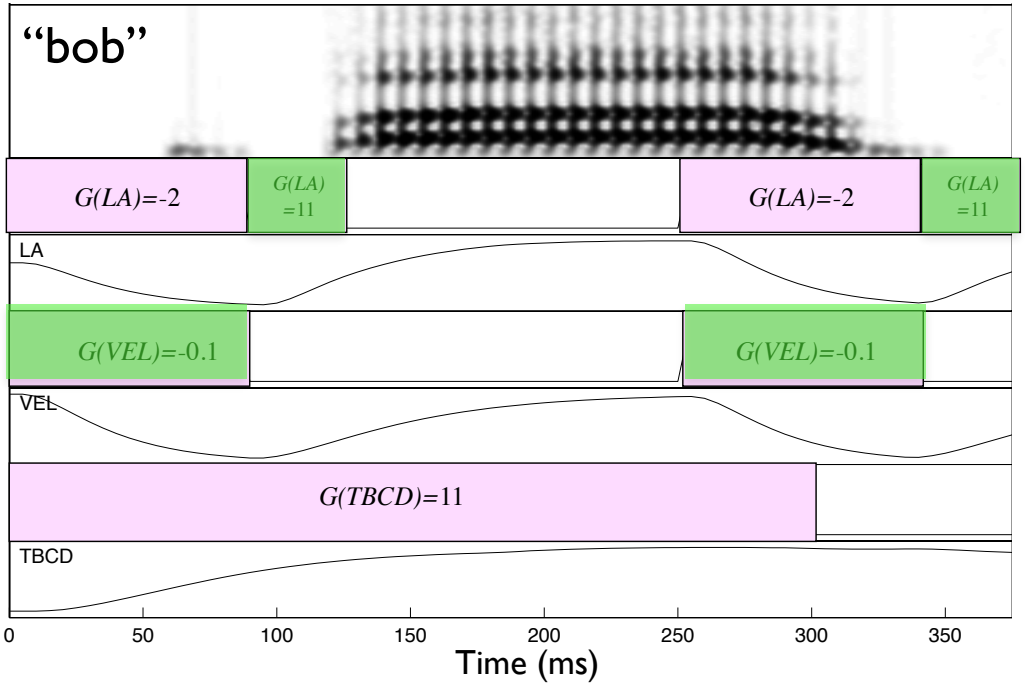
Gestural Scores and Allophonic Variation

Gestures for English Consonants

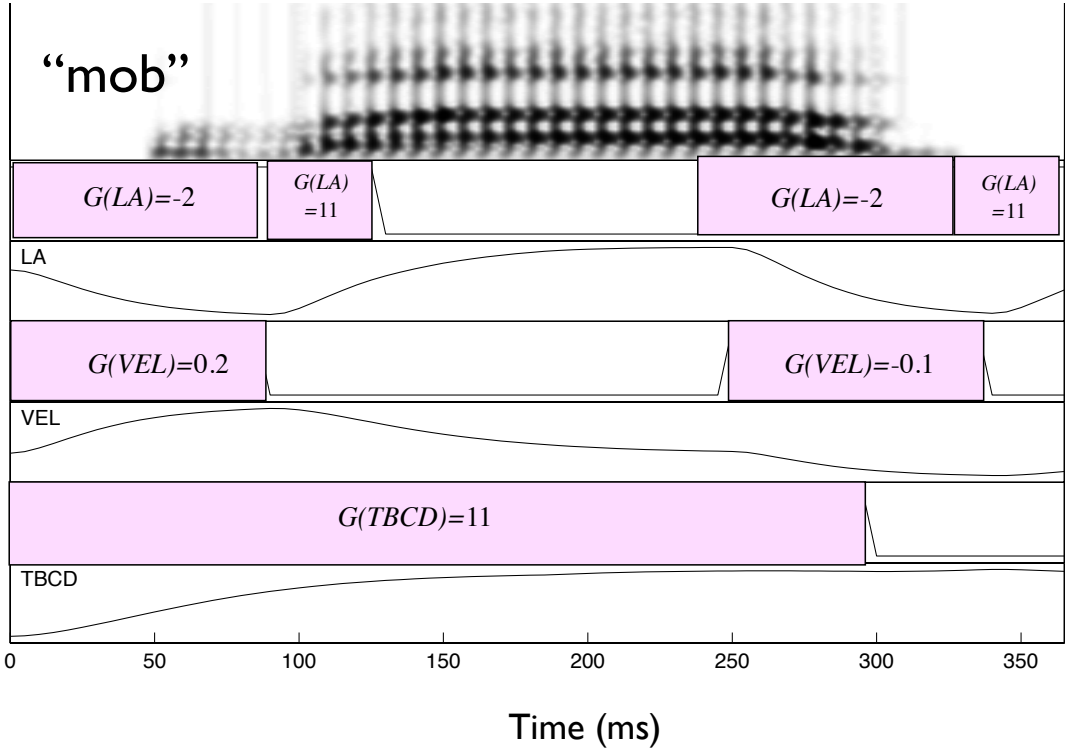
Gestural Score for “bob”




```
%/b/
'LA' 0 0 9 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 9 13 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0

%/aa/
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1

%/b/
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
```

“bob” to “mob”

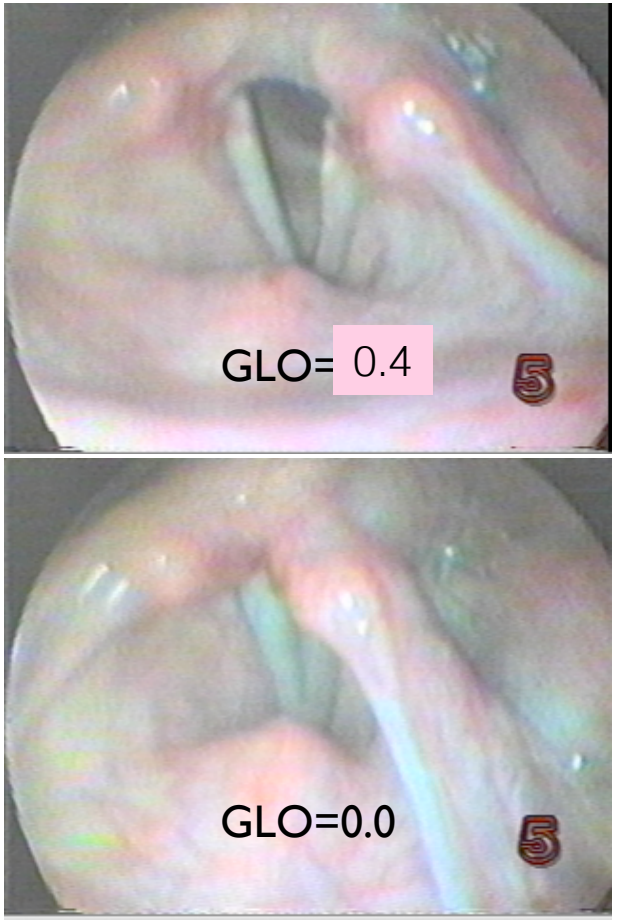
- Change initial VEL goal from -0.1 to 0.2



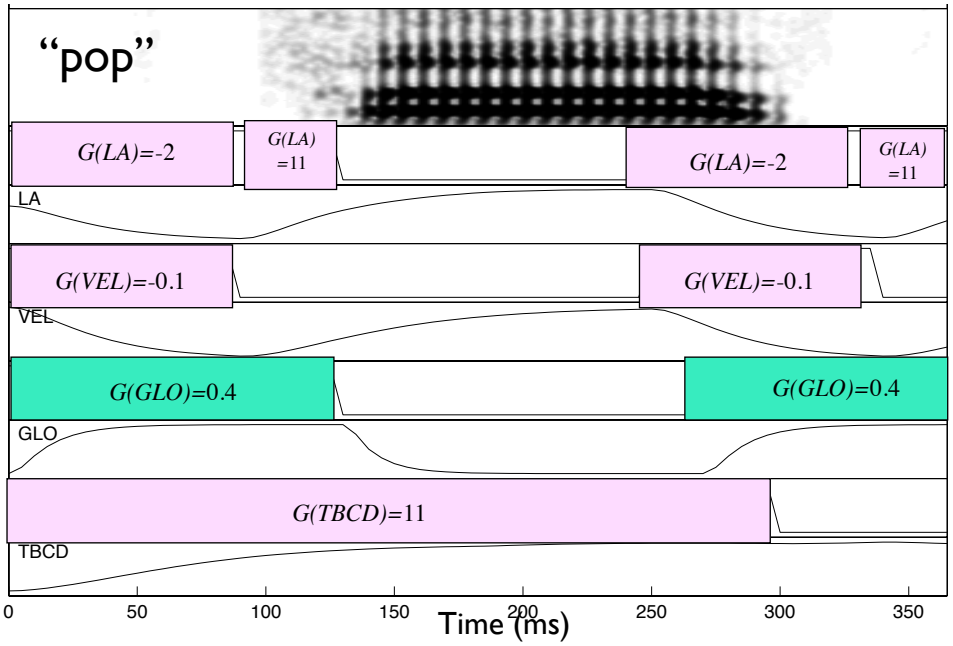

```
%/m/
'LA' 0 0 9 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 9 13 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 0 9 0 0.2 8 1 NA=1 0 0

%/aa/
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1

%/b/
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
```

Glottal ApertureTask for voiceless stops and fricatives

- How do we change "bob" to "pop"?
- Goal for GLO = 0.4 for voiceless stops and fricatives
- Default during speech: GLO=0.0 (will produce voicing)



“pop”



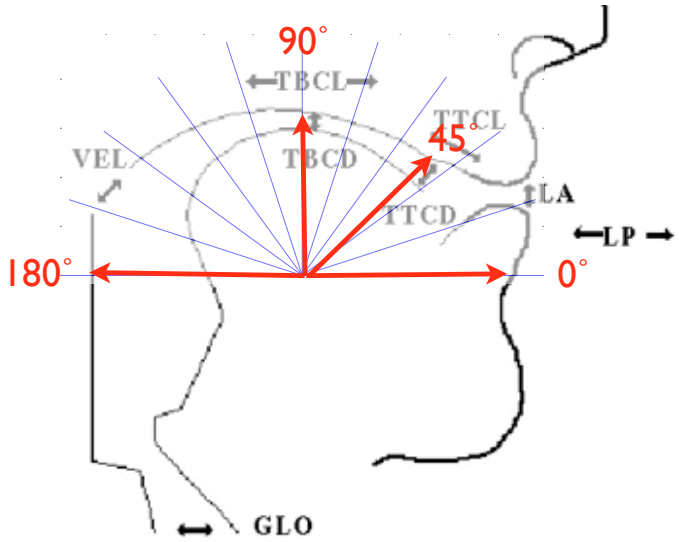

```
10 0 5

%/p/
'LA' 0 0 9 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 9 13 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0
'GLO' 0 0 18 0 0.4 16 1 GW=1 0 0

%/aa/
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1

%/p/
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
'GLO' 0 25 40 0 0.4 16 1 GW=1 0 0
```

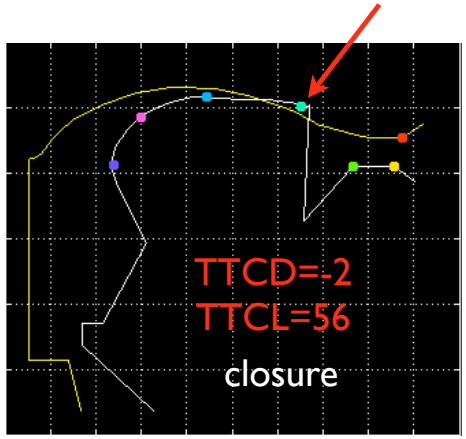
Compositionality

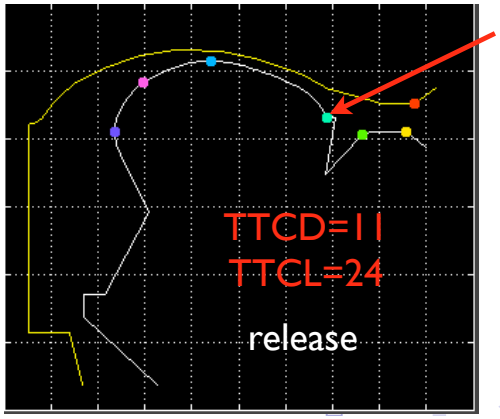
- Note that the gestures scores for related words are compositionally related.
- To create "pop" from "bob" involves adding two composition units (glottal opening gestures). Everything else stays the same (to a first approximation).
- This is the basis of phonology as a compositional system.
- The compositionally traditionally attributed to the phonological symbol sequence is true even at the of the temporal structure of the composing gestures.

