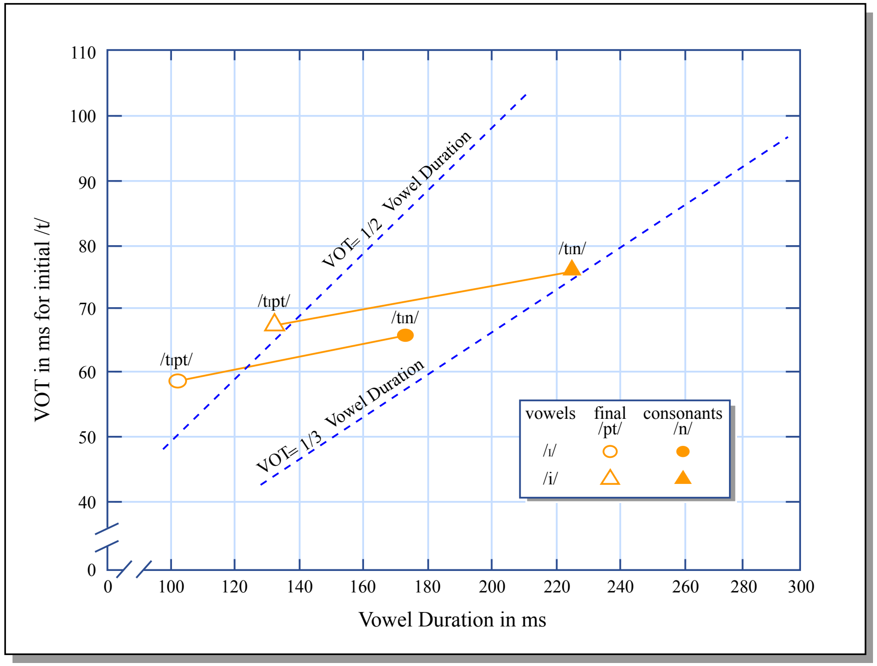

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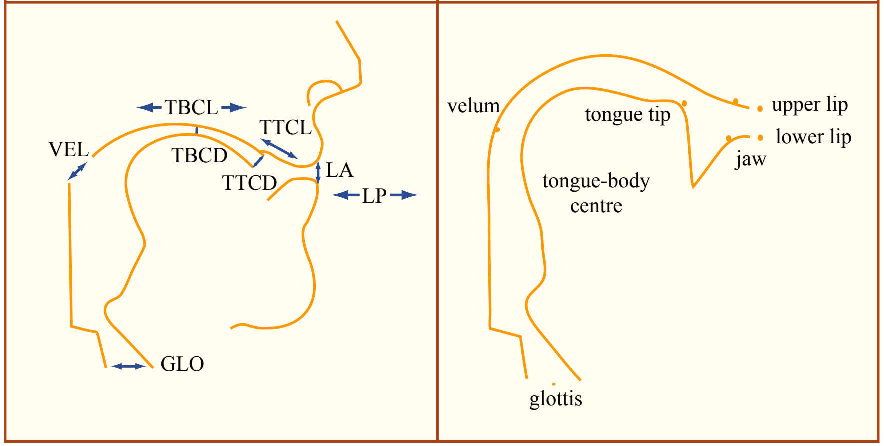
Articulatory Phonology

- Theory developed by Browman and Goldstein (1986, 1987, 1989 etc).
- Not a theory of phonology.
- The basic unit of articulatory control is the **gesture**.
- A gesture specifies the formation of a linguistically significant constriction.
- Defined within the framework of Task Dynamics (Saltzmann and Munhall 1989).

Articulatory Phonology

- A gesture specifies the formation of a linguistically significant constriction.
- The goals of gestures are defined in terms of <u>tract variables</u> (e.g. lip aperture).
- Movement towards a particular value of a tract variable is typically achieved by a set of articulators.
- A gesture takes a tract variable from its current value towards the target value.

