Semi-Occluded Vocal Tract Exercises (SOVTEs): Theory and Application

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The University of Maine

MSLHA 2023 Annual Conference,

October 26th, 2023

Structure of the talk…

1. Review of Vocal Function, Theoretical Background (Relevant for SOVTEs)
2. SOVTE Literature Review, My SOVTE Research
3. Clinical Applications

1. Review of Vocal Function and Theoretical Background

Speech/Voice Subsystems

- Respiratory system
  - Aerodynamic Power (subglottal pressure)
- **Phonatory system**
  - Sound **Source** (changing glottal airflow)
- **Resonatory / Articulatory system**
  - Acoustic **Filter** (resonances determined by vocal tract length, constriction magnitude and location)

Phonation Review Topics

- **Adduction**
- **Intensity / Loudness**
  - Subglottal pressure
- **Frequency / Pitch**
  - Mass
  - Tension

What Produces and Controls <u>Adduction</u> for Voicing?

- ***Antagonistic muscle groups***
  - ***Adduction***:
    - ***LCA*** (lateral cricoarytenoid muscle)
    - ***IA*** (interarytenoid muscle in back of the arytenoids; **INT**)
    - ***LTA*** (lateral thyroarytenoid muscle or TA muscularis)
  - ***Abduction***:
    - ***PCA*** (posterior cricoarytenoid muscle)

Breathy　　Normal　　Pressed

Clinical Importance:

-What is the amount of antagonistic force?

-Each muscle operates independently of the others.

Termination of Voicing (4 ways):

1. **Decrease adduction (abduct) outside of phonatory adductory range**
2. **Increase adduction (medial compression) outside of phonatory adductory range**
3. Decrease subglottal pressure
4. Increase downstream resistance (to infinity; e.g., sustain /b/)