Tongue Tip Tasks

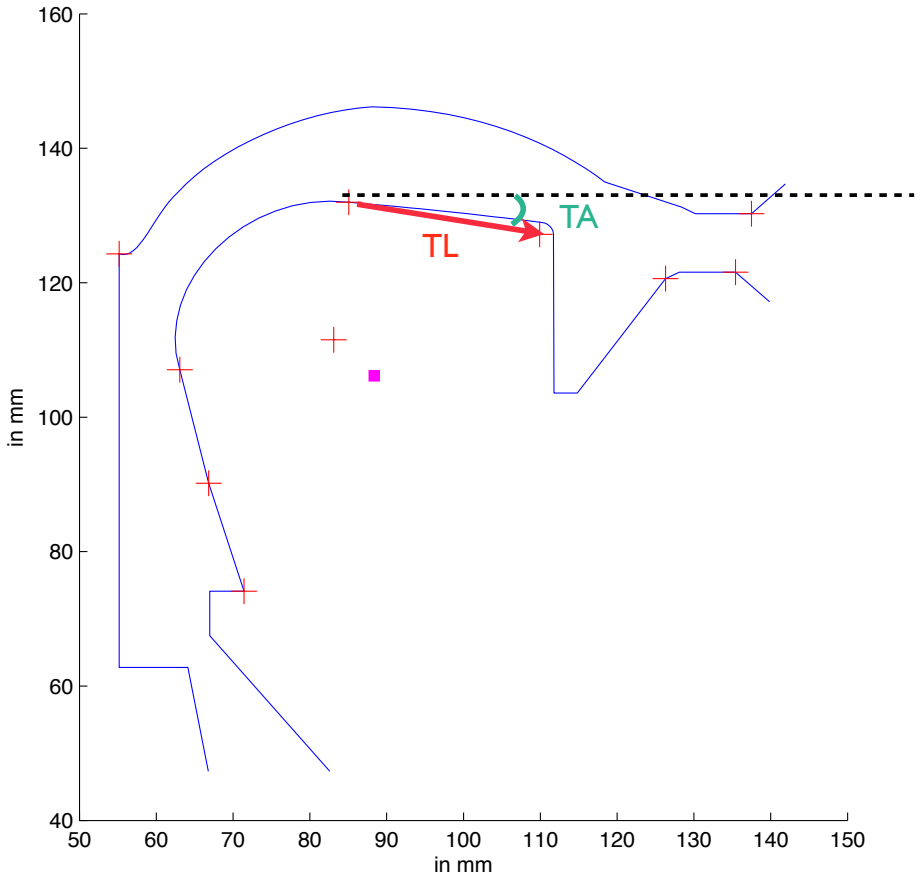
for /t,d,n/





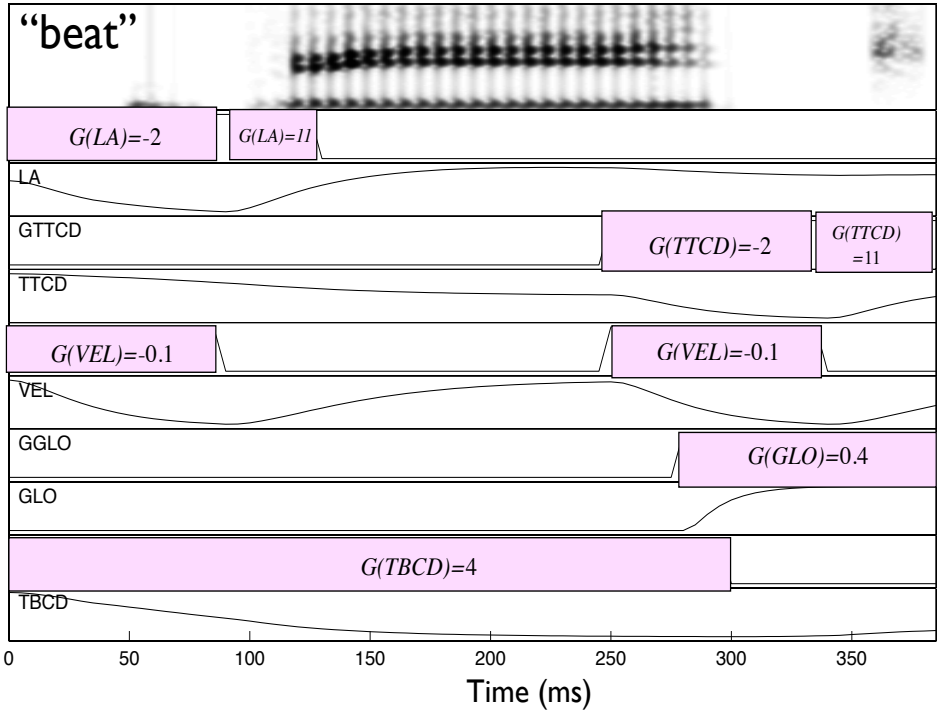


Articulators for TT Tasks



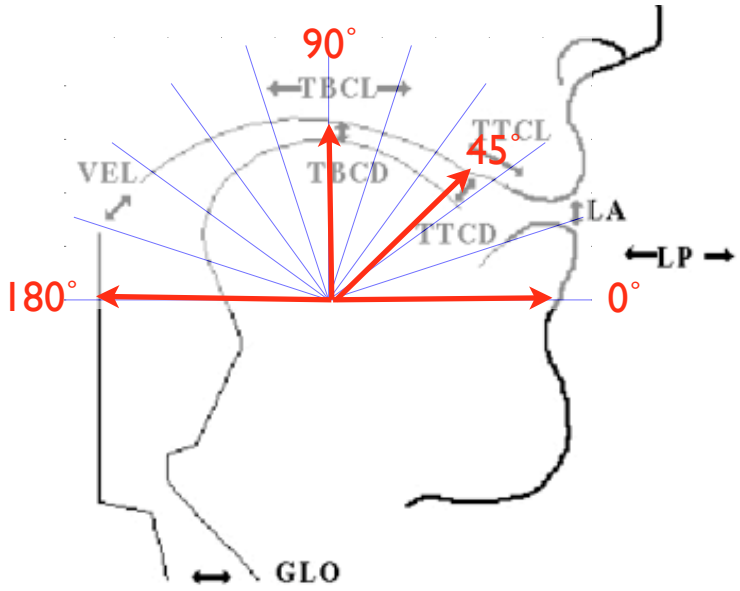
- And also Jaw Angle (JA), Tongue Center (CL, CA)

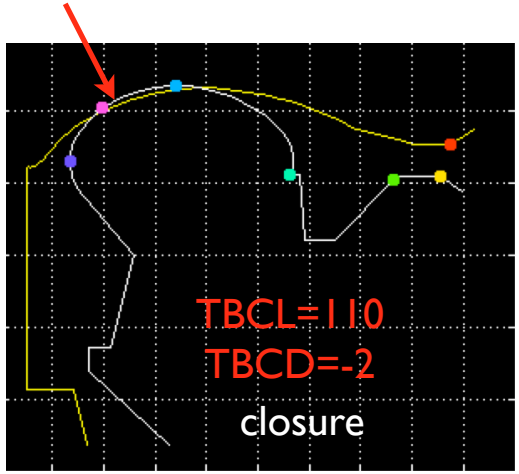
“beat”

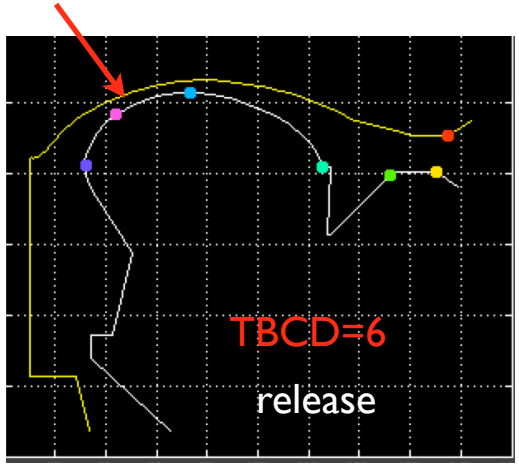



```
%/b/
'LA' 0 0 9 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 9 13 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0

%/iy/
'TBCD' 0 0 30 0 4 4 1 JA=1,CL=1,CA=1 1 1
'TBCL' 0 0 30 0 95 4 1 JA=1,CL=1,CA=1 1 1


%/t/
'TTCD' 0 25 34 0 -2 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 100 0.
'TTCL' 0 25 34 0 56 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCL' 0 34 39 0 24 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCD' 0 34 39 0 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
'GLO' 0 28 39 0 0.4 16 1 GW=1 0 0
```

Tasks for velar stops







“cop”

```
10 0 7

% k
'TBCD' 0 0 9 0 -2 8 1 JA=100,CL=1,CA=1 100 0.01
'TBCL' 0 0 9 0 110 8 1 JA=10,CL=1,CA=1 10 0.1
'TBCD' 0 9 13 0 6 8 1 JA=10,CL=1,CA=1 1 1
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0
'GLO' 0 3 14 0 0.4 16 1 GW=1 0 0

%AA
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1

%P
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
'GLO' 0 28 37 0 0.4 16 1 GW=1 0 0
```

Tasks for stop consonants

Lip (Labial)		T Tip (Alveolar)		T Body (Velar)	
CLO	REL	CLO	REL	CLO	REL
LA=-2	LA=11	TTCL=56 TTCD=-2	TTCL=24 TTCD=11	TBCL=110 TBCD=-2	TBCD=6
b VEL=-.1		d VEL=-.1		g VEL=-.1	
P VEL=-.1 GLO=.4		t VEL=-.1 GLO=.4		k VEL=-.1 GLO=.4	
m VEL=.2		n VEL=.2		nx VEL=.2	