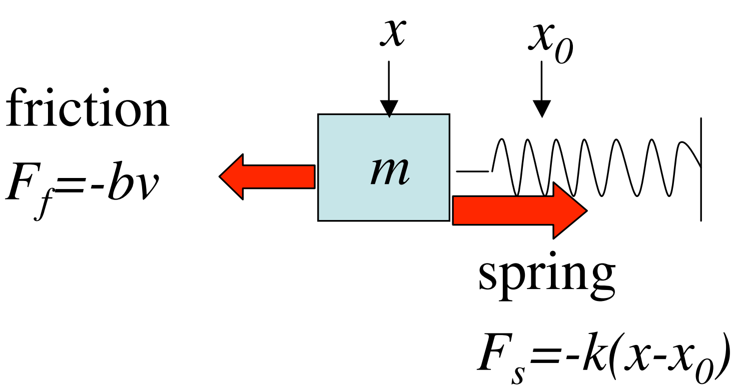
Tract variable		Articulators involved
LP	lip protrusion	upper and lower lips, jaw
LA	lip aperture	upper and lower lips, jaw
TTCL	tongue-tip constriction location	tongue-tip, tongue-body, jaw
TTCD	tongue-tip constriction degree	tongue-tip, tongue-body, jaw
TBCL	tongue-body constriction location	tongue-body, jaw
TBCD	tongue-body constriction degree	tongue-body, jaw
VEL	velic aperture	velum
GLO	glottal aperture	glottis



Articulatory Phonology

- Since a gesture involves the formation of a constriction it is usually specified by:
  - constriction degree
  - (constriction location)
  - (constriction shape)
  - stiffness
- In the Task Dynamic model, movement along a tract variable is modeled as a spring-mass system.
- In Browman and Goldstein's model critical damping is assumed, so articulators move towards the target position on the tract variable in a non-linear, assymptoting motion.

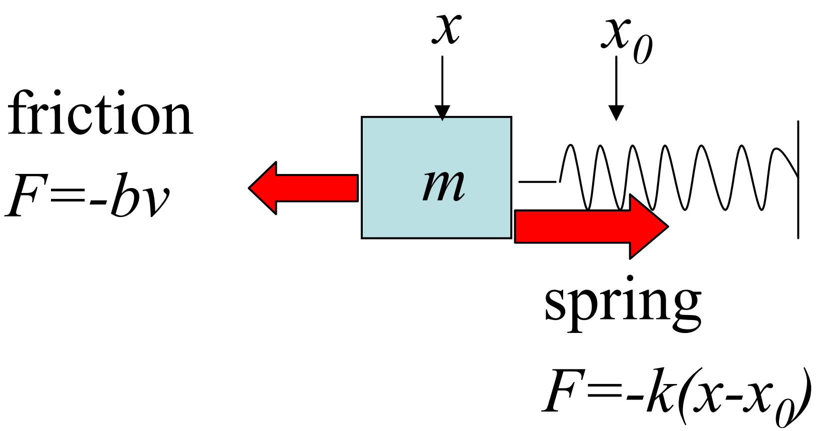
Damped mass-spring model



- Hooke's Law (linear spring): $F_s = -k(x - x_0)$
- Friction: $F_f = -bv = -b\dot{x}$
- Newton's 2nd Law: $F = ma = m\ddot{x}$
- Equate: $m\ddot{x} = -b\dot{x} - k(x - x_0)$

$$m\ddot{x} + b\dot{x} + k(x - x_0) = 0$$

Damped mass-spring model



- If there's no damping (b = 0), then the solution is sinusoidal oscillation.
- B&G assume critical damping (no oscillation):

$$x(t) = (A + Bt)e^{-\sqrt{\frac{k}{m}}t}$$

Damped mass-spring model

$$x(t) = (A + Bt)e^{-\sqrt{\frac{k}{m}}t}$$

- Gesture moves towards its target along an exponential trajectory, never quite reaching the target.
- If stiffness, *k*, is higher, tract variable changes faster.
- So a gesture specifies a movement from current tract variable values towards target values, following an exponential trajectory.
- Speech movements do show characteristics of being generated by a second order dynamical system (a damped ‘mass-spring’ system)

- In the movements of a damped mass-spring system, peak velocity is proportional to displacement (distance moved).
  - slope depends on stiffness *k*.
- This relationship has often been observed in arm movements and speech articulator movements.
- E.g. Ostry & Munhall (1985) studied tongue body movements during [ku, ko, ka, gu, go, ga] at two speech rates.

