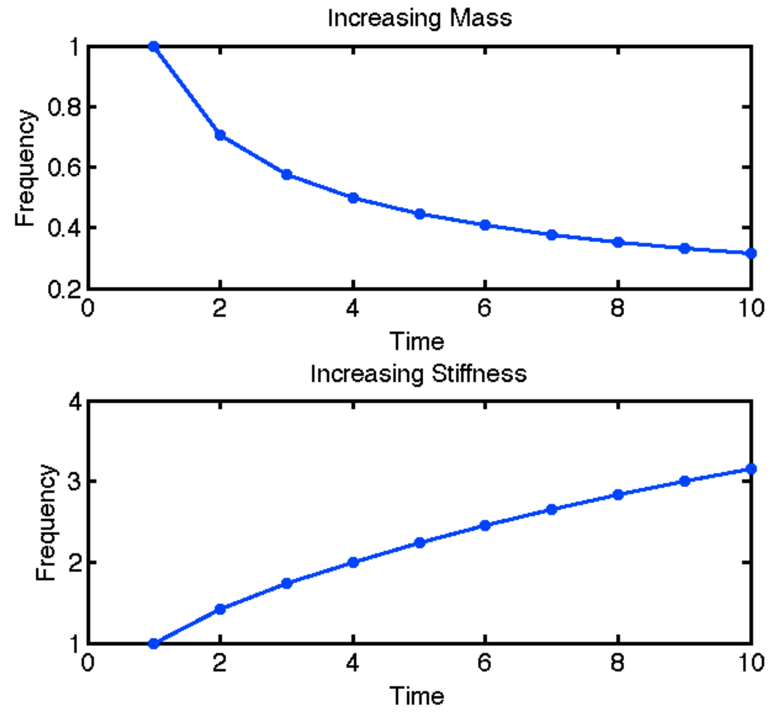
Perturbation of Modes and Vocal Tract Constrictions

Principle 1: Perturbation of mass+spring

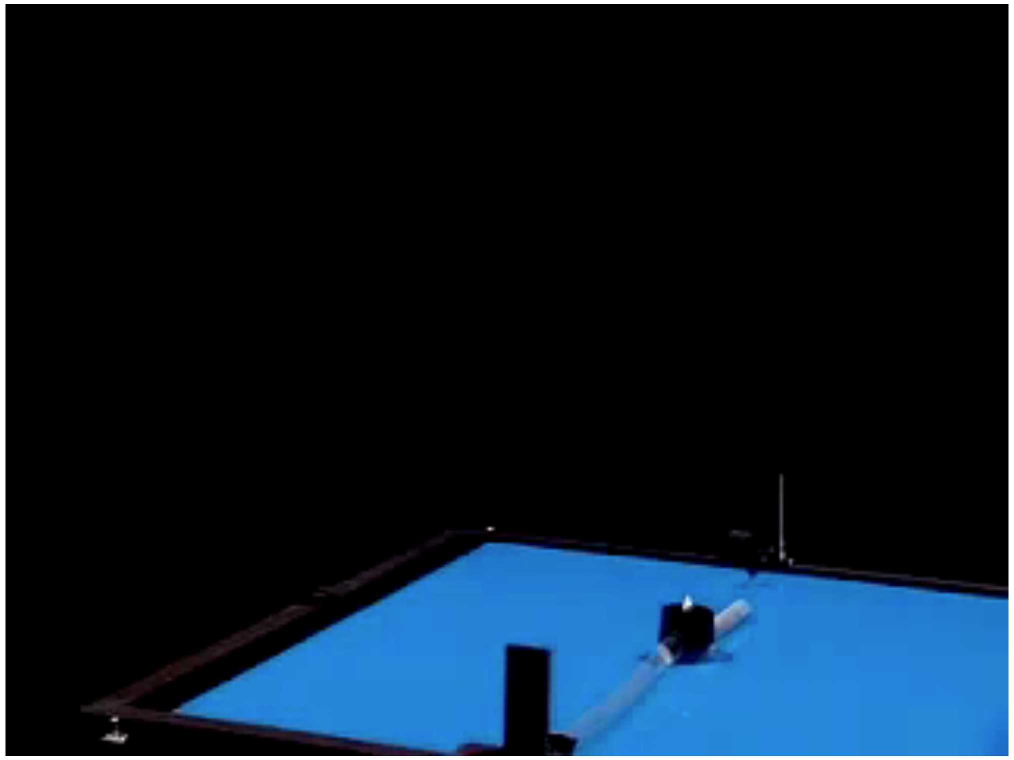
- Perturb (change) spring stiffness by increasing it. What is effect on oscillation frequency?
  - Frequency will *increase*. Why?
- Perturb (change) mass by increasing it. What is effect on oscillation frequency?
  - Frequency will *decrease*. Why?

Spectrogram of one mass system

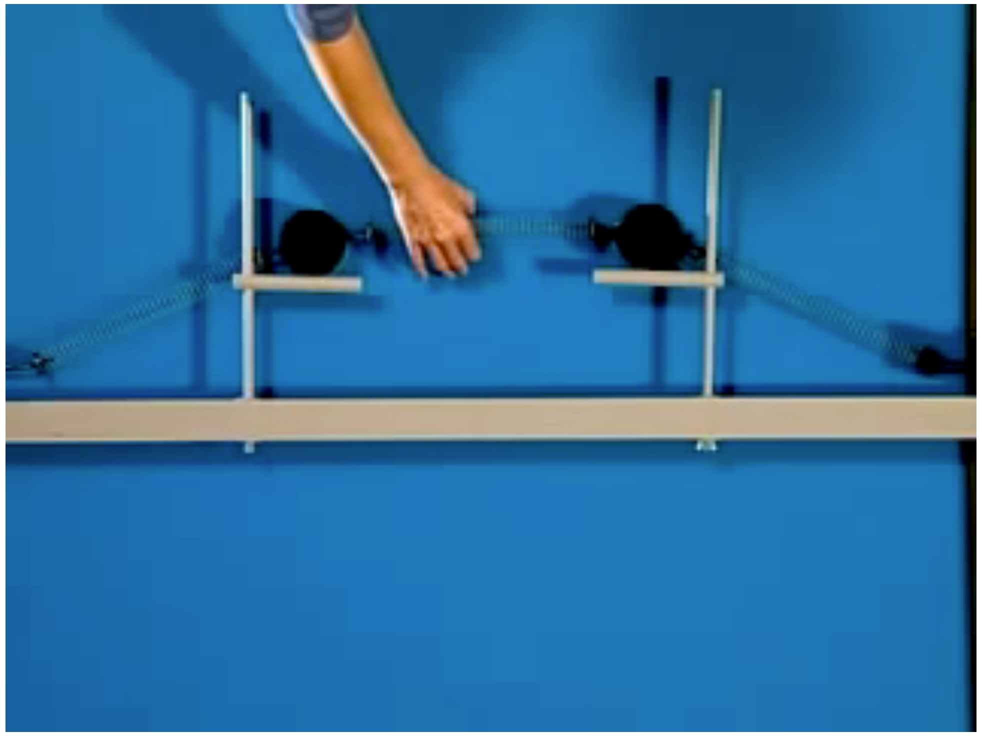


Multiple Masses

- One mass attached to two springs to walls
- will vibrate at a single frequency, depending on mass and stiffness.



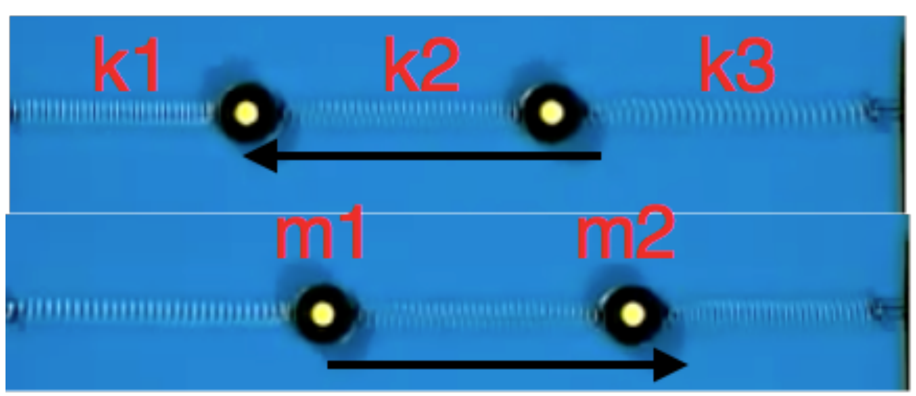
- Two masses, each attached to the wall and to each other
- will oscillate at two different frequencies, depending on initial conditions. why?



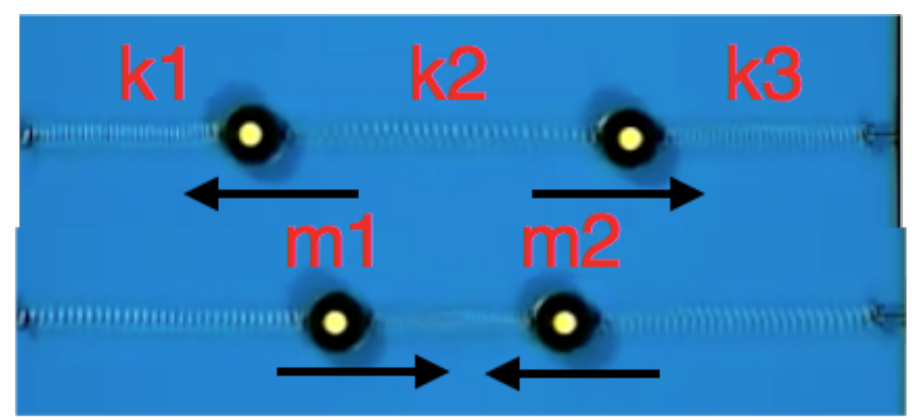
Two-mass system

- In a vibratory system with 2 m and 3 k, there will be 2 modes of vibration:
  - In-phase mode: the middle spring just rides up and down with the masses.
  - Out-of-phase mode: the middle spring stretches and compresses.