Stops: Oral Constriction Gestures

```
% /b/

% clo
'LA' ... -2 8 1 JA=8,UH=5,LH=1 100 0.01

% rel
% 'LA' ... 9 13 0 11 8 1 JA=8,UH=5,LH=1 1 1

% /d/

% clo
'TTCL' ... 56 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' ... -2 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 100 0.01

% rel
'TTCL' ... 24 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCD' ... 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1

% /g/

% clo
'TBCL' ... 110 8 1 JA=10,CL=1,CA=1 10 0.1
'TBCD' ... -2 8 1 JA=100,CL=1,CA=1 100 0.01

%rel
'TBCD' ... 6 8 1 JA=10,CL=1,CA=1 1 1
```

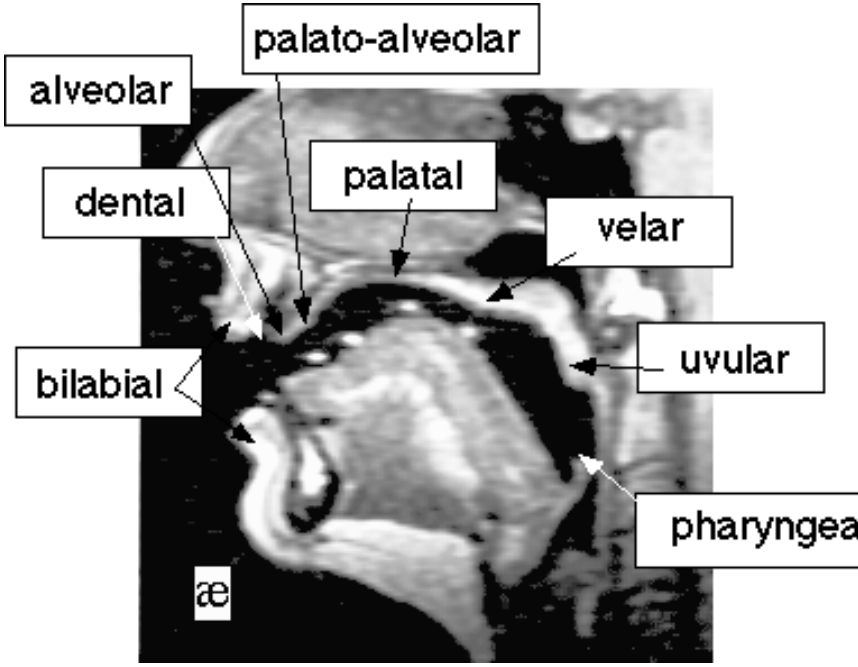
Glottal and Velic gestures for stops and fricatives

```
% Velic closure for stops and fricatives

'VEL' ... -0.1 8 1 NA=1 0

% Velic opening for nasals

'VEL' ... 0.2 8 1 NA=1 1 1

% Glottal opening for voiceless stops and fricatives

'GLO' ... 0.4 16 1 GW=1 0
```

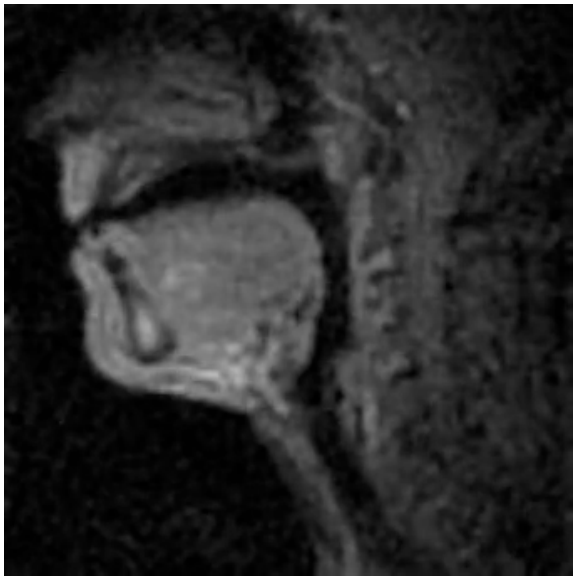
Differentiating oral constriction gestures

A given constrictor can produce several different distinctive gestures by varying:

- Constriction Degrees
  (how narrow is the constriction?)
  - stop ("dip, tip")
    complete obstruction of tube
    generates "pop" sound source
  - fricative ("zip, sip")
    narrowing to create jet noise source
  - approximant ("rip")
    narrowing with no source change
- Constriction Locations
  (exactly where is is it?)



Constriction Locations (TTCL) for fricatives



dental

/aθa/

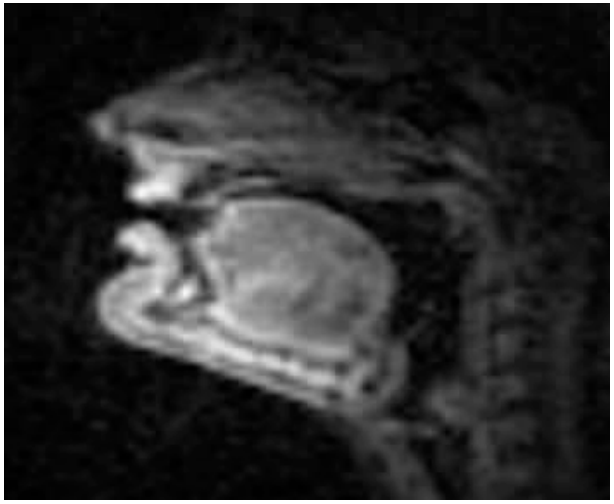
alveolar

/asa/

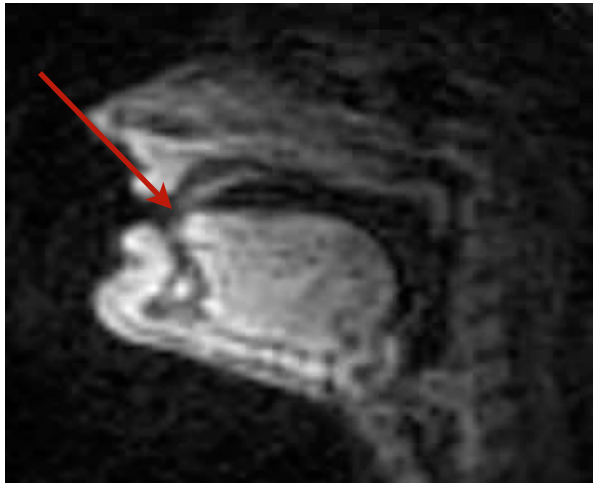
palatoalveolar

/aʃa/

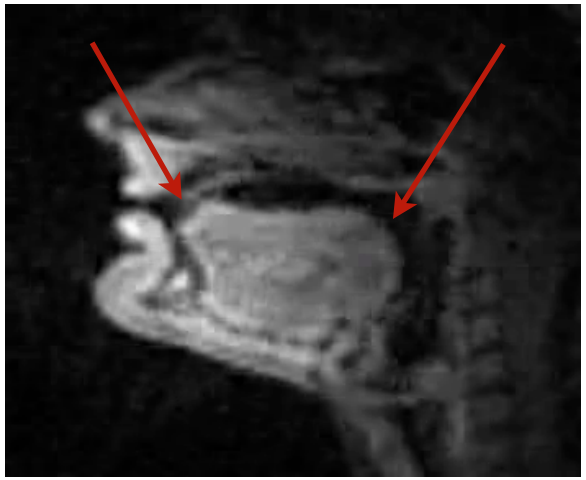
Fricatives: Oral Constriction Tasks



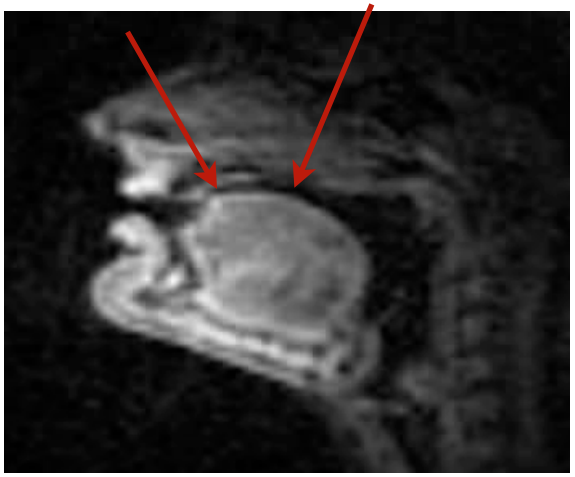
θ



z



ʃ

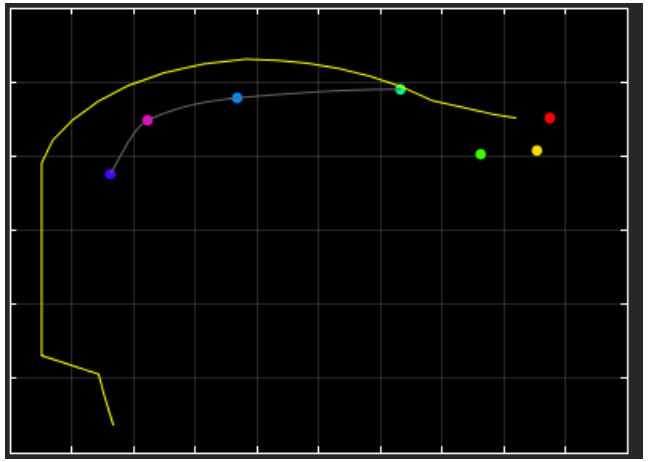


Fricatives: Oral Constriction Tasks

	θ		s		ʃ	
	clo	rel	clo	rel	clo	rel
TT	TTCL=40 TTCD=1.2	TTCL=24 TTCD=11	TTCL=56 TTCD=1.2	TTCL=24 TTCD=11	TTCL=60 TTCD=1.2	TTCL=40 TTCD=11
TB			TTCL=110 TBCD=10		TBCL=95 TBCD=8	

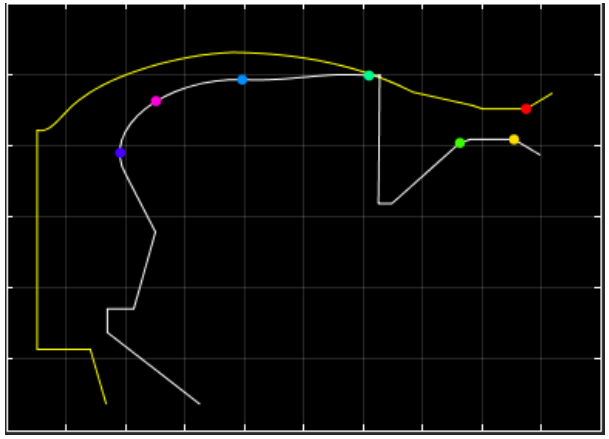
“sop”

```
10 0 5

% s
'TTCD' 0 0 9 0 1.2 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 10 0.1
'TTCL' 0 0 9 0 56 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 0 9 13 0 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCL' 0 9 13 0 24 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1


'TBCL' 0 0 9 0 110 8 1 JA=10,CL=1,CA=1 10 0.1
'TBCD' 0 0 9 0 10 8 1 JA=10,CL=1,CA=1 10 0.1

'GLO' 0 3 14 0 0.4 16 1 GW=1 0 0
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0


%AA
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1

%P
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
'GLO' 0 28 37 0 0.4 16 1 GW=1 0 0
```