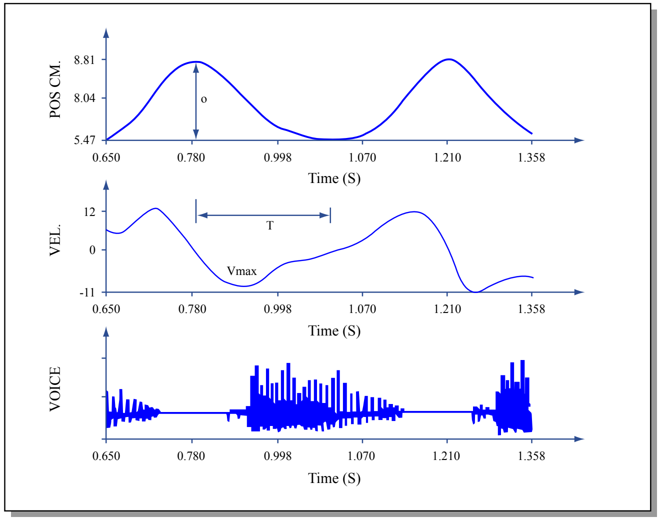
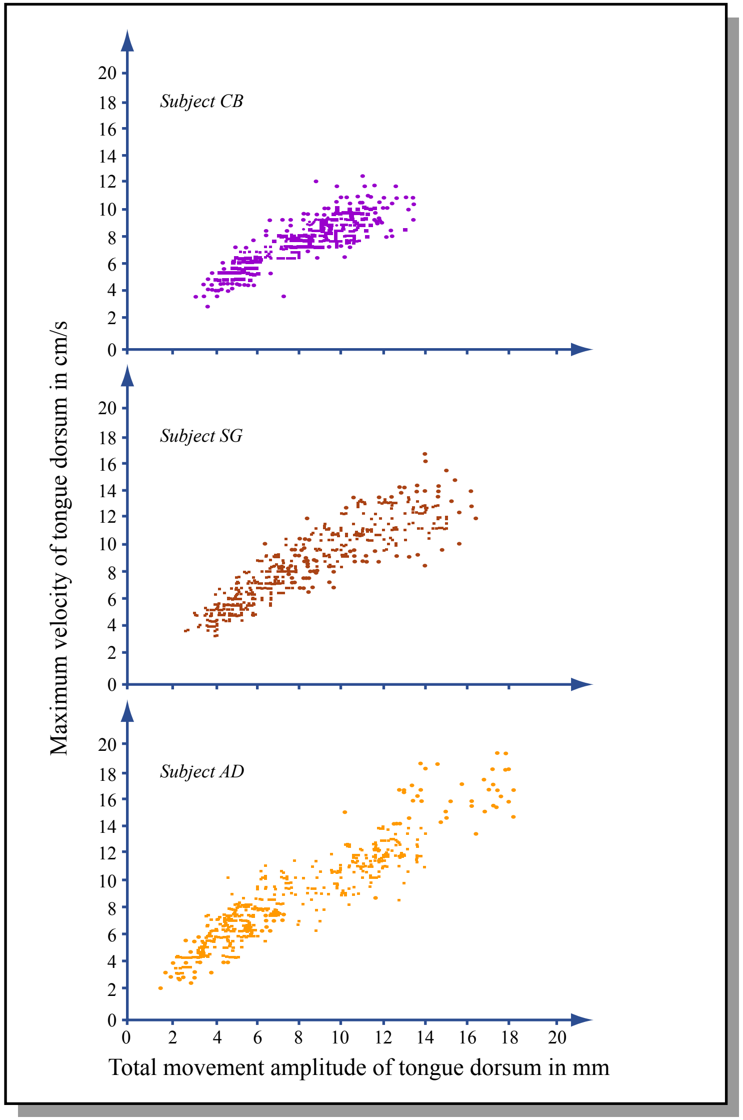


Image by MIT OpenCourseWare. Adapted from Ostry, D. J., and Munhall K. G. "Control of Rate and Duration of Speech Movements." *Journal of the Acoustical Society of America* 77 (1985): 640-8.



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Articulatory Phonology

- Gestures are coordinated together to produce utterances (represented in the 'gestural score' format).