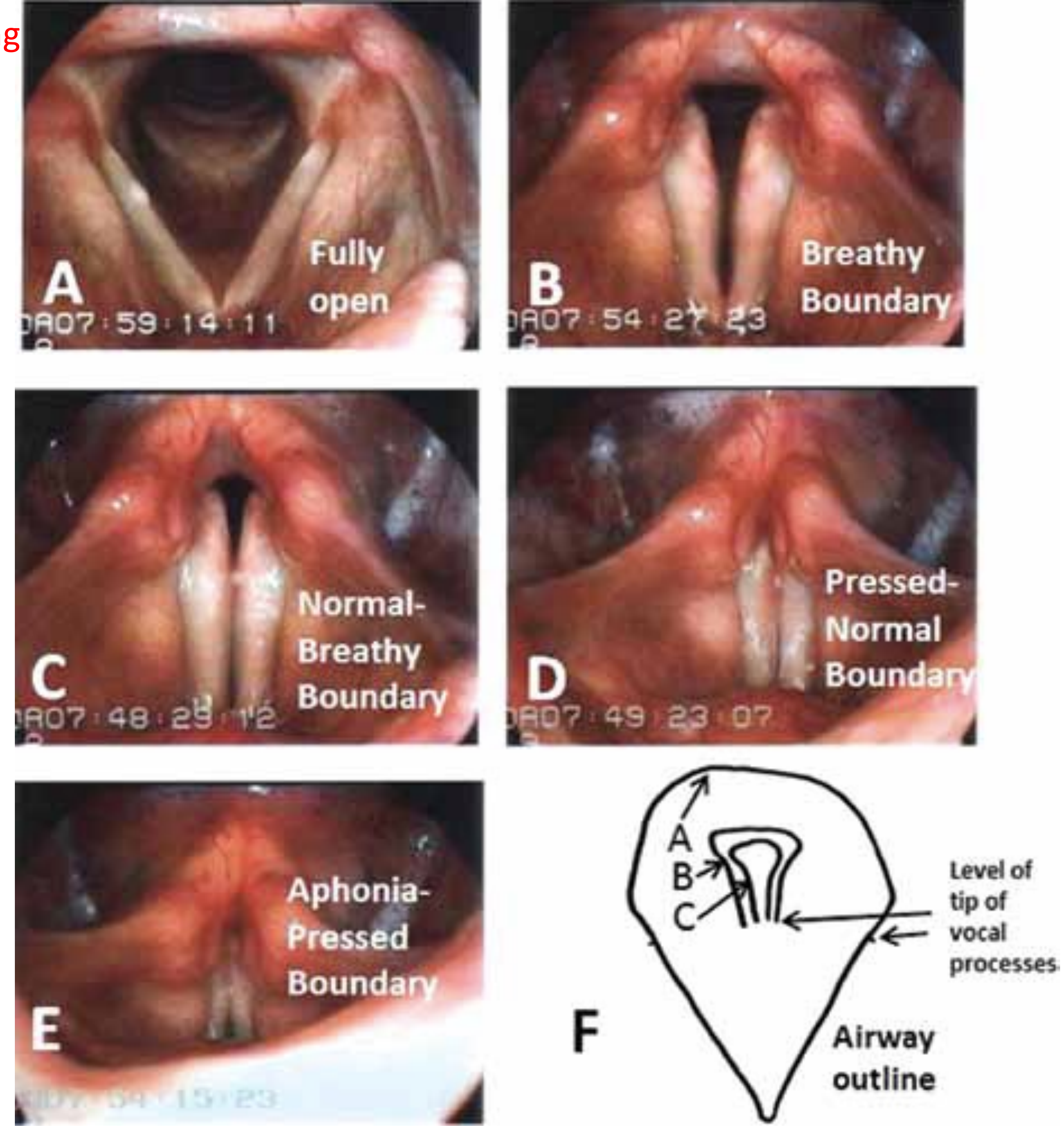
Clinical Importance re: Adduction

- When your client phonates, how close do you think
  - the vocal processes are?
  - the vocal folds are?
  - the arytenoid cartilages are?
- When your client phonates,
  - how much antagonistic action do you think there is?
  - is there general heightened muscle contraction, or general relaxation?

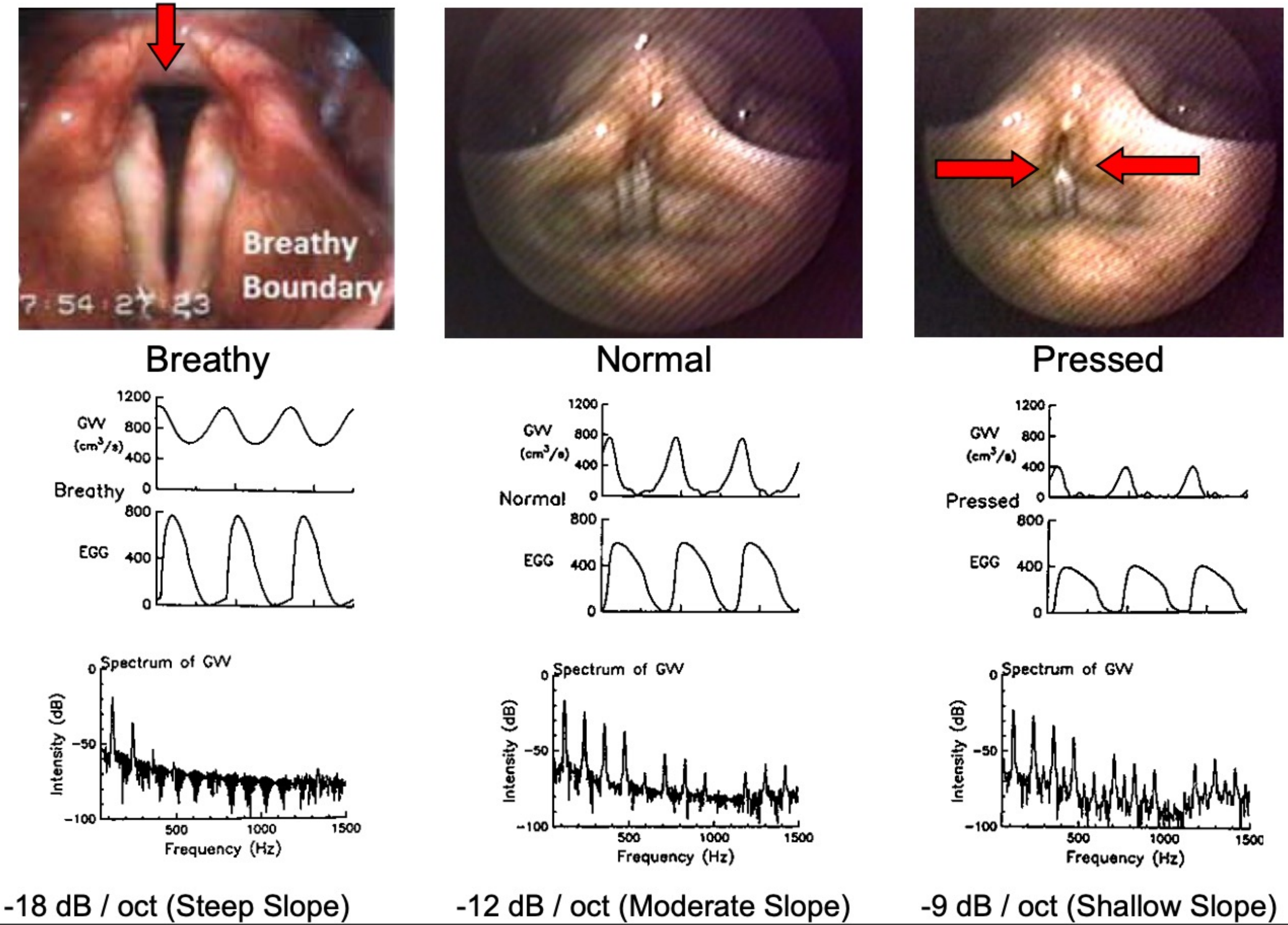
Breathing

Pre-phonatory configuration

- Adductory configuration of the VFs prior to vibration



Scherer, R.C. (2014). "Laryngeal function during phonation", Chapter 8 in Rubin, J.S., Sataloff, R.T., and Korovin, G.S. (eds), Diagnosis and Treatment of Voice Disorders, Fourth Edition, Plural Publishing, Inc., San Diego. (May 2014; pp 117-144; ISBN13: 978-1-59756-553-0).