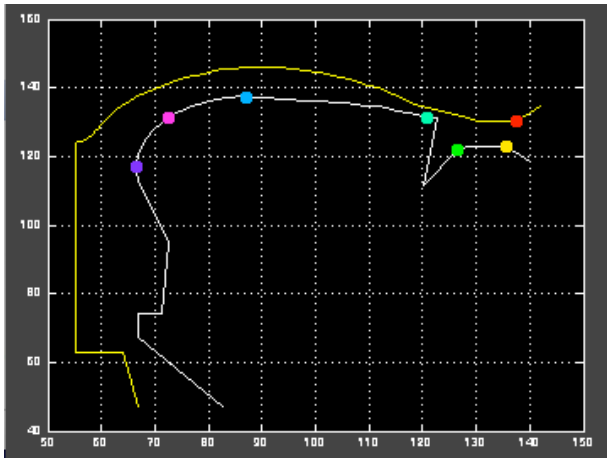
“shop”

```
10 0 5

% s
'TTCD' 0 0 9 0 1.2 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 10 0.1
'TTCL' 0 0 9 0 60 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 0 9 13 0 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCL' 0 9 13 0 50 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1


'TBCL' 0 0 9 0 95 8 1 JA=10,CL=1,CA=1 10 0.1
'TBCD' 0 0 9 0 8 8 1 JA=10,CL=1,CA=1 10 0.1

'GLO' 0 3 14 0 0.4 16 1 GW=1 0 0
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0


%AA
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1

%P
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
'GLO' 0 28 37 0 0.4 16 1 GW=1 0 0
```

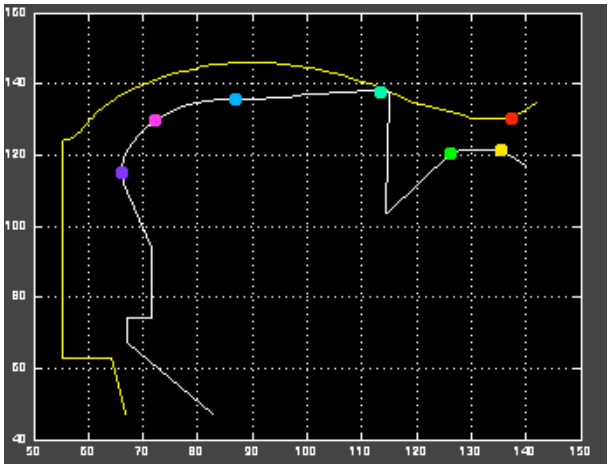


Fricatives: examples

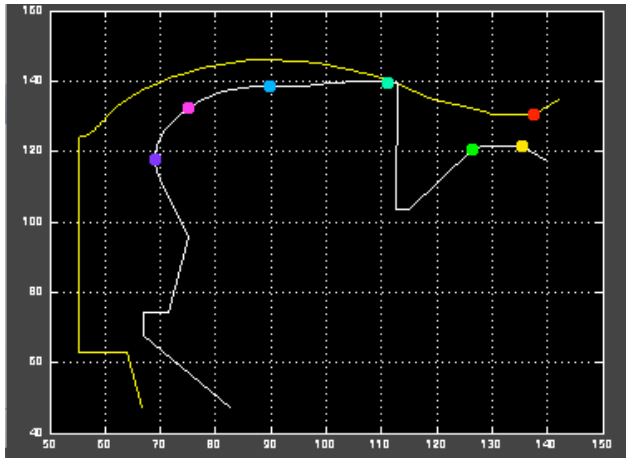
θ



s



ʃ



Fricatives: Oral Constriction Gestures

```
% /th/

% clo
'TTCL' ... 40 10 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' ... 1.2 10 1 JA=32,CL=32,CA=32,TL=1,TA=1 10 0.1

% rel
'TTCL' ... 24 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCD' ... 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1

% /s/

% clo
'TTCL' ... 56 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' ... 1.2 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 10 0.1

'TBCL' ... 110 8 1 JA=10,CL=1,CA=1 10 0.1
'TBCD' ... 10 8 1 JA=10,CL=1,CA=1 10 0.1

% rel
'TTCL' ... 24 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCD' ... 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1

% /sh/

%clo
'TTCL' ... 60 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' ... 1.2 10 1 JA=640,CL=32,CA=32,TL=1,TA=1 10 0.1

'TBCL' ... 95 8 1 JA=10,CL=1,CA=1 100 0.01
'TBCD' ... 8 8 1 JA=10,CL=1,CA=1 100 0.01

%rel
'TTCL' ... 40 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCD' ... 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
```

Liquids: Multiple oral constrictions

"lie"

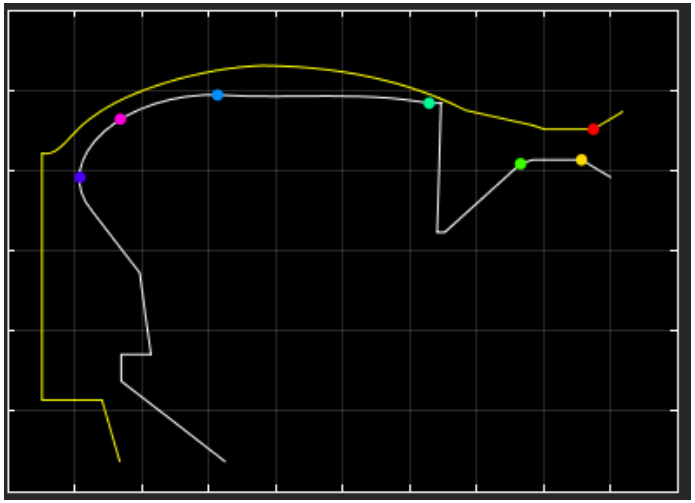
- Tongue Tip
  CD: approximant (2mm)
  CL: alveolar (56 degrees)
- Tongue Body
  CD: approximant, (4mm)
  CL: uvular (125 degrees)

"rye"

- Lips
  CD: approximant
- Tongue Tip/Body
  CD: approximant, CL:palatal
- Tongue Root

“lop”

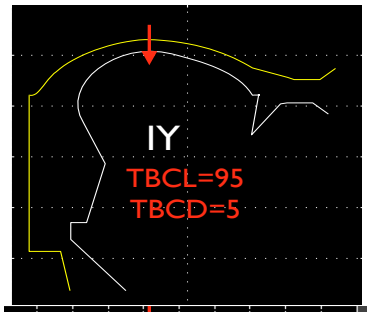
```
10 0 5

% 1
'TTCD' 0 0 9 0 2 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCL' 0 0 9 0 56 8 1 JA=32,CL=32,CA=32,TL=1,TA=1 1 1
'TTCD' 0 9 13 0 11 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1
'TTCL' 0 9 13 0 24 8 1 JA=512,CL=512,CA=512,TL=1,TA=1 1 1

'TBCD' 0 0 9 0 4 8 1 JA=10,CL=1,CA=1 100 0.01
'TBCL' 0 0 9 0 125 8 1 JA=10,CL=1,CA=1 10 0.1

%AA
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1

%P
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
'GLO' 0 28 37 0 0.4 16 1 GW=1 0 0
```

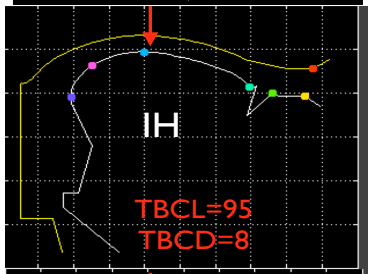


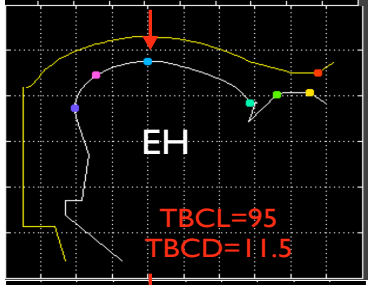
Contrastive Consonant Segments & Gestures

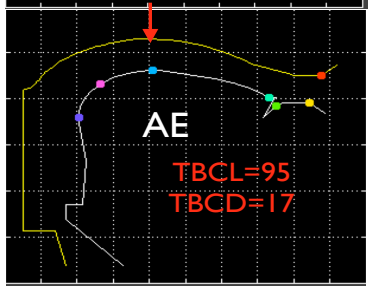
	lips	tip	body	velum	glottis
b	bilabial stop				
p	bilabial stop				opening
m	bilabial stop			opening	
t		alveolar stop			
d		alveolar stop		opening	
n		alveolar stop			opening
k			velar stop		
g			velar stop	opening	
ŋ			velar stop		opening
s		alveolar fric	(velar approx)		opening
z		alveolar fric	(velar approx)		
l		alveolar stop	(uvular approx)		
h					opening

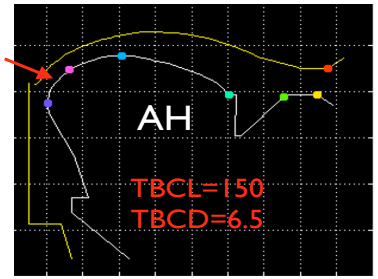
Vowel Tasks

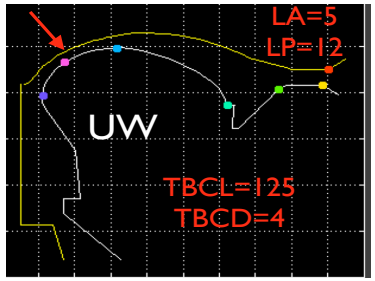

IY
TBCL=95
TBCD=5

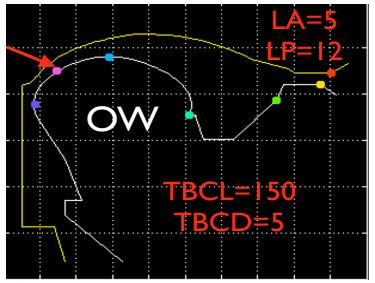

IH
TBCL=95
TBCD=8

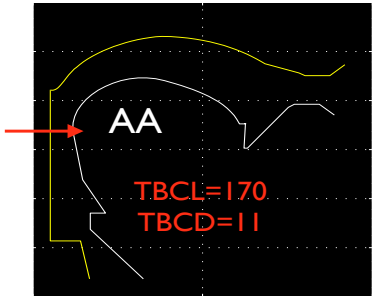

EH
TBCL=95
TBCD=11.5


AE
TBCL=95
TBCD=17


AH
TBCL=150
TBCD=6.5


LA=5
LP=12
UW
TBCL=125
TBCD=4


LA=5
LP=12
OW
TBCL=150
TBCD=5

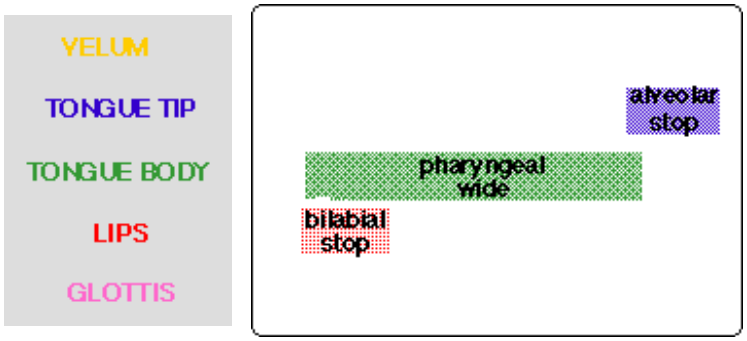

AA
TBCL=170
TBCD=11

Glides: Oral Constriction Gestures

```
% /w/

%clo
'LA' ... 1 8 1 JA=8,UH=5,LH=1 1 1

'TBCL' ... 125 8 1 JA=10,CL=1,CA=1 10 0.1
'TBCD' ...   2 8 1 JA=10,CL=1,CA=1 100 0.01

%rel
'LA' ... 11 8 1 JA=8,UH=5,LH=1 1 1

% /j/

'TBCL' ... 95 8 1 JA=10,CL=1,CA=1 100 0.01
'TBCD' ...  2 8 1 JA=10,CL=1,CA=1 100 0.01
```