  Therefore: OP Mode has more effective stiffness (3 springs vs. 2) and therefore has higher frequency.



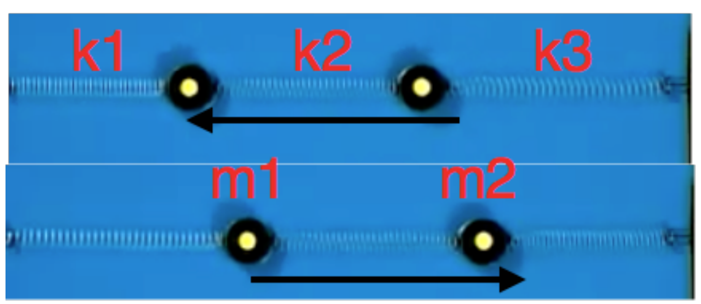
Lowest frequency mode



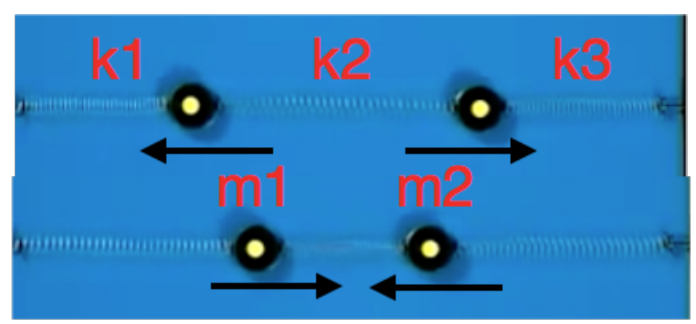
2nd harmonic frequency mode

Perturbation of mass in two-mass system

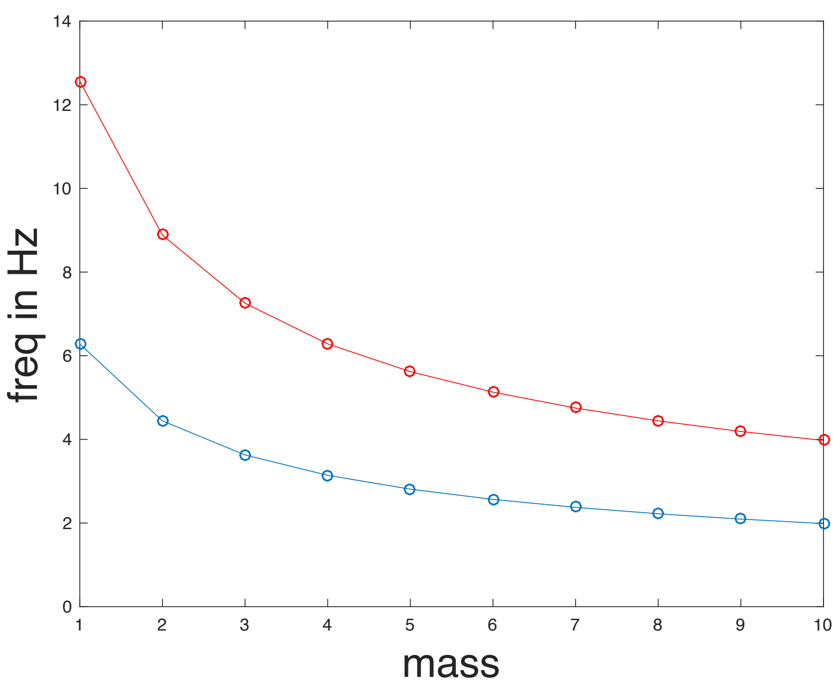
- Two-mass system has two modes:
- Increase either of the masses in the low frequency mode. What happens to frequency?
- Increase either of the masses in the high frequency mode. What happens to frequency?



Lowest frequency mode



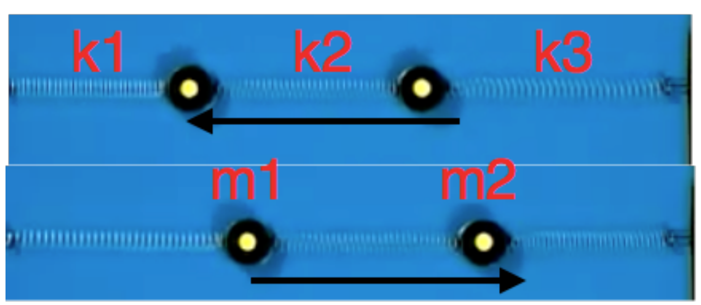
2nd harmonic frequency mode



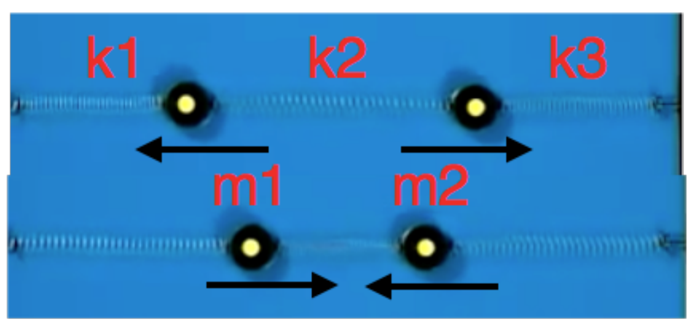
Perturbation of stiffness in two-mass system

- Increase the stiffness of either of the end springs (k1, k3) in the low frequency mode, what happens to frequency?

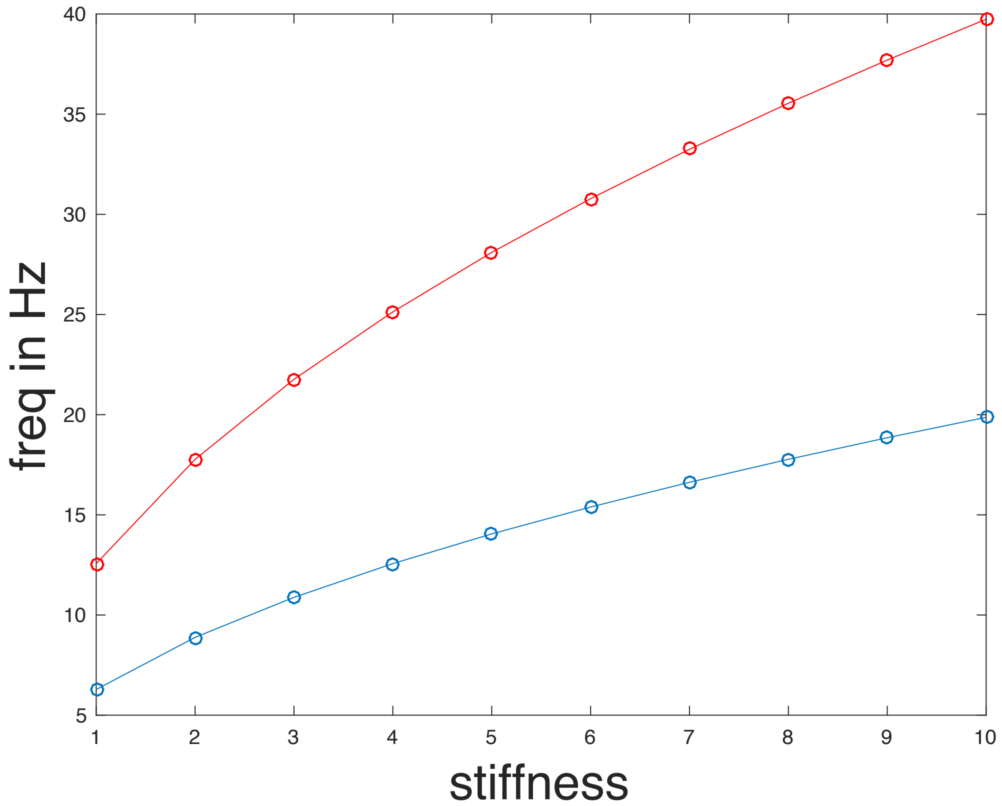
- Increase the stiffness of either of the end springs (k1, k3) in the high frequency mode, what happens to frequency?