This set of figures show the glottal configuration (top panes), airflow pattern and vocal fold contact area (middle panes) and source spectrum (bottom panes) for breathy (left panes), normal (middle panes), and pressed (right panes) voice qualities.

More adduction → ↑ medial compression, ↓ airflow, ↑ contact time, and a more shallow spectral slope

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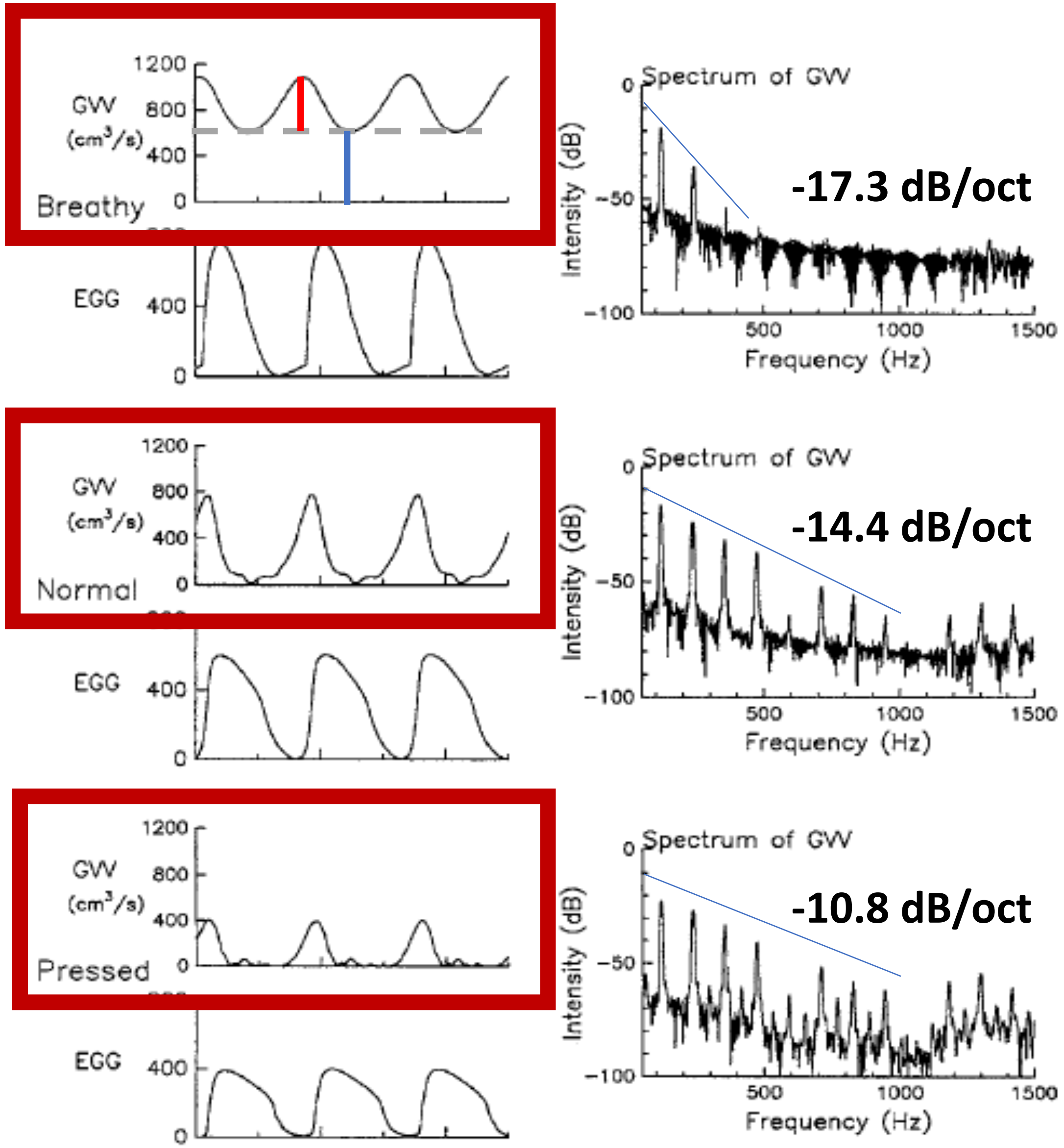
Vocal Fold Adduction (closeness of the arytenoids)

- **<u>Aerodynamics</u>** → **DC** and **AC** airflow
  - glottal flow waveform changes with adduction
- Acoustics → Slope of the source spectrum
- Physiology → EGG CQ
- Perception → voice quality
  - breathy,
  - balanced,
  - pressed