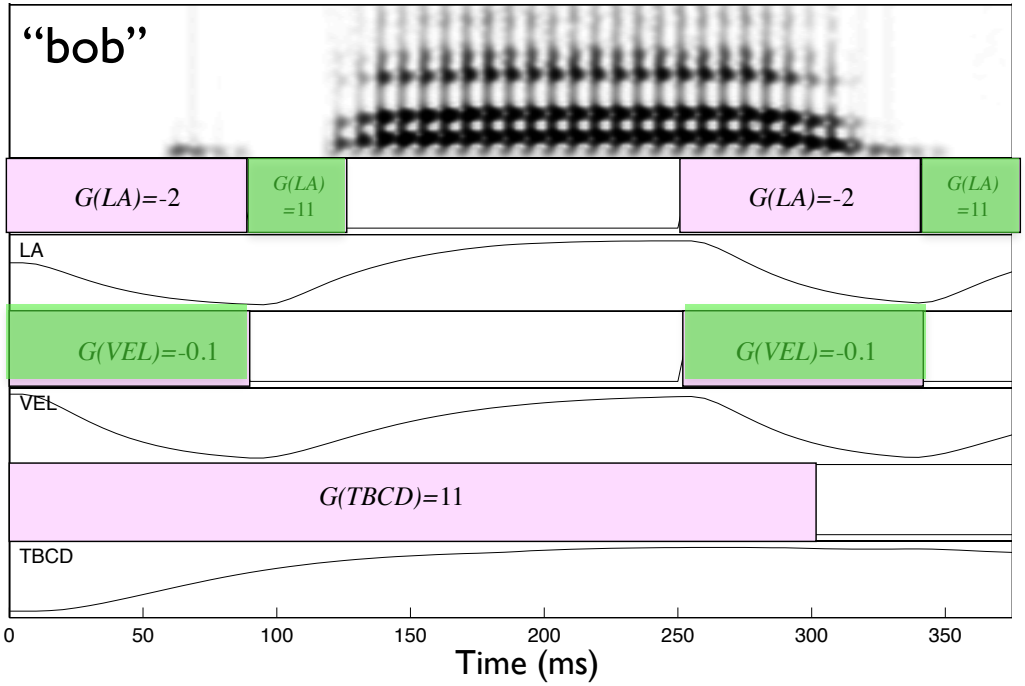
Gestural Scores

- Representation of the temporal organization of gestures
  - Time along horizontal dimension
  - Boxes represent intervals of time during which gestures are active in the vocal tract.
  - Gestures of oral constrictors, velum, glottis are displayed on different rows, e.g., "bad":



  - Labels on the boxes indicate the constriction degree (and location) of the gesture.
  - Default Simplifications (gestures left out of displays):
    Glottal narrowing for voicing
    Velic closure for oral stops
    Release gestures

Gestural Score for “bob”

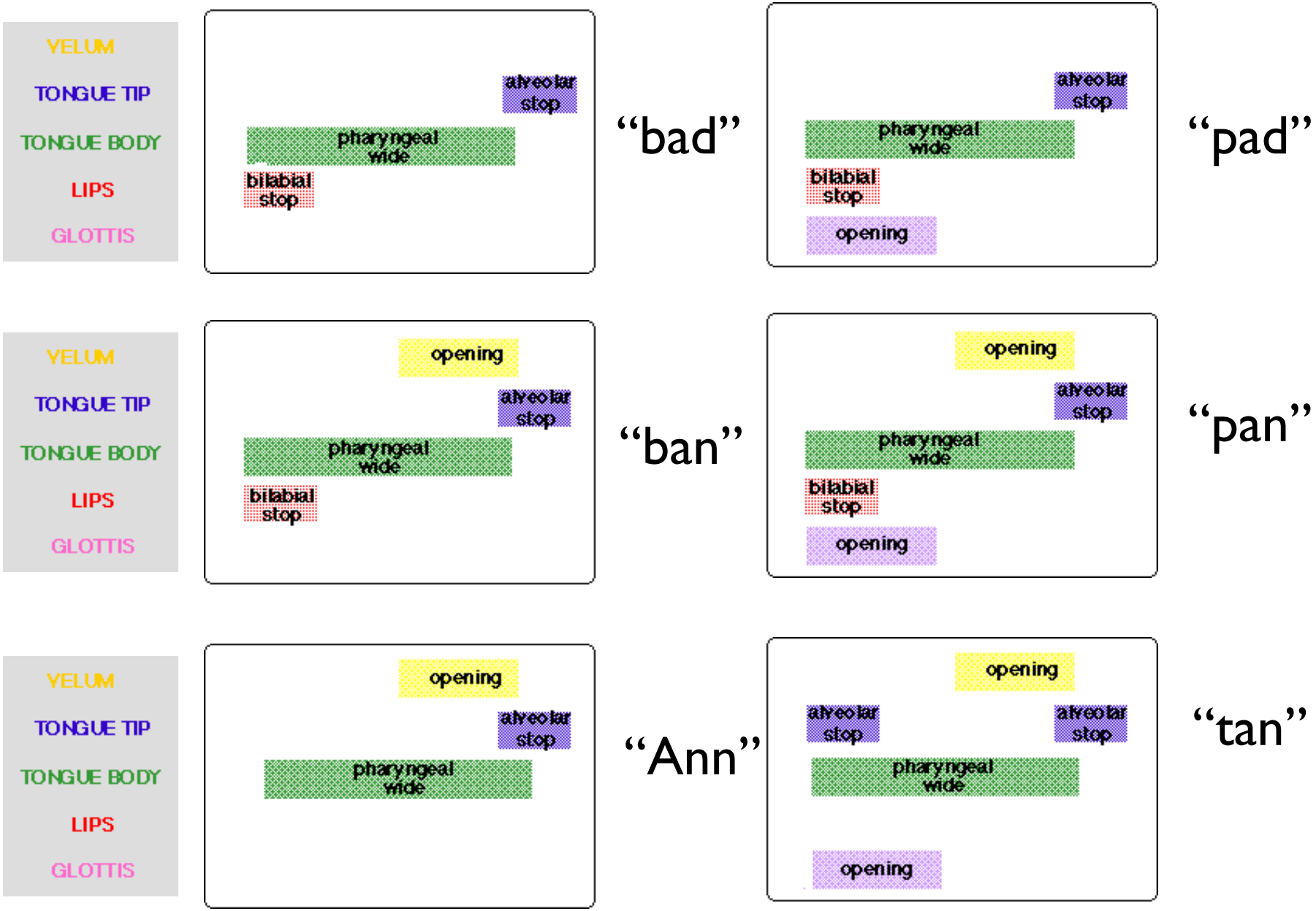



```
%/b/
'LA' 0 0 9 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 9 13 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 0 9 0 -0.1 8 1 NA=1 0 0

%/aa/
'TBCD' 0 0 30 0 11 4 1 JA=1,CL=1,CA=1 1 1
'TBCL' 0 0 30 0 170 4 1 JA=1,CL=1,CA=1 1 1

%/b/
'LA' 0 25 34 0 -2 8 1 JA=8,UH=5,LH=1 100 0.01
'LA' 0 34 37 0 11 8 1 JA=8,UH=5,LH=1 1 1
'VEL' 0 25 34 0 -0.1 8 1 NA=1 0 0
```

Gestural Scores & contrast

- Because of the compositionality of gestural scores, contrast can be read off the score.
- Contrast can be found in:
  - presence or absence of particular gestures
  - gestures' values of CD and CL
    - Can be abbreviated with “names” but are quantitative values (of target and stiffness of appropriate task variables)
  - organization of gestures in time

Presence or absence of gestures: compositionality



Contrast in gesture parameters: CL and CD

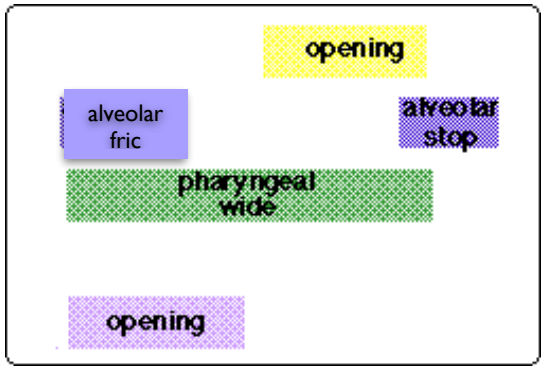
YELUM

TONGUE TIP

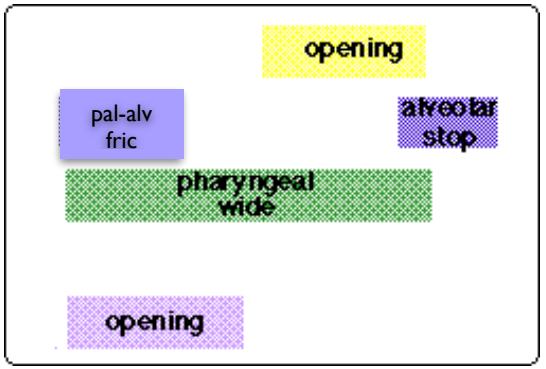
TONGUE BODY

LIPS

GLOTTIS

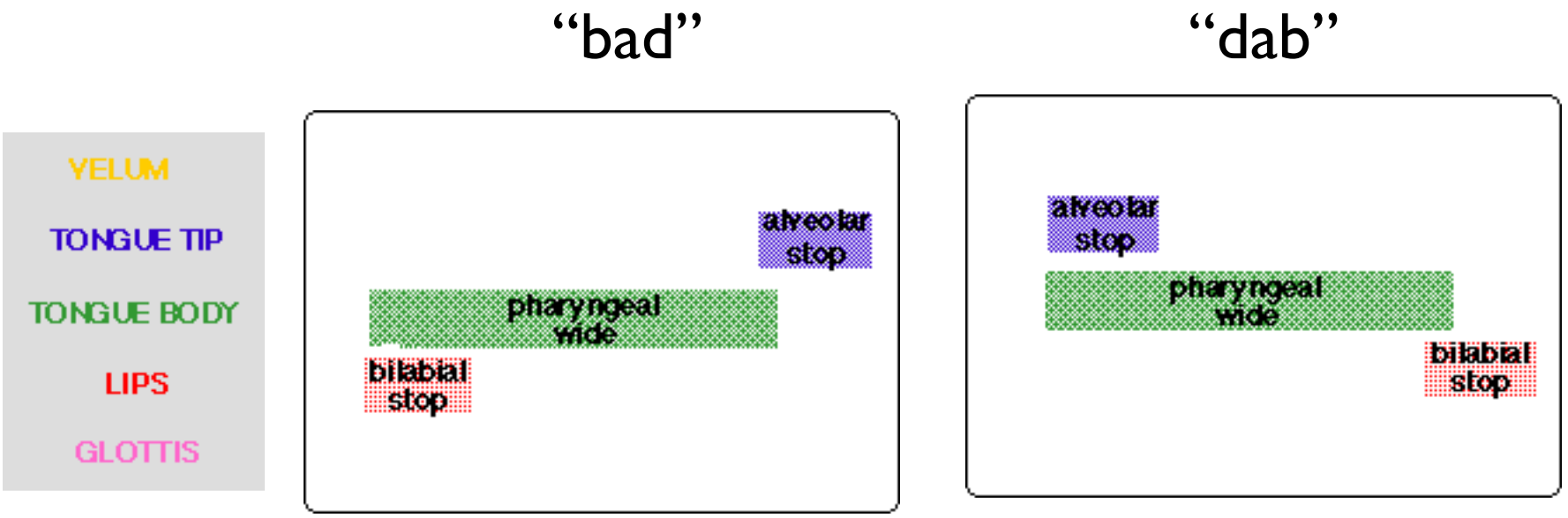


"sad"