Lowest frequency mode

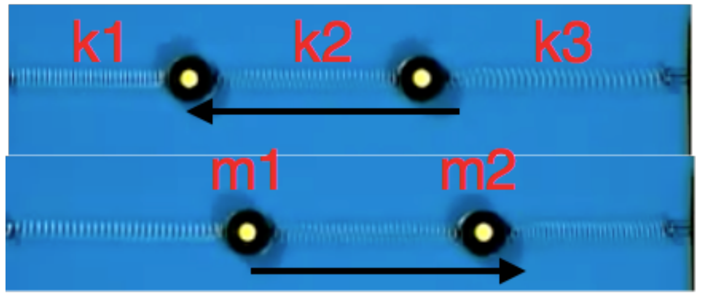


2nd harmonic frequency mode

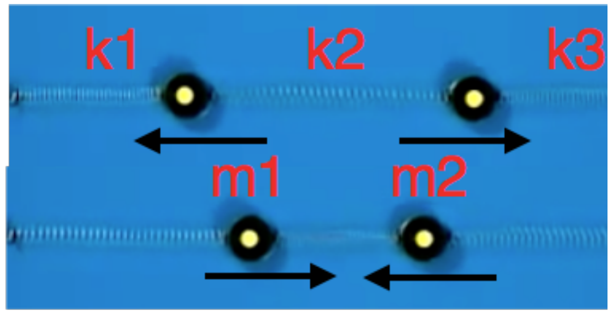


Perturbation of stiffness in two-mass system

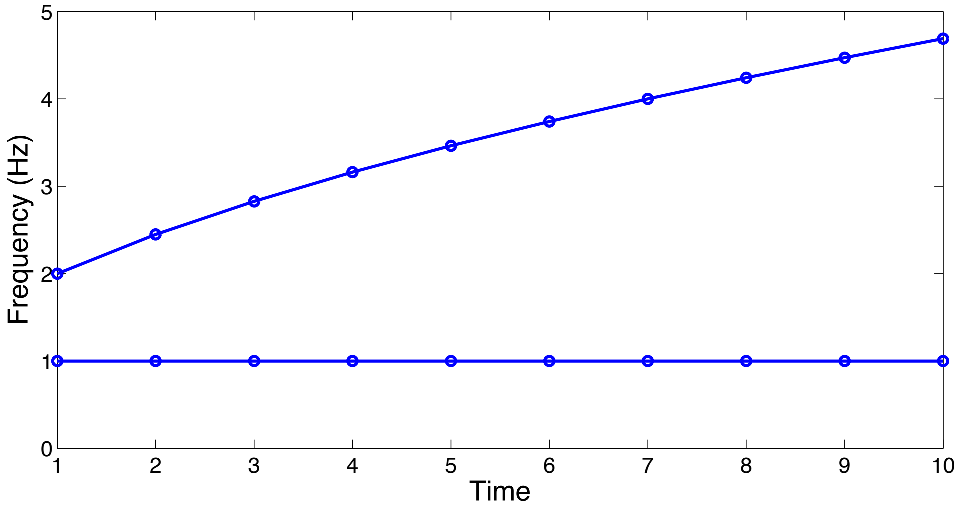
- Now increase the stiffness of the middle spring (k2) in the low frequency mode, what happens to frequency?
- Increase the stiffness of the middle spring (k2) in the high frequency mode, what happens to frequency?
- Principle 2: effect of mass or stiffness perturbation depends on the position of the perturbation as well as the mode.



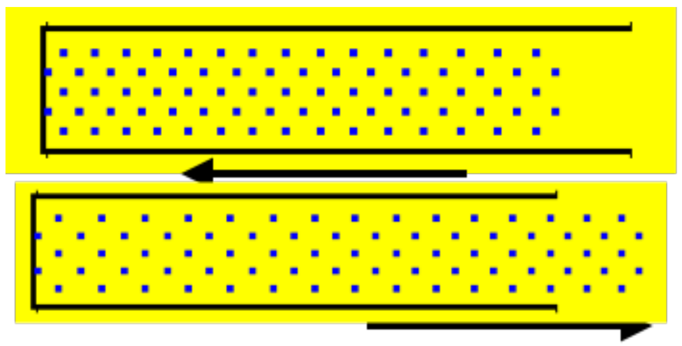
Lowest frequency mode

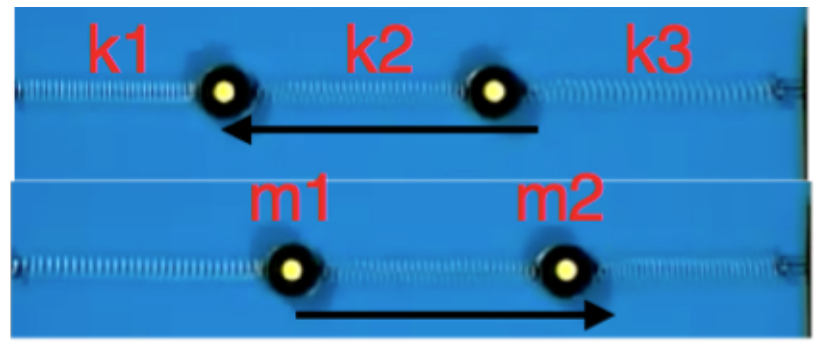


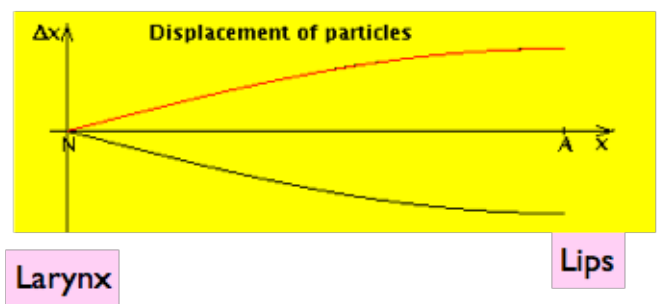
2nd harmonic frequency mode



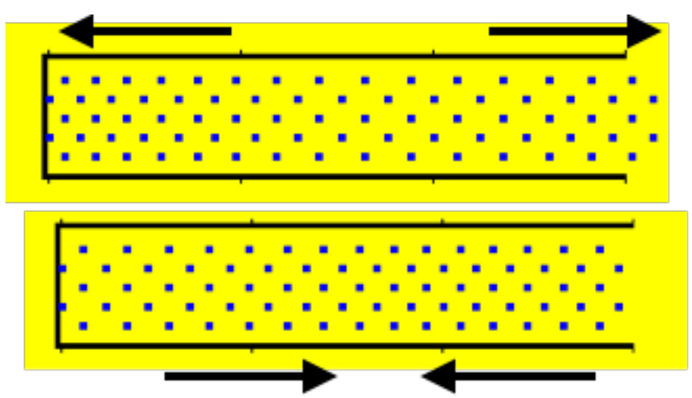
Perturbing lowest two modes of air in tube open at one end