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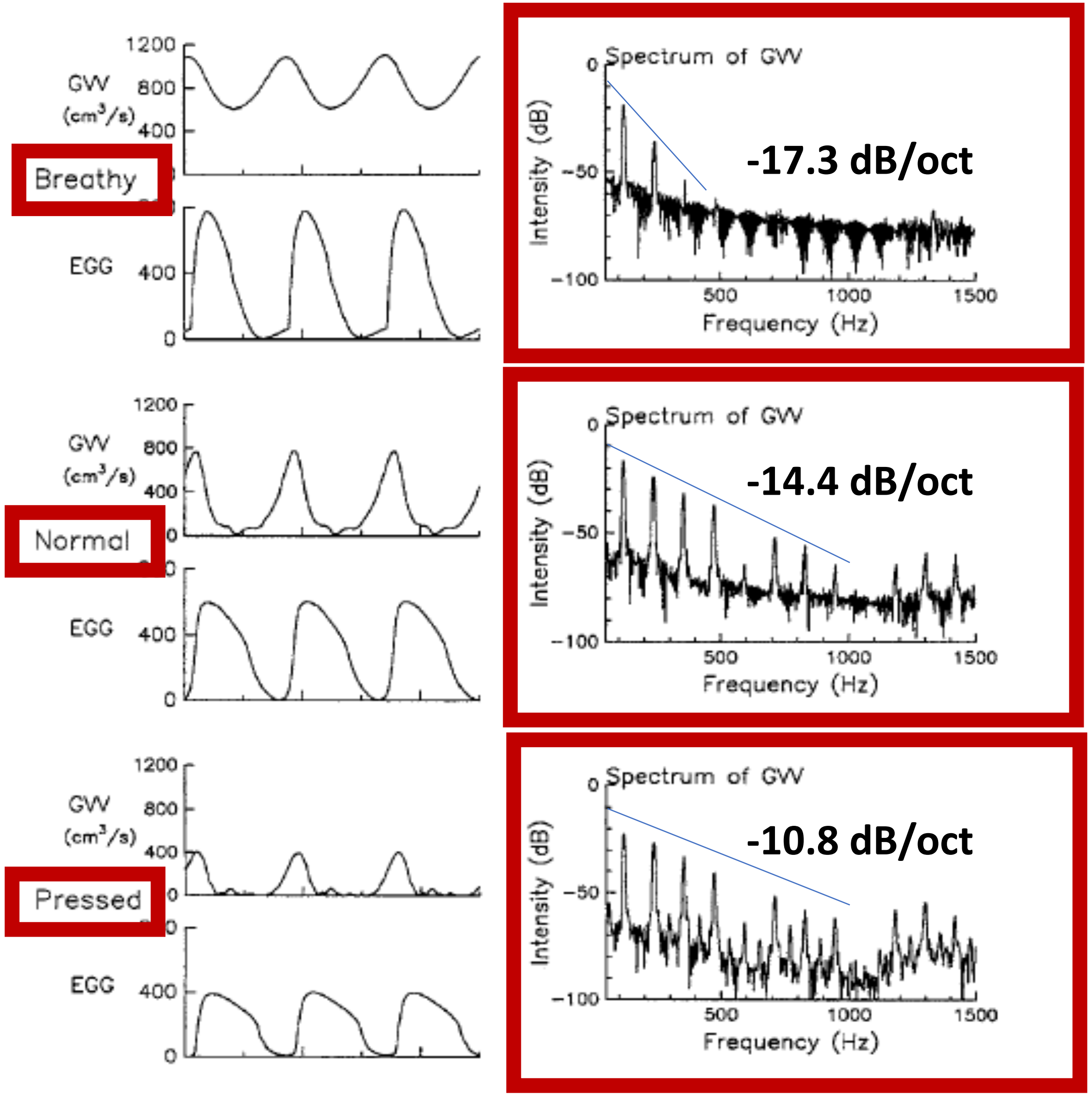