"shad"

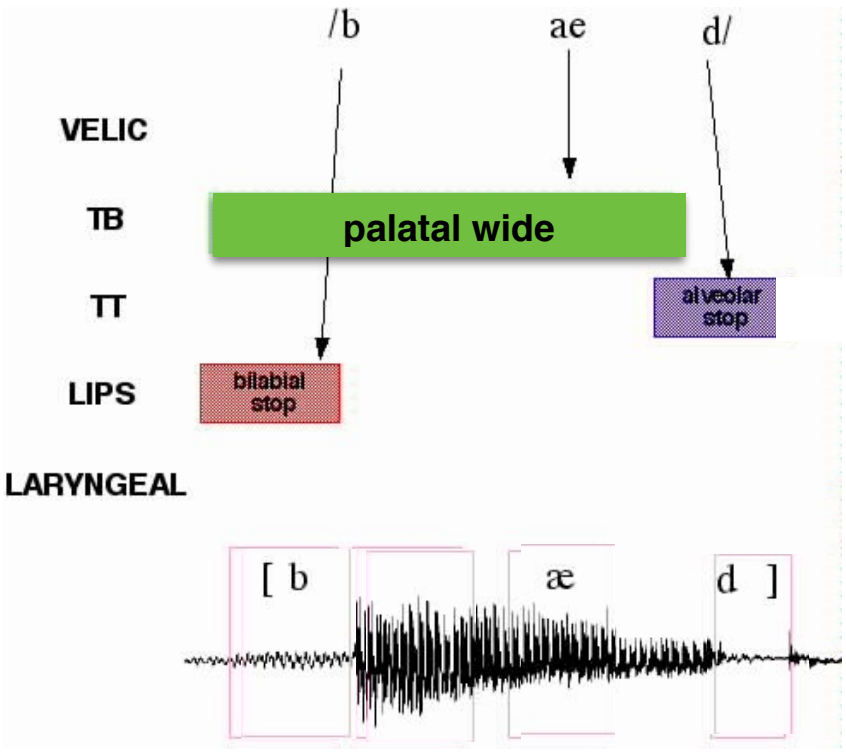
Contrast: organization in time

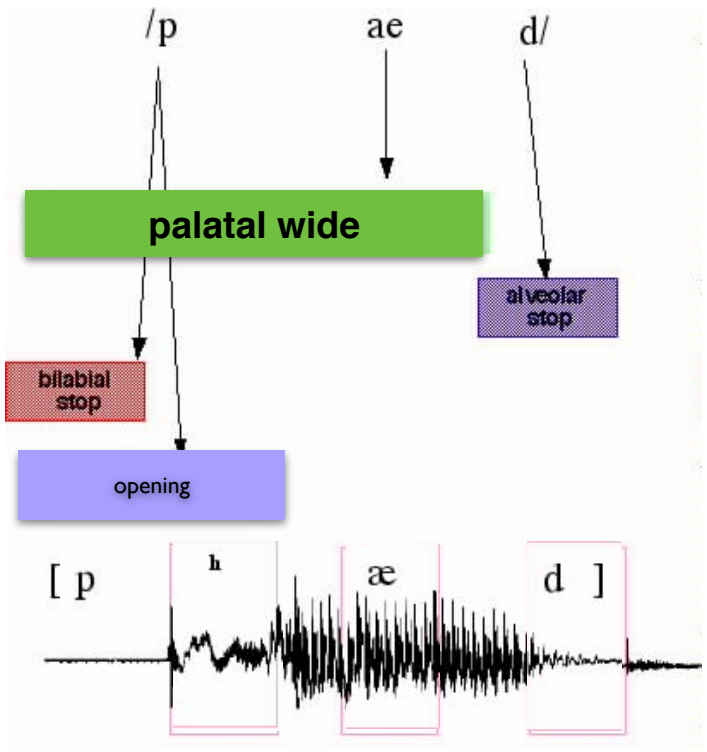


Allophony & Gestural Scores

- The same phonological segment can be realized differently in different contexts. These realizations are traditionally called allophones and represented in a "narrow phonetic transcription."
  - For example in English voiceless stops are realized as:
    - aspirated stops when they are single stops in word initial position:
      /pæd/ —> [p^hæd];
    - unaspirated stops following word initial /s/: /spæt/ —> [spæt]
- When analyzed in terms of gestural composition, the allophonic variants usually exhibit the same same set of gestures but differences in sound result due to different overlapping gestures in the different contexts.
- Since the temporal organization is also represented in the gestural score, the gesture score captures both contrastive units and allophonic variants in a single representation.

Aspiration of initial voiceless stops



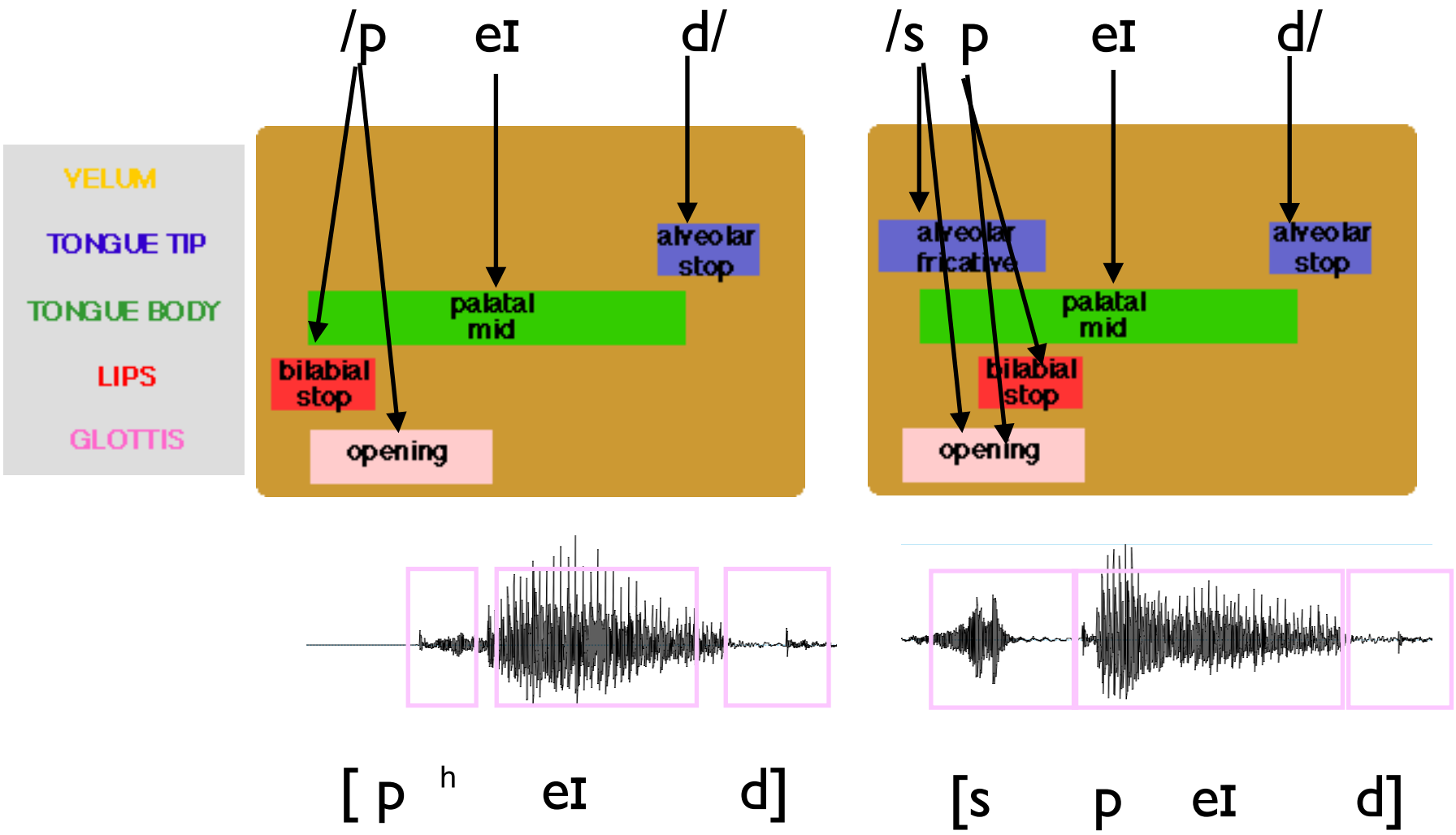


Allophony: voiceless stops and clusters

- Voiceless stops are aspirated when they are single word-initial consonants.
- Approximants are at least partially voiceless following initial voiceless stops.
- Voiceless stops are unaspirated following /s/ at the beginning of a word.

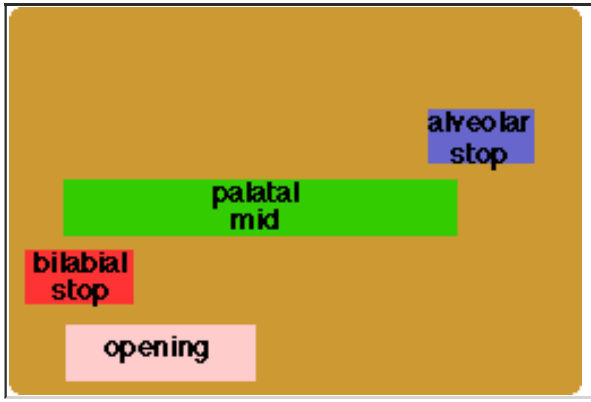
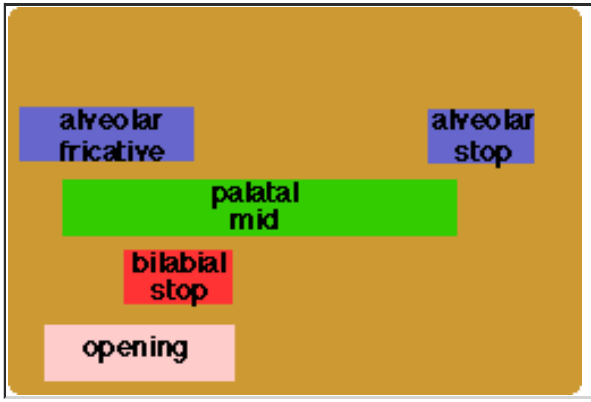
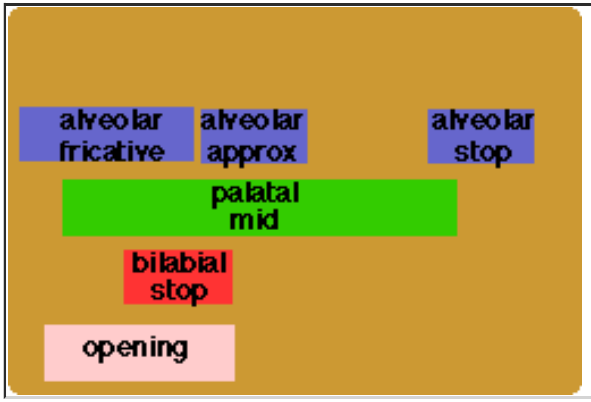
Principle 1: Glottal Gestures in onset
English allows only one glottal opening gesture in onset