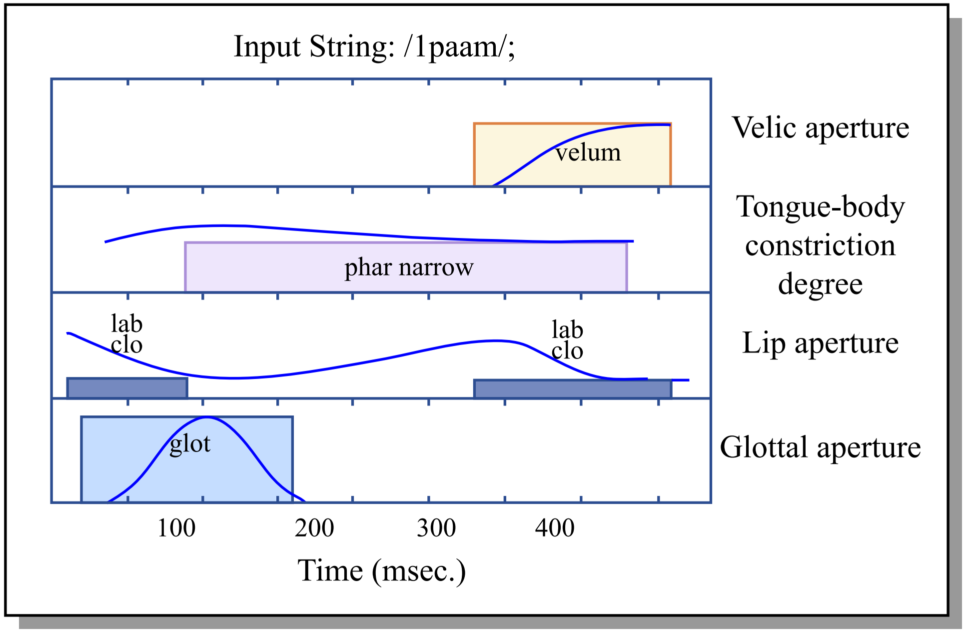


Image by MIT OpenCourseWare. Adpated from Browman, C. P., and Goldstein, L. "Articulatory Gestures as Phonological Units." *Journal of Phonetics* 18 (1990): 299-320.

Gestural overlap

- Overlap is the basic mechanism for modeling coarticulation - coarticulation as coproduction (Fowler 1980).
  - E.g. vowel gestures will typically overlap with consonant gestures.
- When two gestures involve the same tract variables (e.g. vowels and velars, two vowels), blending results (a compromise between the demands of the two simultaneously active gestures).
  - In CV blending, consonant constriction prevails.
  - Constriction location is averaged.
- Coarticulatory effects will also result from the fact that gestures specify movement from the current location to form a particular constriction, so the articulator movements resulting from a given gesture will depend on the initial state of the articulators.

Timing and coordination

- In Articulatory Phonology, coordination is specified in terms of the cycle of an abstract undamped spring-mass system with the same stiffness as the actual critically damped gesture.
- The onset of a gesture is 0°, the target is taken to be achieved at 240°, and the release at 290°.
- In Browman and Goldstein (1990, 1995), coordination is assumed to be achieved by rules specifying simultaneity of particular points in the cycles of two gestures.
  - e.g. in -C_1C_2- cluster 0° in C_2 is aligned to 240° in C_1.
- So timing is specified in terms of coordination of landmarks internal to gestures, not via specified durations and an external clock.

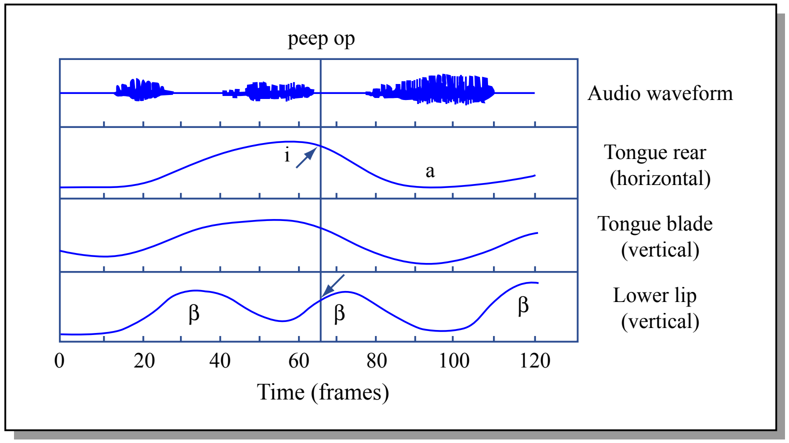
Phasing rules

- Provisional rules for coordinating gestures in English:

(1) A vocalic gesture and the leftmost consonantal gesture of an associated consonant sequence are phased with respect to each other. An *associated consonant sequence* is defined as a sequence of gestures on the C tier, all of which are associated with the same vocalic gesture, and all of which are contiguous when projected onto the one-dimensional oral tier.