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- **<u>Physiology</u>** → EGG CQ (contact quotient)
- Perception → voice quality
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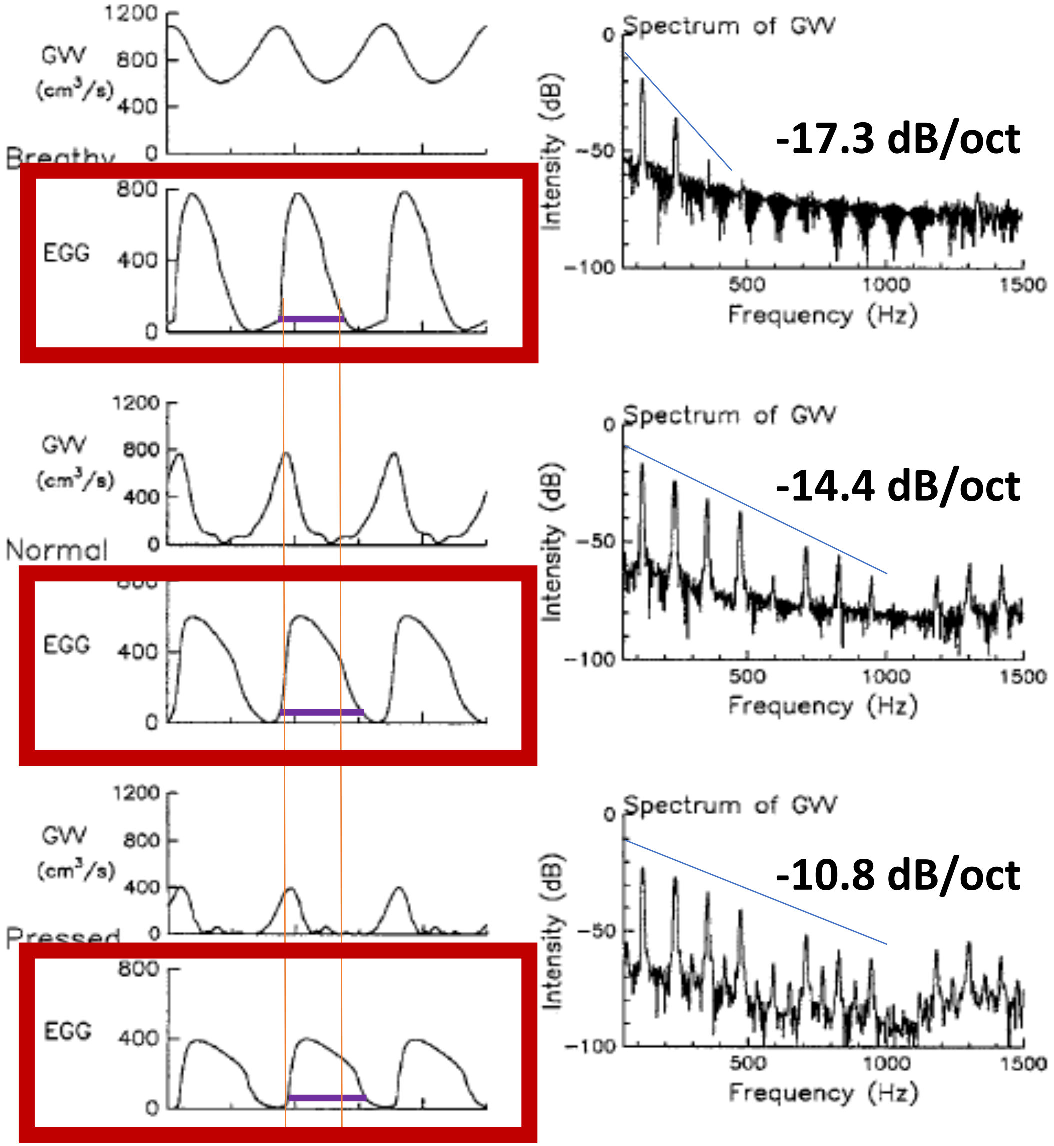

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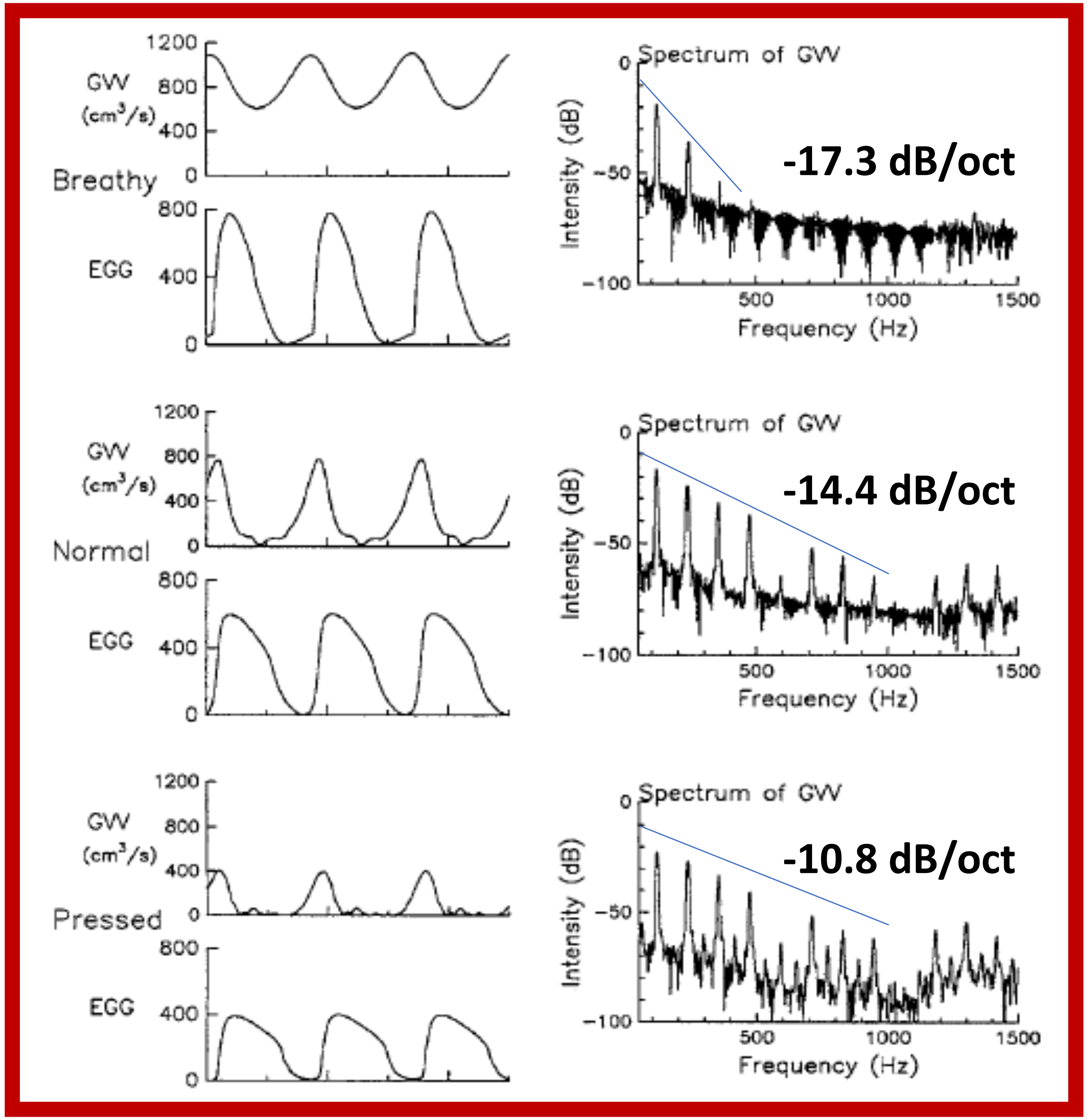