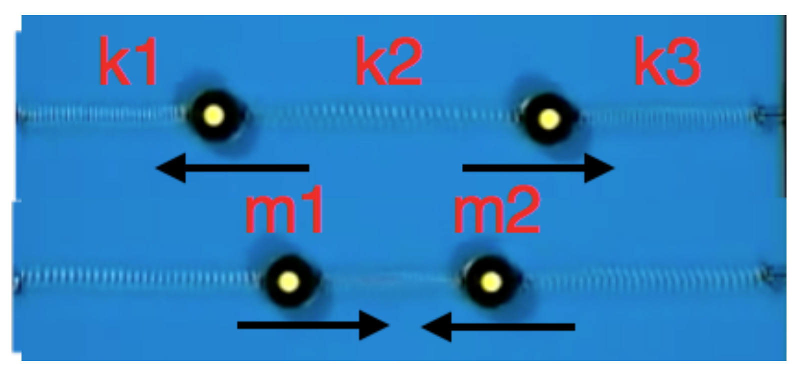


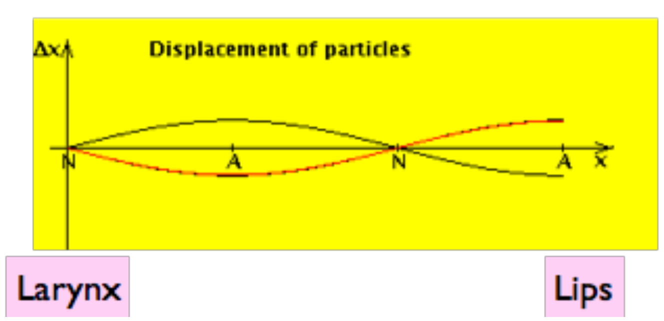




Lowest Mode







Next Higher Mode

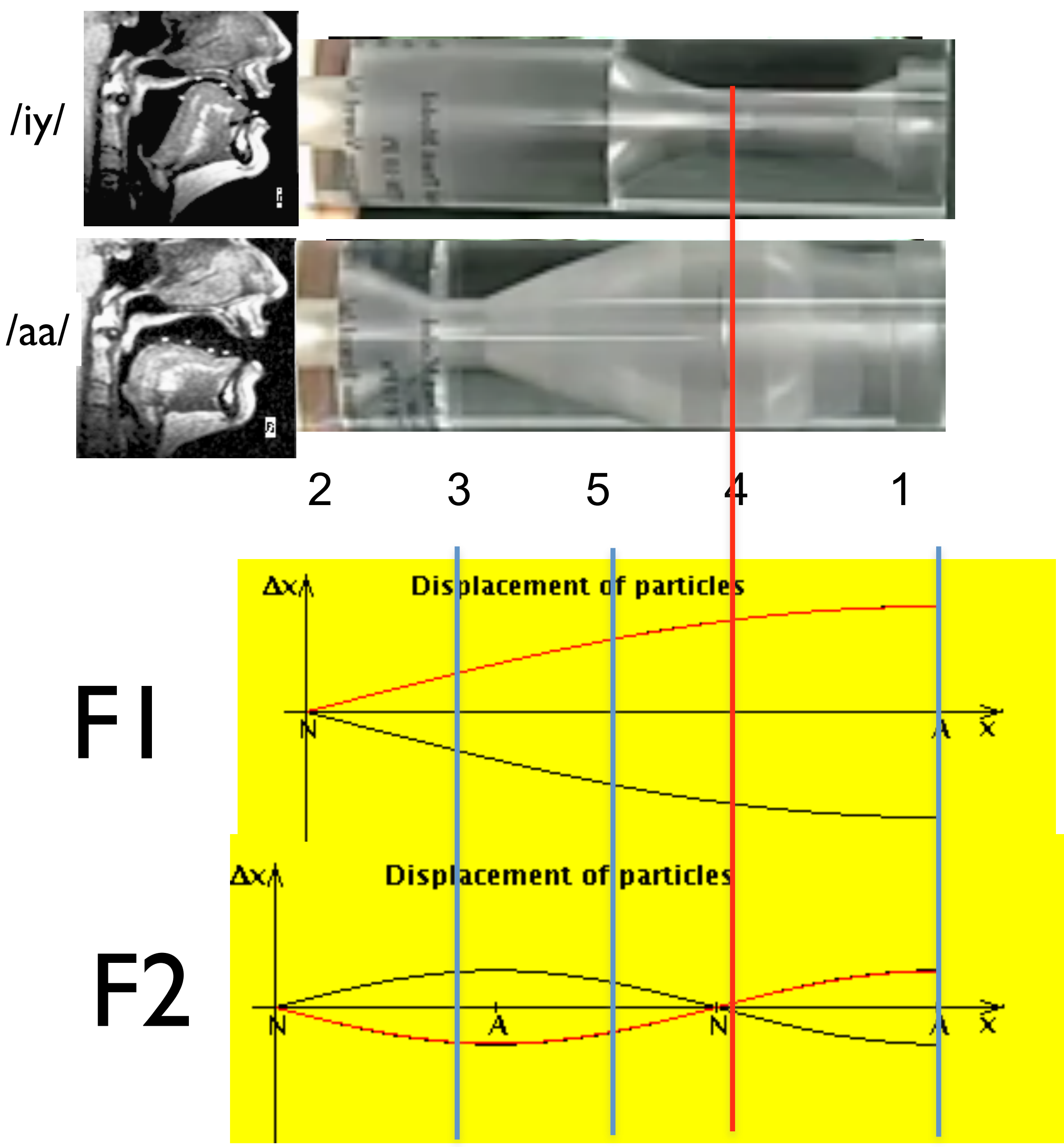
Constriction in vocal tract = m $\Uparrow$ k $\Uparrow$

- Portions of air have mass and springiness.
- Constricting a portion of air by constricting a tube:
  - Raises the mass, since packed molecules are harder to move, i.e. a constriction raises density.
  - Raises the stiffness (as in a tire), i.e., a constriction raises pressure.
  - So a constriction in a tube amounts to raising both mass and stiffness at the location of the constriction.

Effect of increasing mass and stiffness on mode frequencies

- Effect of mass and stiffness could cancel each other out.
- However, however, because of the effect of position, either mass or stiffness effects can be dominant.
- **Mass:**
- Mass has a maximal effect where the molecules are moving most (like the open end), as the movement of the masses will be slowed down.
- An increase of mass at a position where the molecules are not moving (like the closed end) will have no effect on frequency.
- **Stiffness:**
  Stiffness has a maximal effect there the molecules are moving least. Springiness of air doesn't matter where there is nothing to push against.

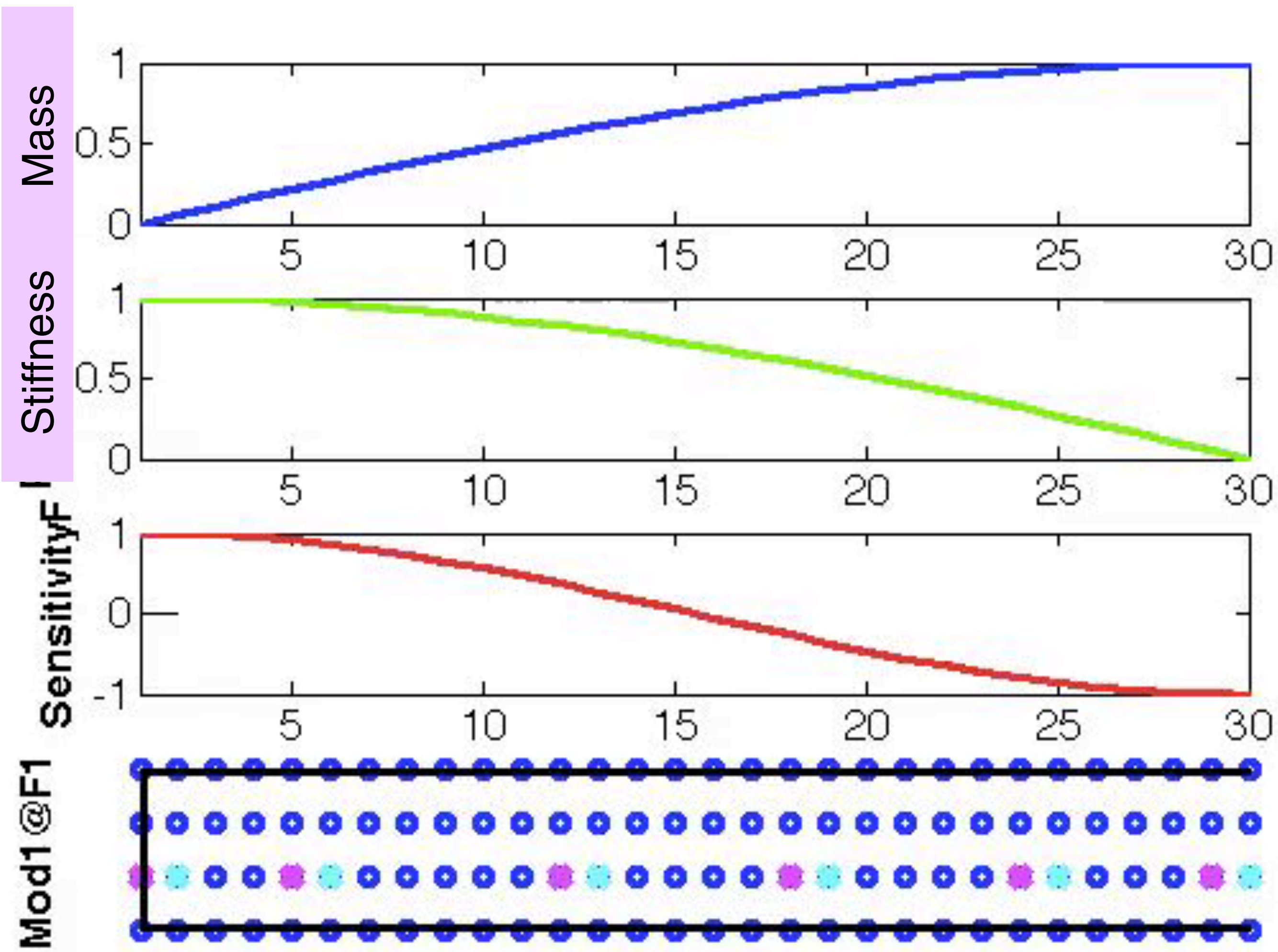
Effect of constricting vocal tract at different locations