(2a) A vocalic gesture and the leftmost consonantal gesture of a preceding associated sequence are phased so that the target of the consonantal gesture (240 degrees) coincides with a point after the target of the vowel (about 330 degrees). This is abbreviated as follows: C(240) = = V (330)

Excerpted from Browman, Catherine P., and Louis Goldstein. "Tiers in articulatory phonology, with some implications for casual speech." In *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*. Edited by John Beckman and Mary Kingston. New York, NY: Cambridge University Press, 1990. ISBN: 978-0521368087 .



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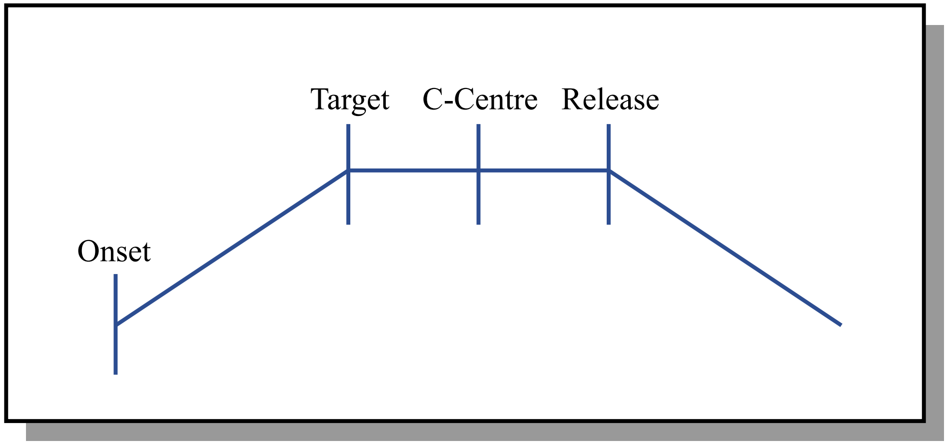
Gafos (2002)

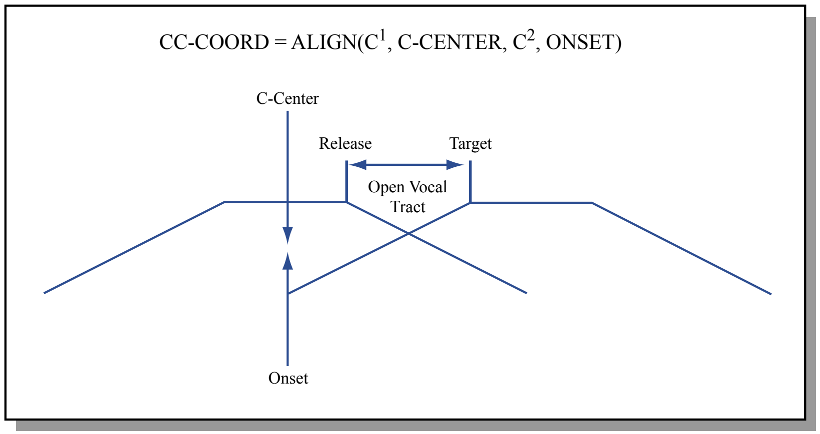
- Analyzes gestural coordination in terms of OT constraints.
- Assumes coordination operates in terms of a few landmarks in gestures: Onset, Target, C-Center, Release, Release offset.

ALIGN (G^1, landmark^1, G^2, landmark^2): Align landmark^1 of G^1 to landmark^2 of G^2
Landmark^i takes values from the set {ONSET, TARGET, C-CENTER, RELEASE}



Overlap and stop releases

- In consonant clusters, the presence or absence of stop releases can depend on the patterns of coordination between consonants.
  - Close vs. Open transition



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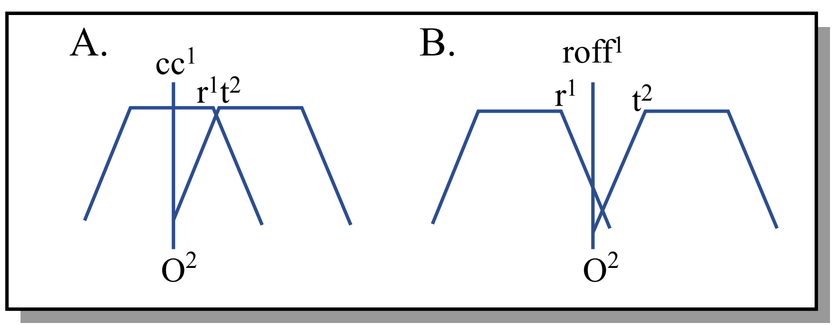

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