Aspiration in /#p…/, but not /#sp…/



Principle I: Glottal Gestures in onset

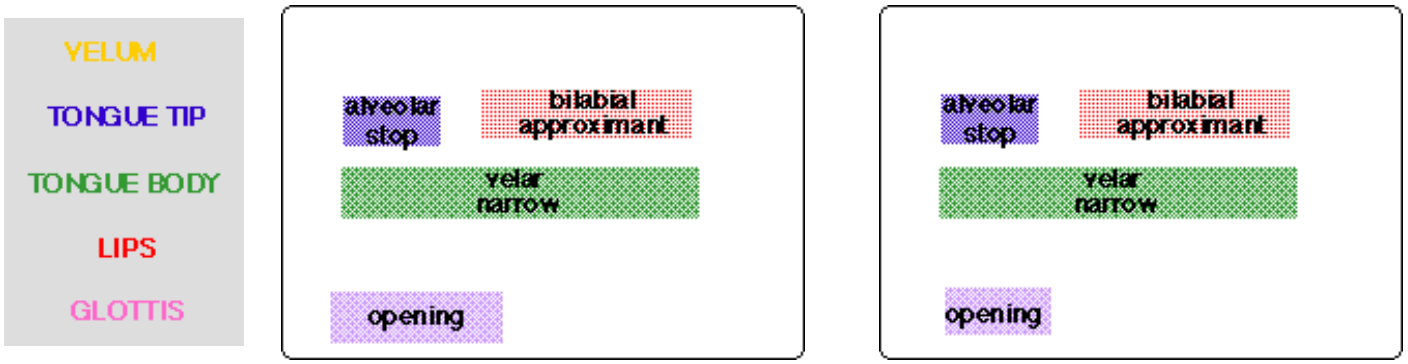
English allows only one glottal opening gesture in onset

	"paid" [pʰeɪd]	"spade" [speɪd]
VELUM TONGUE TIP TONGUE BODY LIPS GLOTTIS		
	"prayed" [p˳ɹeɪd]	"sprayed" [sp˳ɹeɪd]
VELUM TONGUE TIP TONGUE BODY LIPS GLOTTIS		

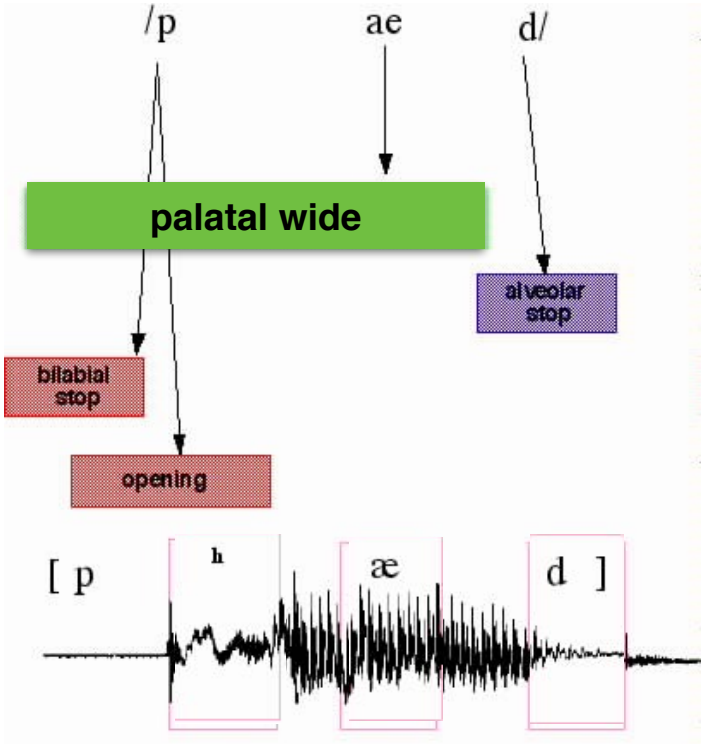
French

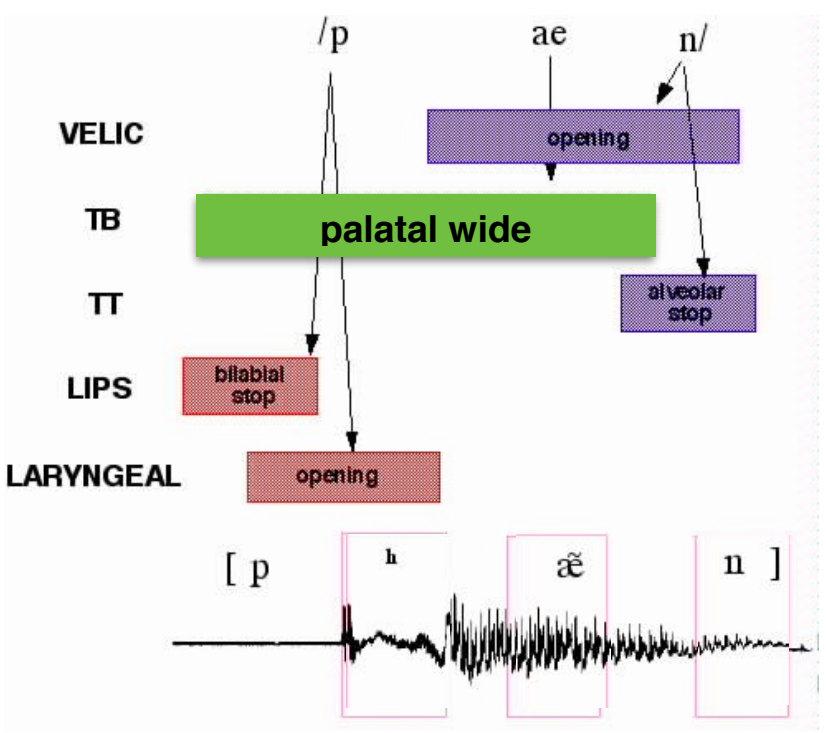
- Voiceless stops are always unaspirated
  - peine “pain”
  - pleine “full”
  - spa “spa”
  - splendide “splendid”
- Glottal opening gesture is shorter in French: equal in length to closure.

“two” “tous”



English: Nasalization of vowels before final nasals

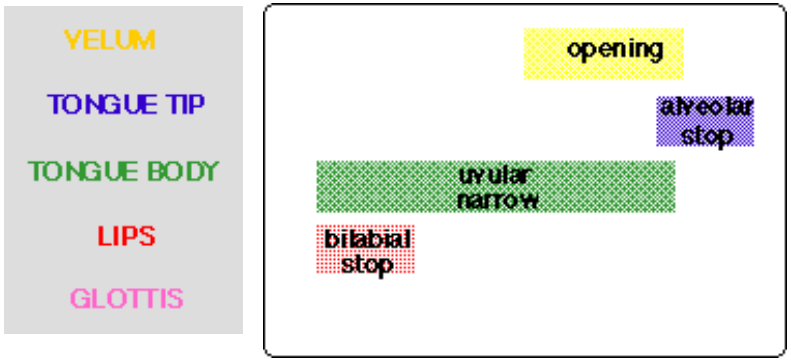




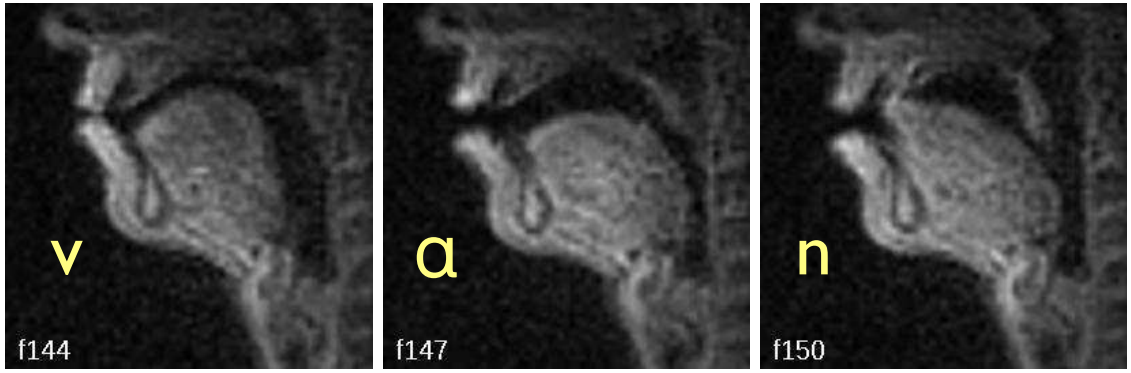
Gestural Score

- Velum lowering gesture for final nasal precedes oral constriction

"bun"



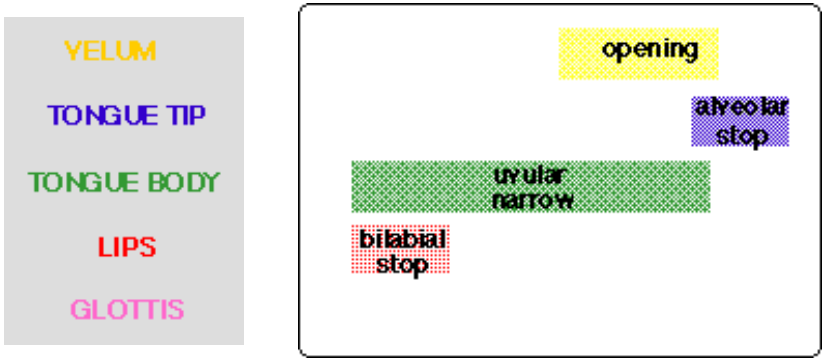
"yvonne"



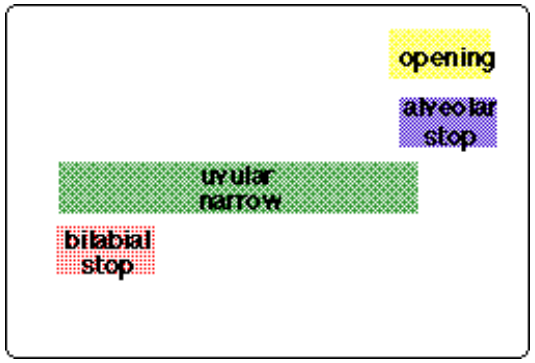
English vs French

- In French, the velum gesture for a final nasal is synchronous with the oral constriction.