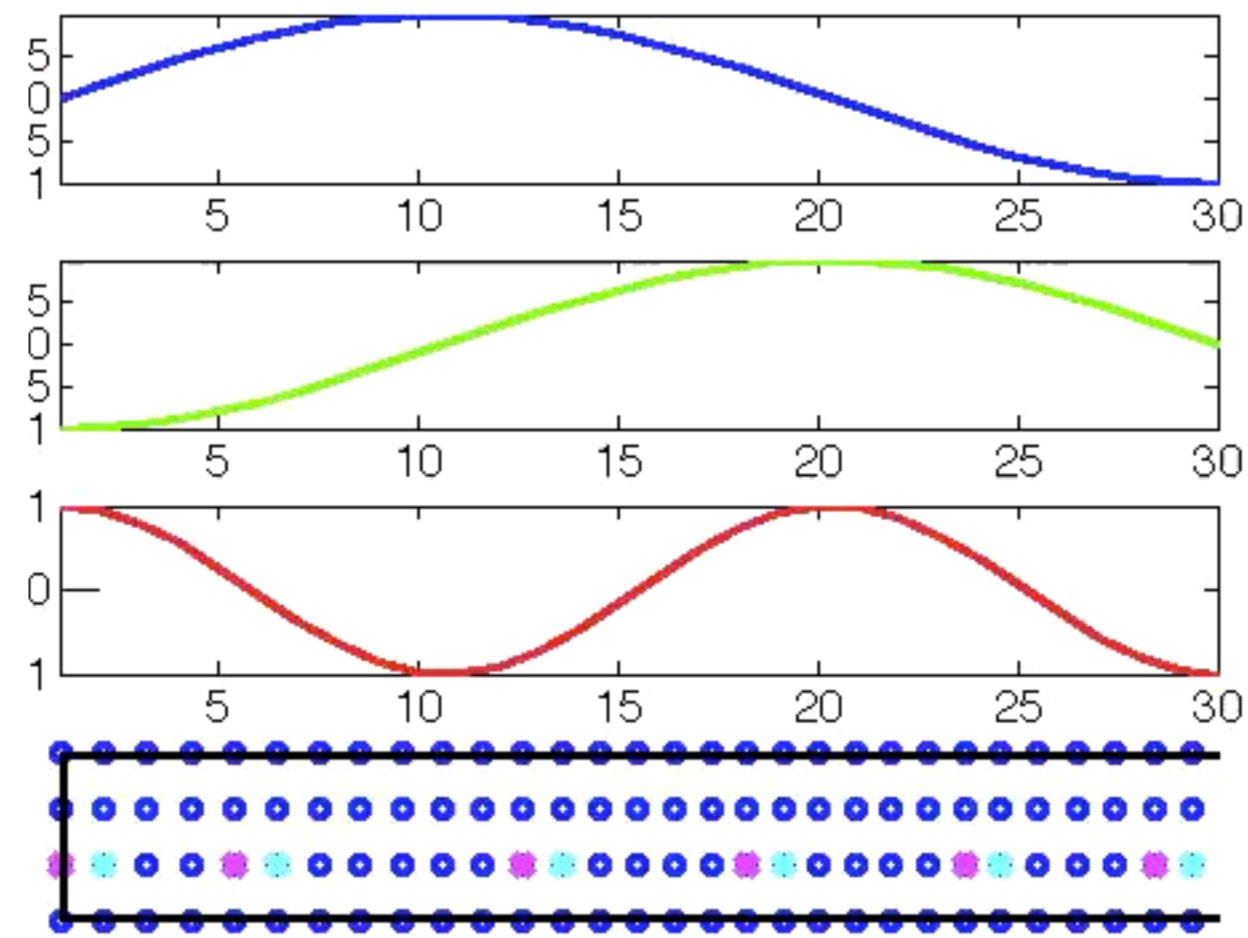


position	F1	F2
1	mass ↓	mass ↓
4	mass ↓	stiff ↑
3	stiff ↑	mass ↓
2	stiff ↑	stiff ↑

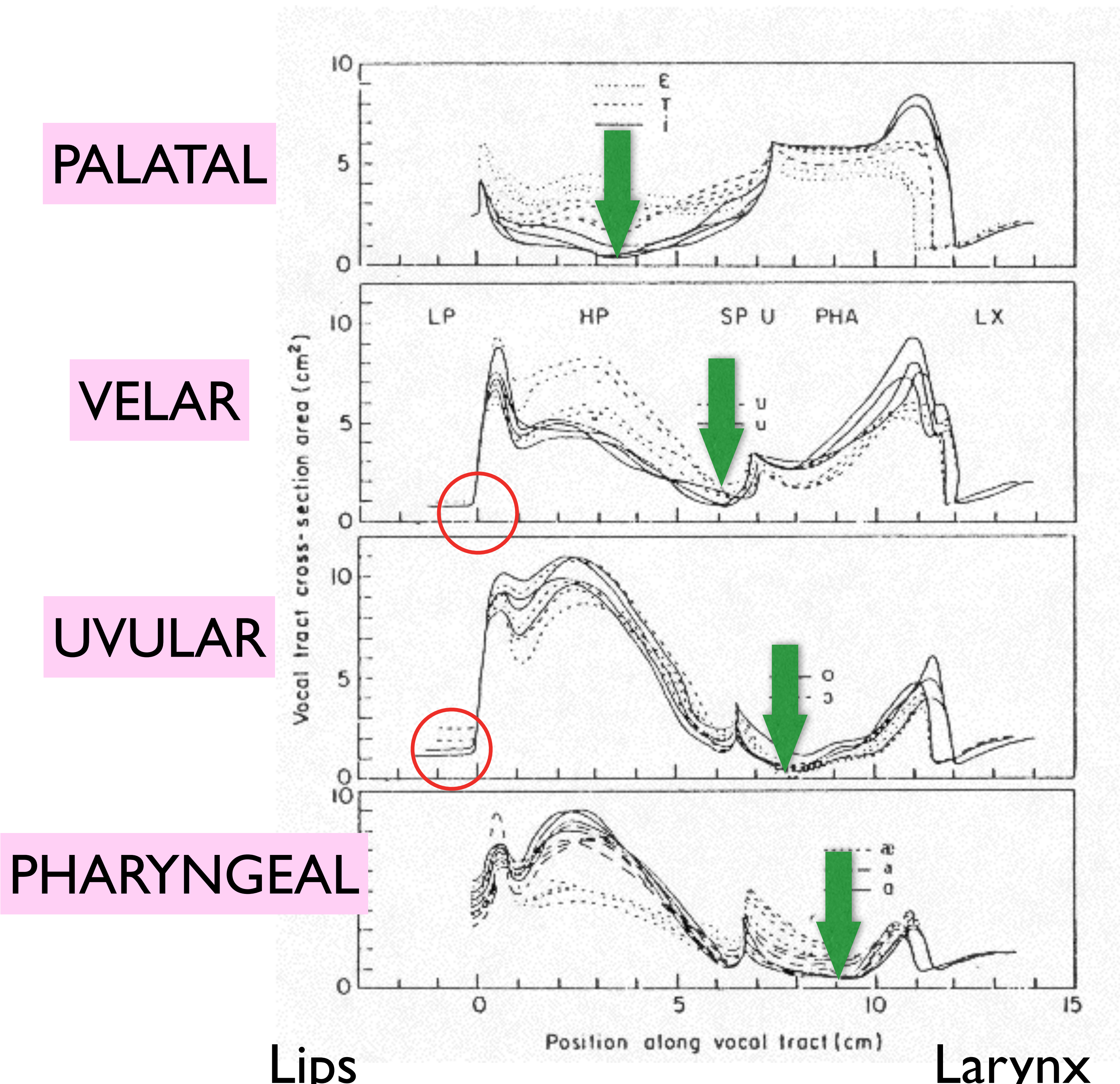
Modes of air vibration in tube with one open end

- Sensitivity of formants to change = stiffness effect squared - mass effect squared





Vowels: Constriction in Different Locations



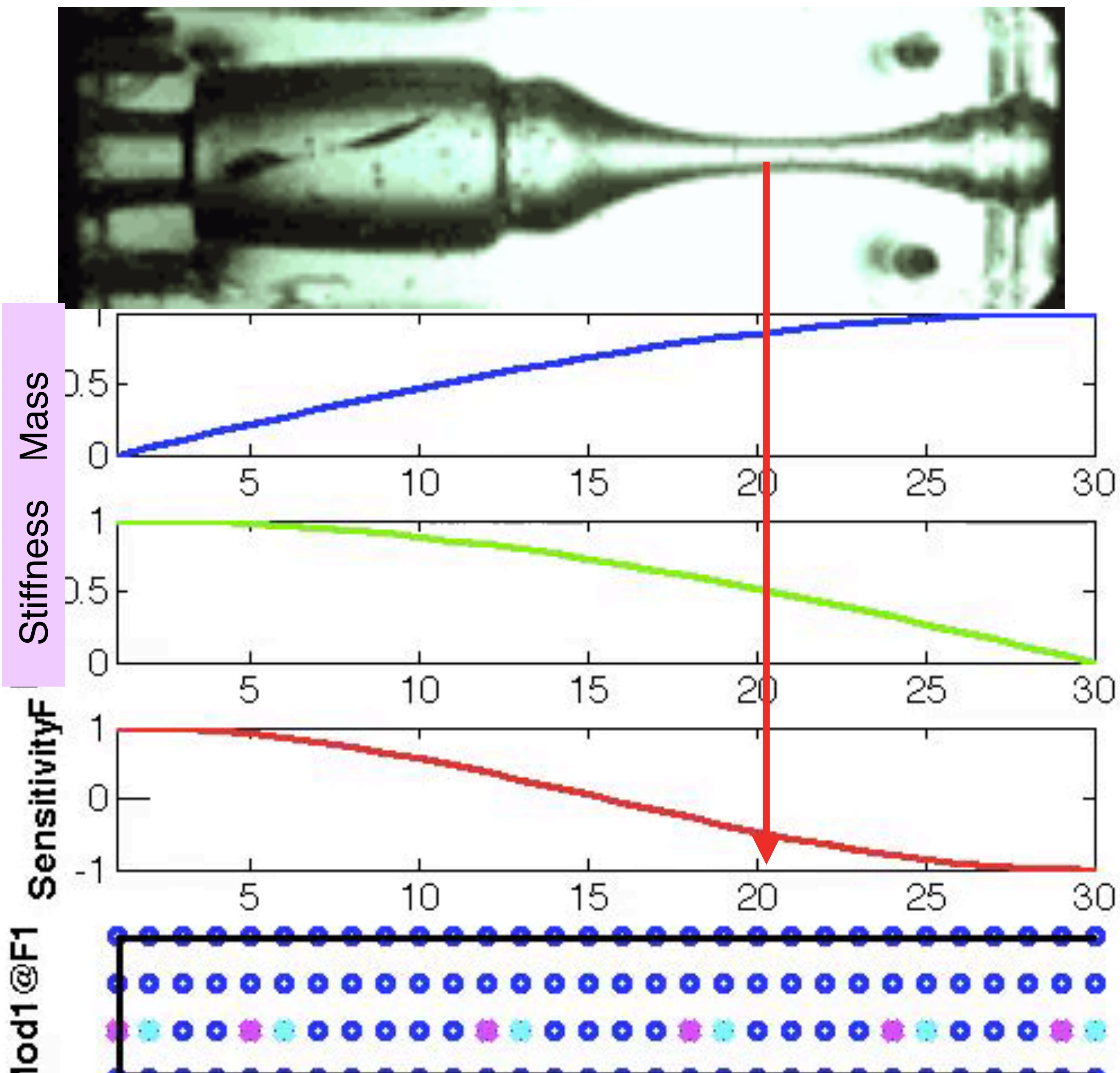
- Wood (1984) measured area functions from a variety of languages show constrictions limited to these four locations.
- Velar and Uvular usually accompanied by lip constrictions.