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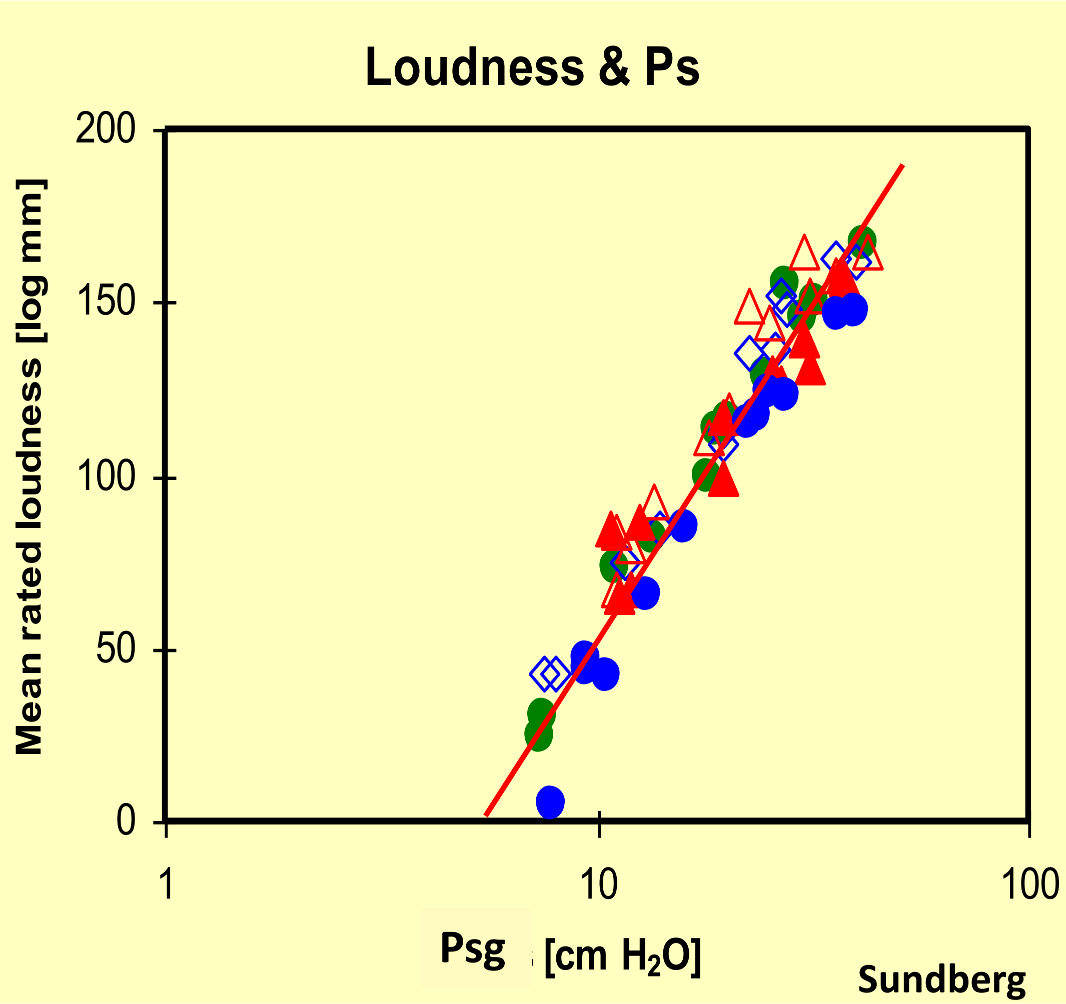
What Produces and Controls Loudness for Voicing?