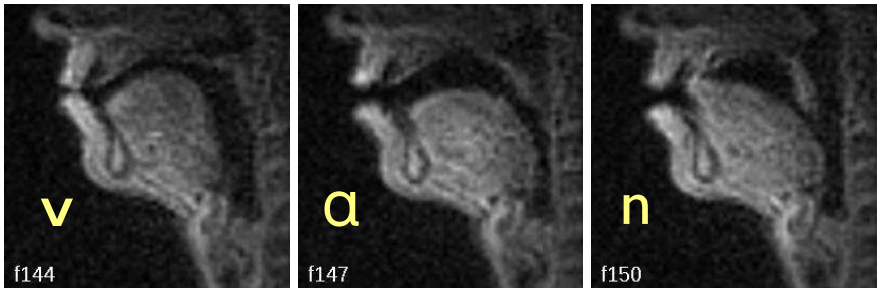
"bun"



"bonne"



"yvonne"



"panne"

Velarization of /l/

- English /l/ is described as "dark" or "velarized" in coda, and "brighter" not velarized in onset.
- The gestures in the two positions are in fact the same, but the timing is different.
- In coda, the retraction of the TB occurs first and contributes to the "velarized" percept.
- Pattern in very similar to that for nasals.

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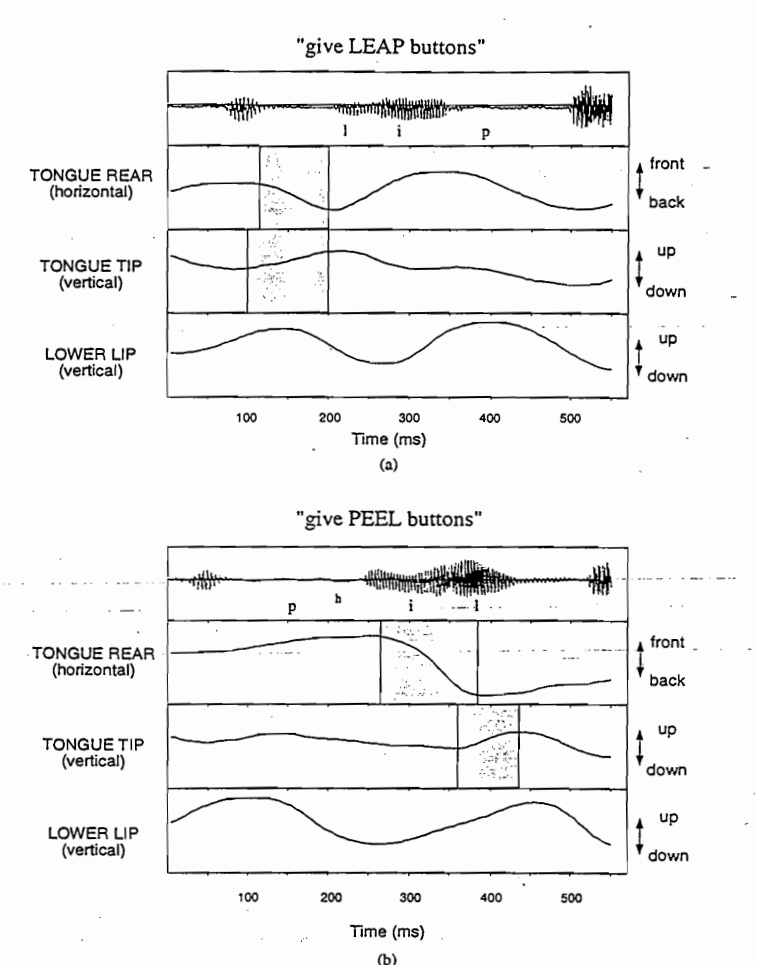


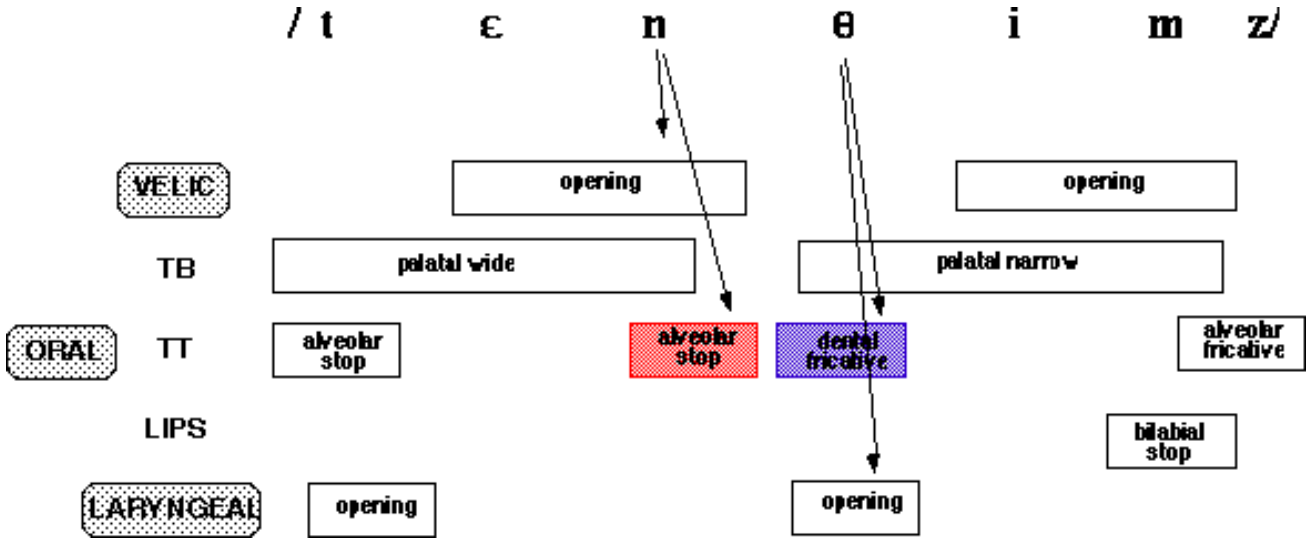
Principle 2: Coordination in onset vs coda in English

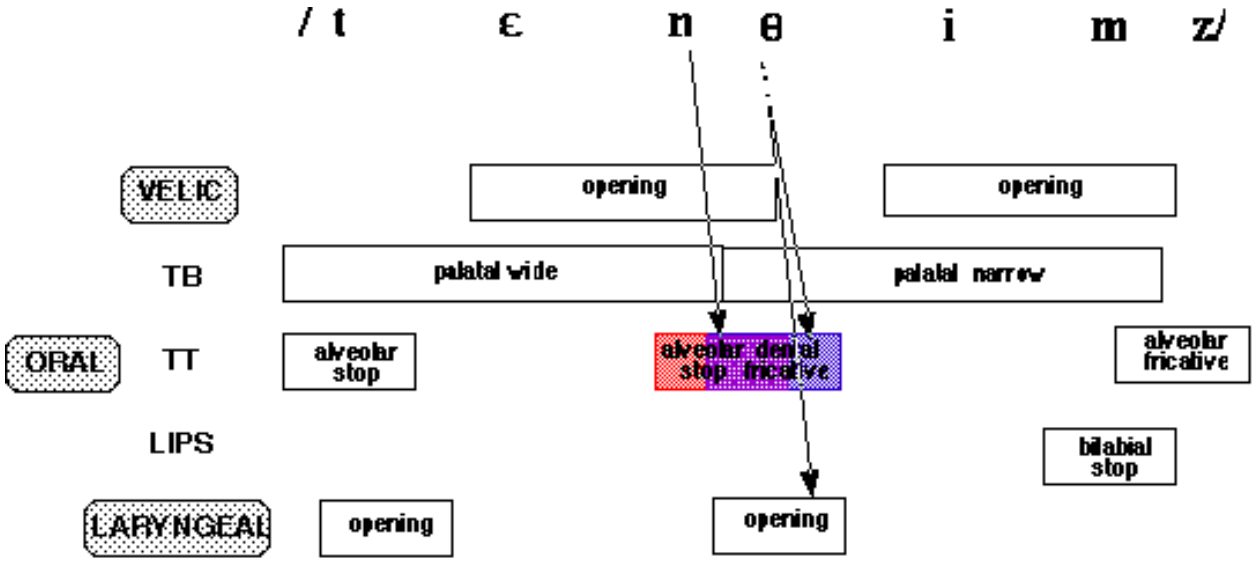
Onset: all gestures composing a C begin relatively synchronously

Coda: gestures composing a C can be sequential, with wider constriction leading

Nasal Assimilation to a following following coronal

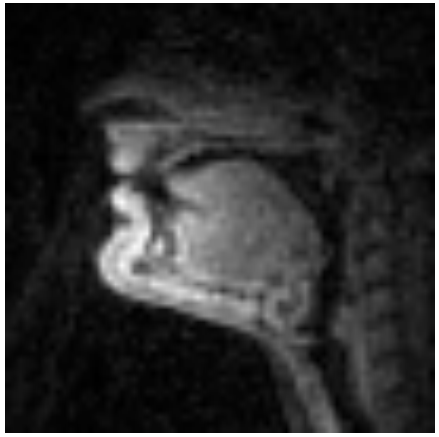
- “ten times” [tɛ̃n] vs “ten things” [tɛ̃n̪]
- overlap of alveolar nasal and dental fricative results in blending of the two TT gestures


/ t ɛ n θ i m z/
VELIC
opening
opening
TB
palatal wide
palatal narrow
ORAL
TT
alveolar stop
alveolar stop
dental fricative
alveolar fricative
LIPS
bilabial stop
LARYNGEAL
opening
opening

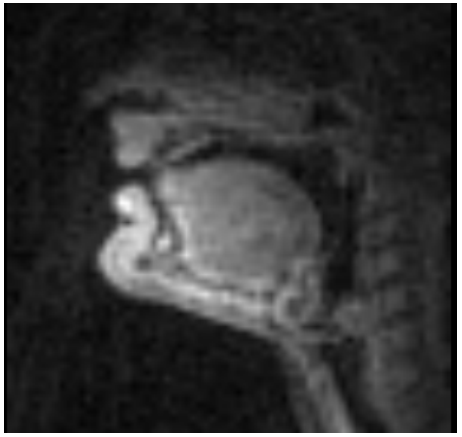

/ t ɛ n θ i m z/
VELIC
opening
opening
TB
palatal wide
palatal narrow
ORAL
TT
alveolar stop
alveolar, dental stop fricative
alveolar fricative
LIPS
bilabial stop
LARYNGEAL
opening
opening

[t ʰ ɛ̃ n̪ θ i m z]

MRI evidence for blending

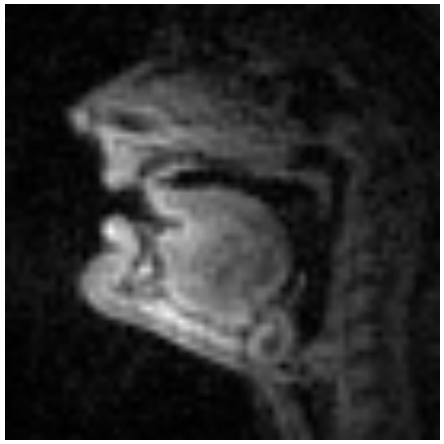


“shorten this”

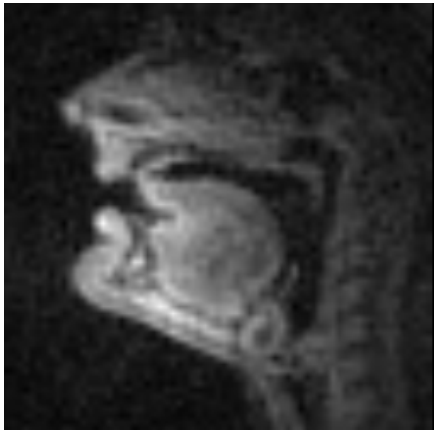


[n̪]

[ð]



“open every”



[n]