How do distinct constrictions produce distinct formant patterns?

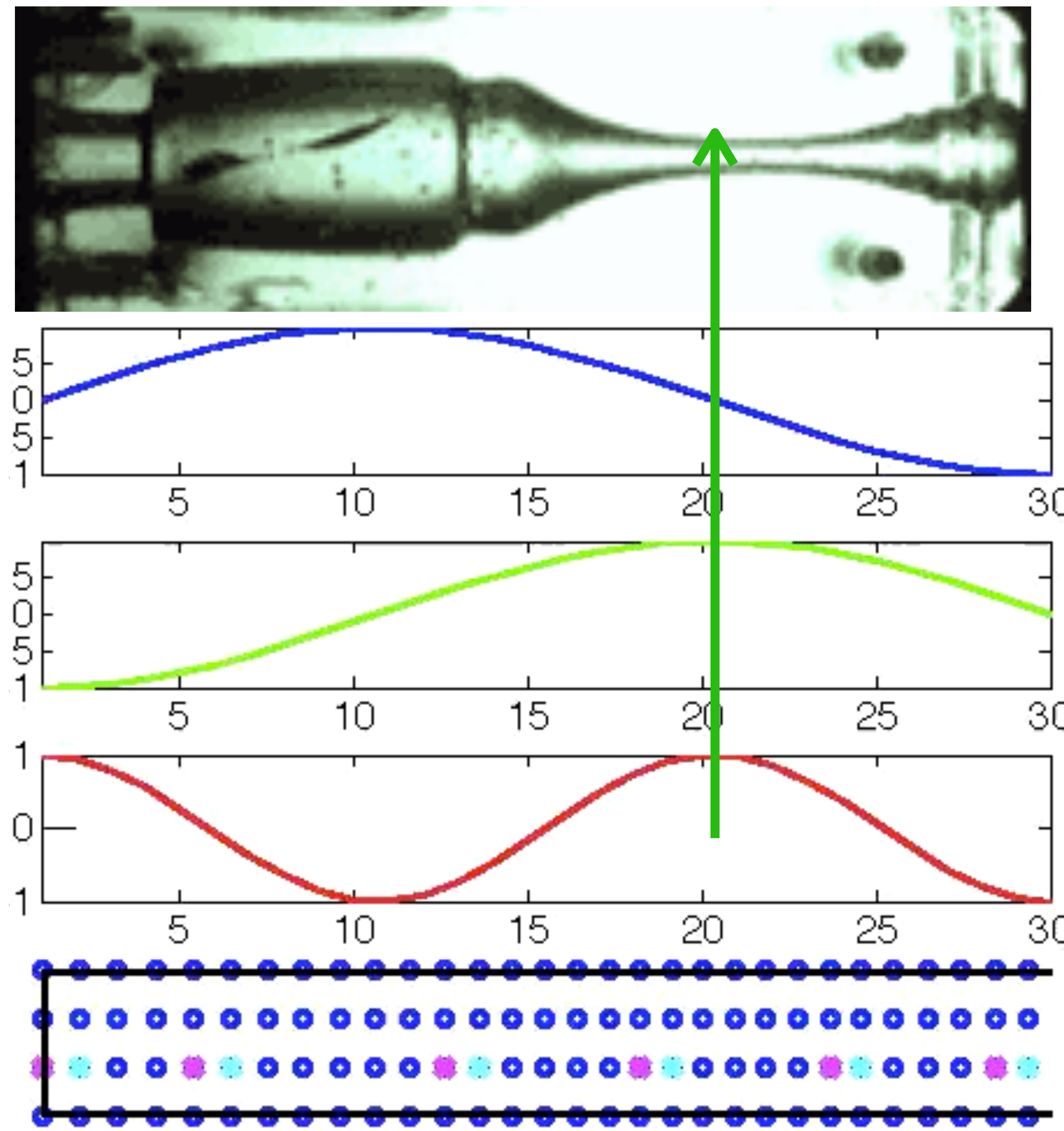
- palatal (e.g. /i/)
  - F1 down, F2 up
- Pharyngeal (e.g. /a/)
  - F1 up, F2 down
- Velar (e.g. /u/)
  - F1 down, F2 down