- ***Loudness*** of the output sound depends on
  - ***Subglottal pressure*** (Psg) [see figure →]
  - ***Glottal adduction***
    - Breathy and pressed can be ***less loud*** than normal adduction (for the same Ps).
  - ***Vocal tract shaping***
    - Formant locations, and how "intense" they are – greater SPL when harmonics are near formants

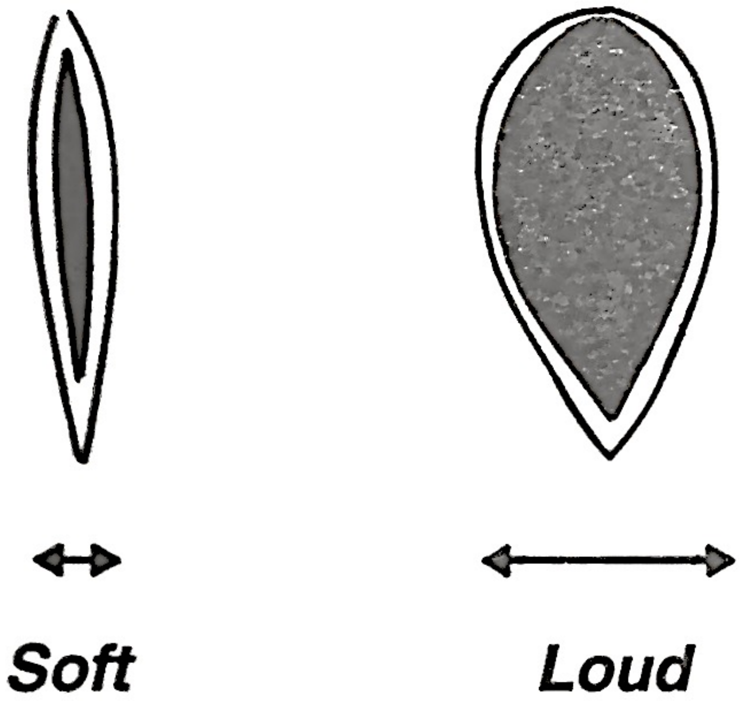


Termination of Voicing (4 ways)

1. Decrease adduction (abduct) outside of phonatory adductory range
2. Increase adduction (medial compression) outside of phonatory adductory range
3. **Decrease subglottal pressure**
4. Increase downstream resistance (to infinity; e.g., sustain /b/)

Psg, amplitude of vibration, and intensity

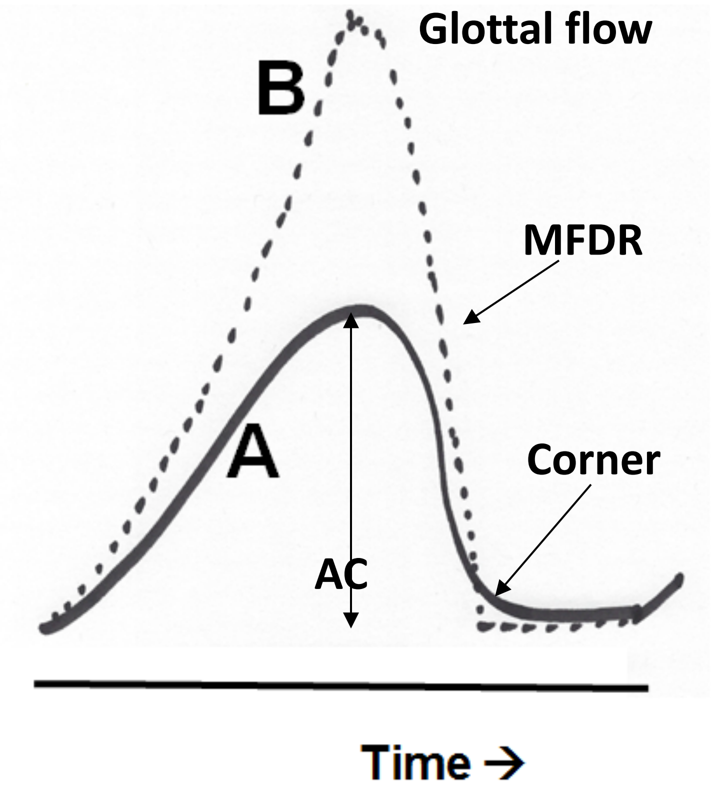
- ↑ in Subglottal pressure, results in ↑ in amplitude of VF vibration
- ↑ in VF amplitude, results in ↑ in mean volume airflow, intensity, and SPL