Palatal Constrictions

F1

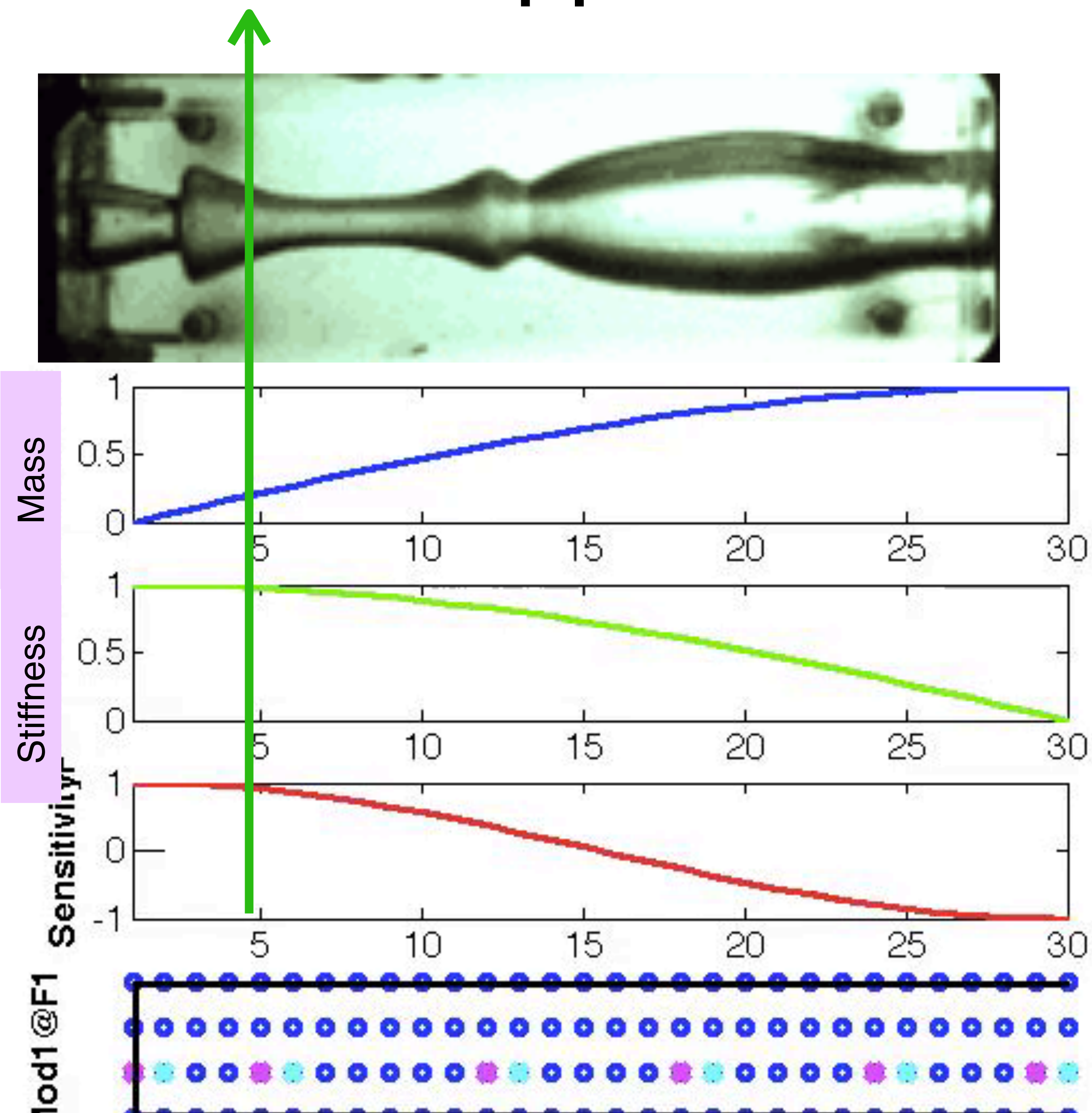


F2

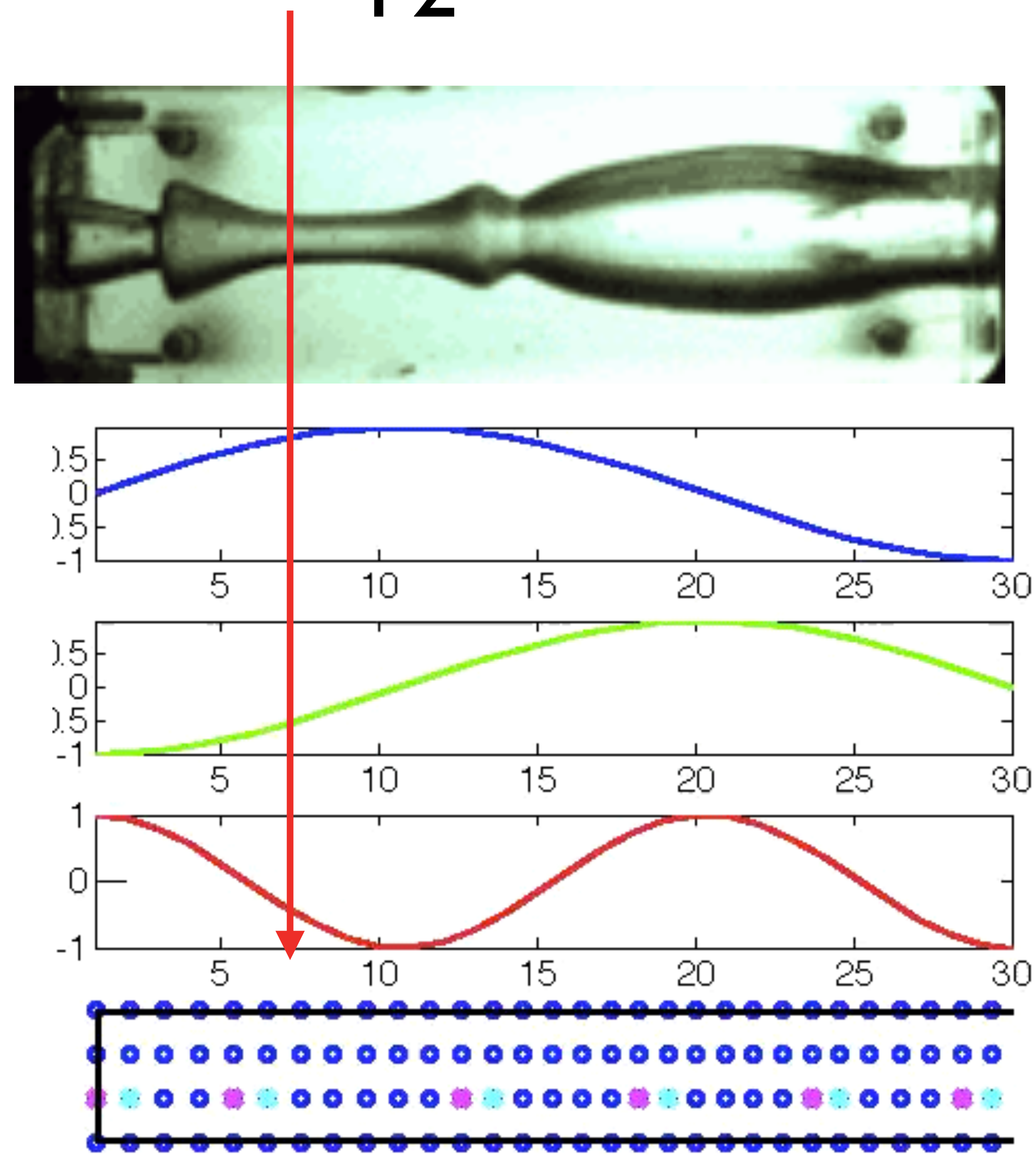


Pharyngeal Constrictions

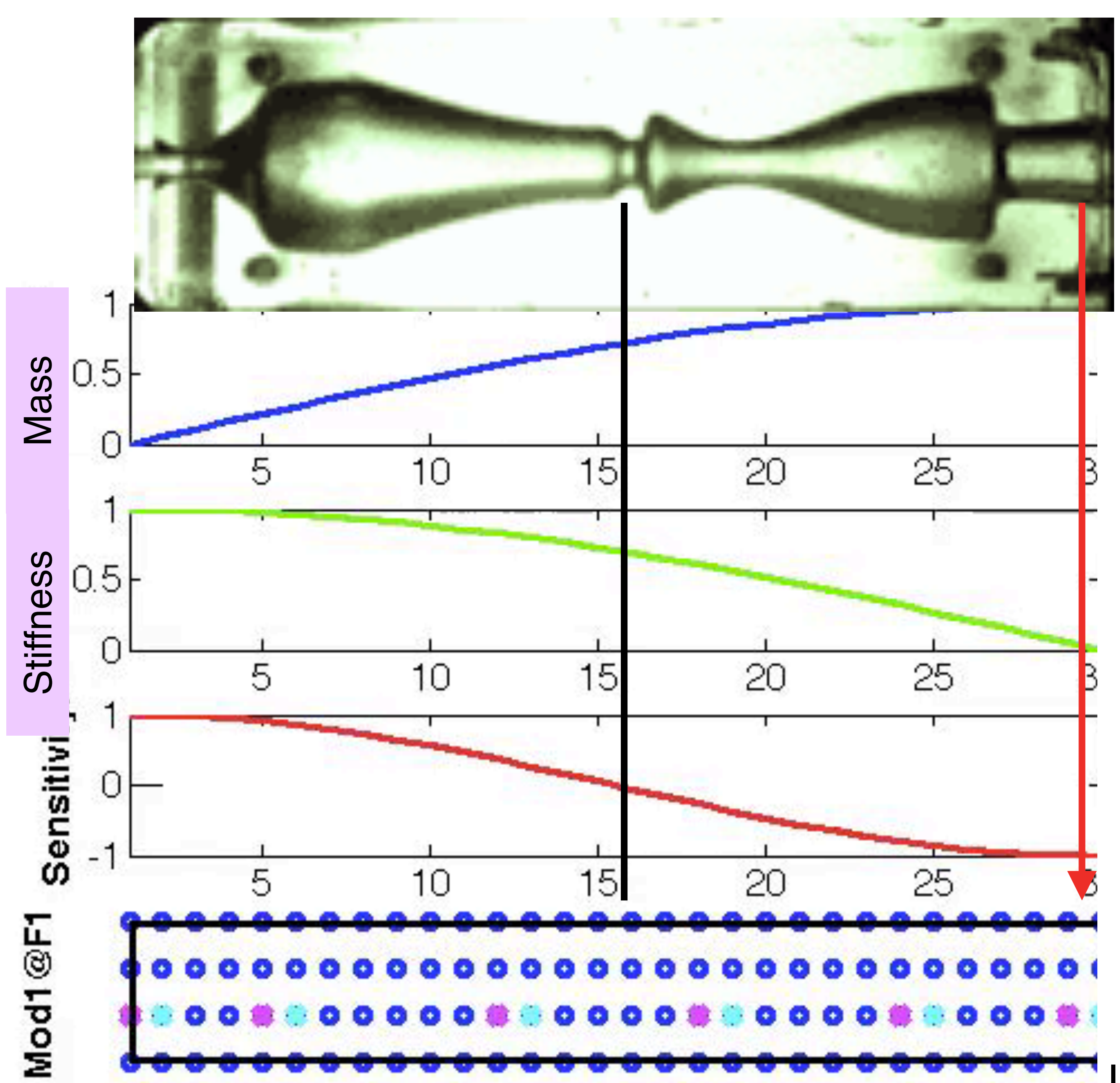
F1

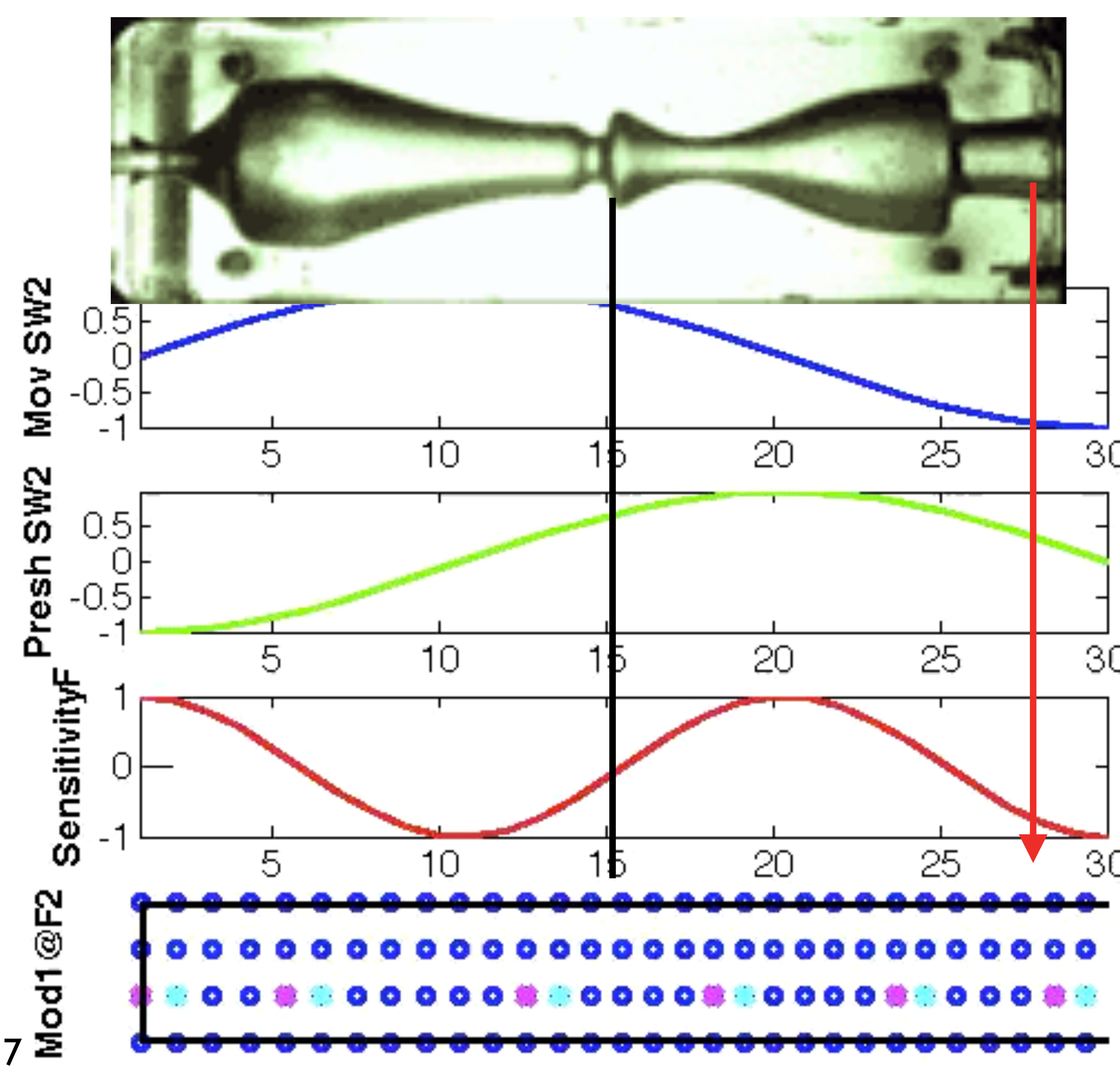


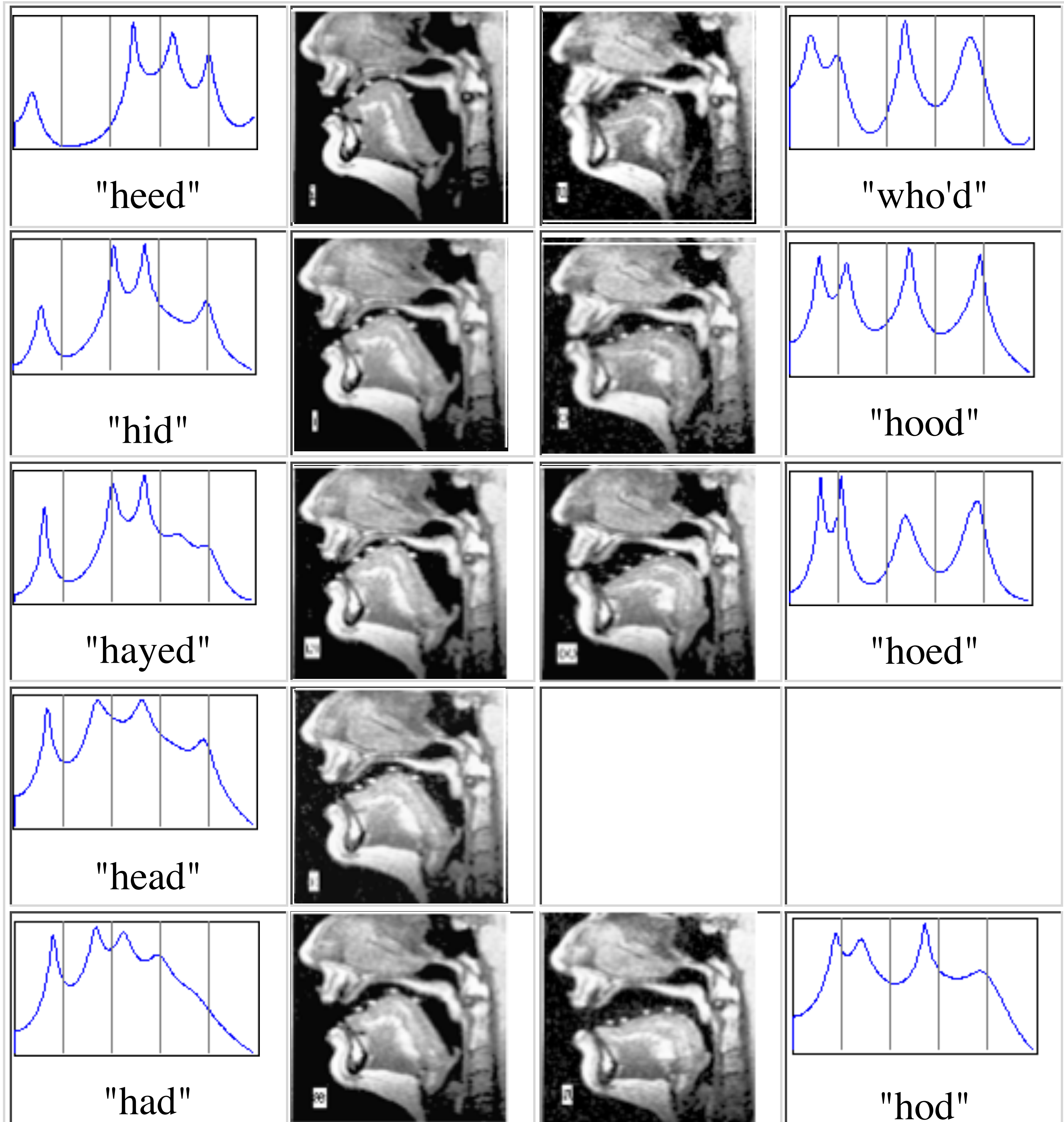
F2



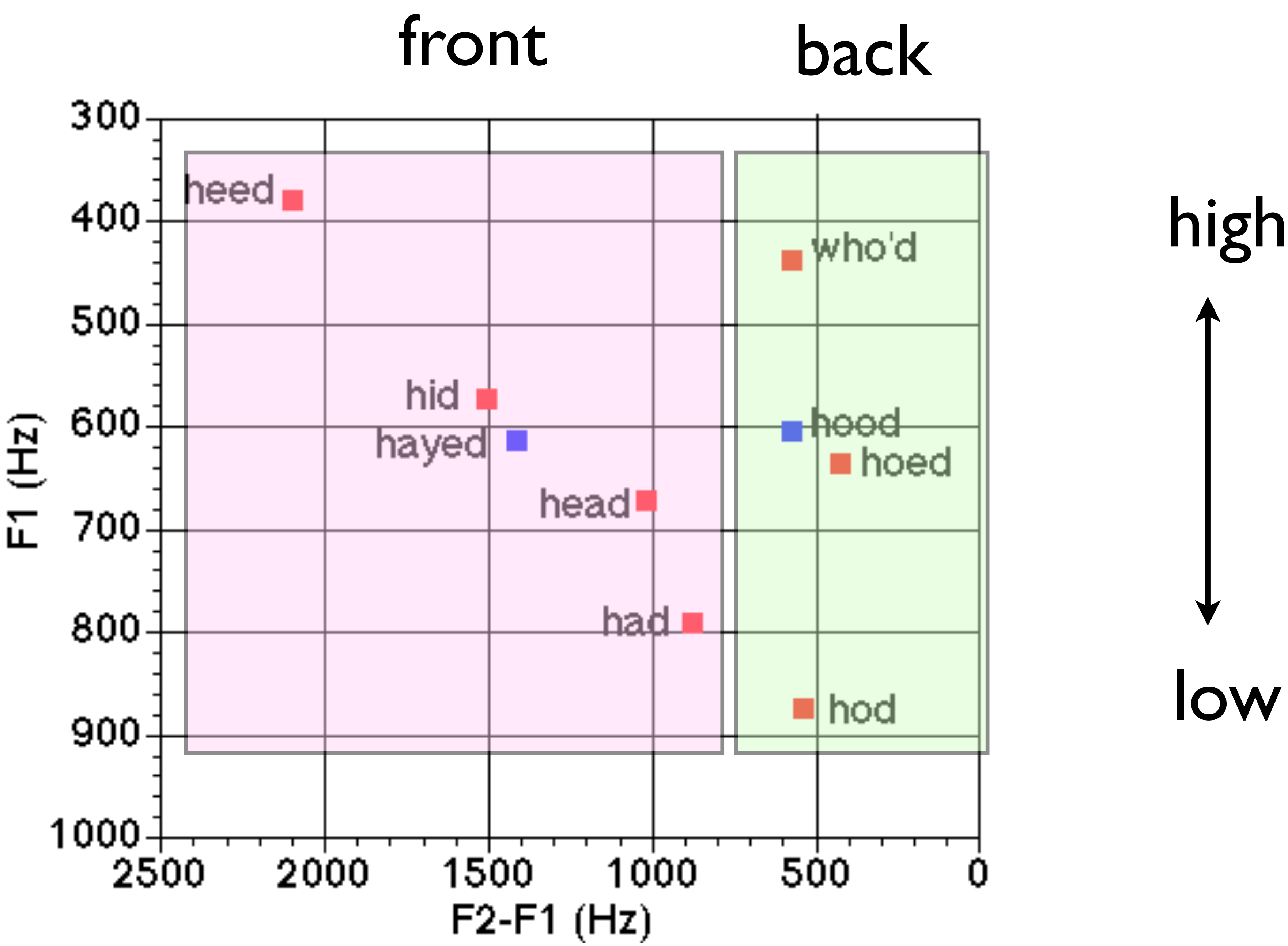
Velar/Uvular + Labial constrictions






"heed"
"who'd"
"hid"
"hood"
"hayed"
"hoed"
"head"
"had"
"hod"

Vowel Space


front
back
high
low
heed
who'd
hid
hayed
hood
hoed
head
had
hod
300
400
500
600
700
800
900
1000
F1 (Hz)
2500
2000
1500
1000
500
0
F2-F1 (Hz)

https://dood.al/pinktrombone/