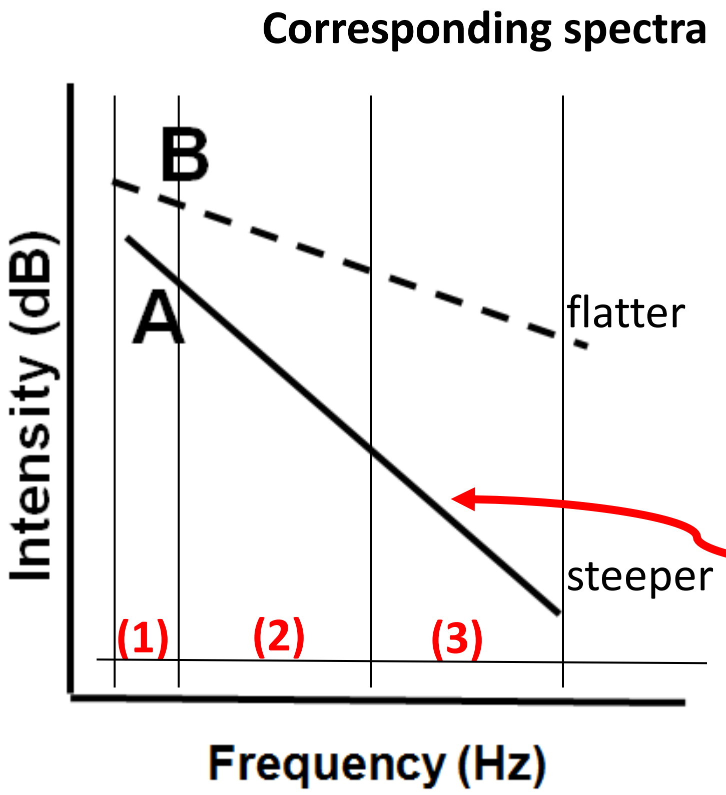


Kent, R. D. (1997). *The speech sciences*. San Diego, CA: Singular Publishing Group.

What Produces and Controls Loudness for Voicing?

- ***Loudness*** and oscillation of the vocal folds:
  - Greater loudness usually has
    - **Increase in Ps**
      - Alter glottal flow to produce louder sound
      - Greater lateral excursions of the vocal folds
      - [And thus raise $\boldsymbol{f_o}$]
    - Greater glottal adduction
    - Stronger mucosal wave motion
    - Glottal flow pulse changes…





Bowed vocal folds (lack of glottal closure during cycle)

→ <u>softer voice, more DC flow, less AC flow, aperiodicity</u>

- NOTE: bowing and more DC flow leads to:
  - **more rounding at the shut-off corner** of the glottal flow
  - **less MFDR** (maximum flow declination rate),
  - **more breathy noise** from the greater DC flow,
  - **less overall intensity**
  - **less energy in the higher harmonics**
    - → **a softer voice that is not as "bright"**

<u>Glottal flow A vs Glottal flow B</u>:

(1) AC flow is higher:

- **Double the height → 3-7 dB increase in intensity of the f_o**

(2) Flow shutoff slope (MFDR) steeper:

- **Double the steepness → 5-9 dB increase in overall SPL**

(3) Shutoff corner sharper:

- **Increase shutoff corner sharpness → 10-20 dB increase in intensity of higher harmonics (above 1500 Hz)**

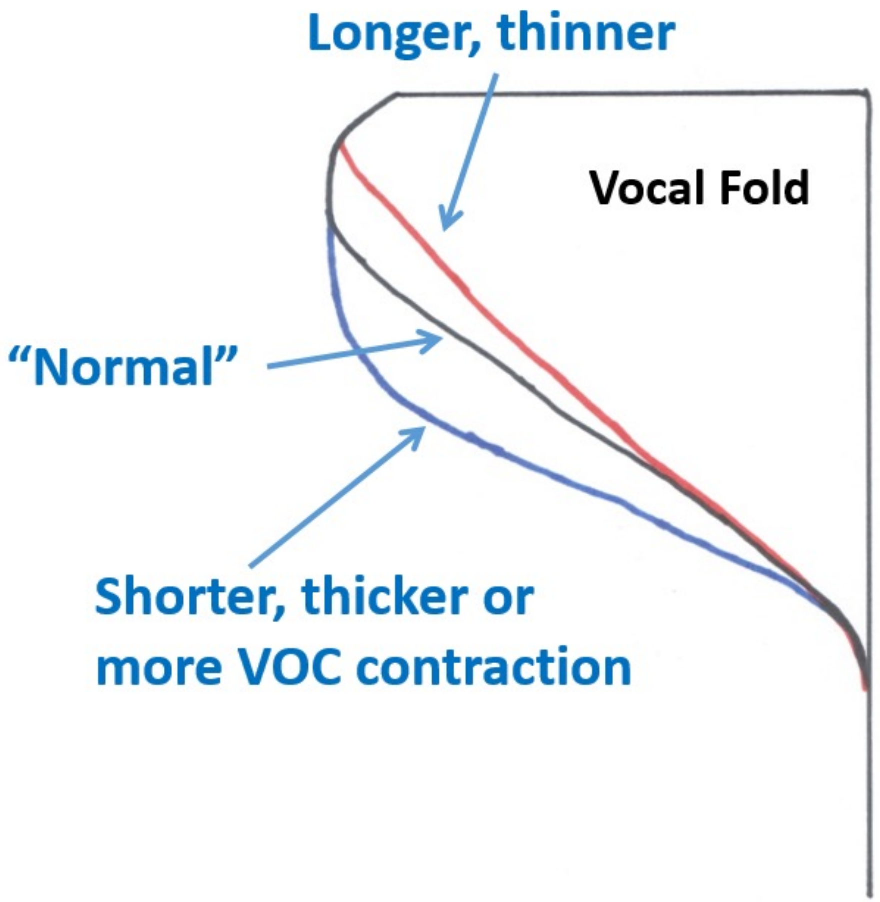
What Produces and Controls Fundamental Frequency (f_o)?

F0 $\propto \sqrt{\frac{k}{m}}$ where *k* is stiffness and *m* is mass

An **increase of f_o** during speech can be due to:

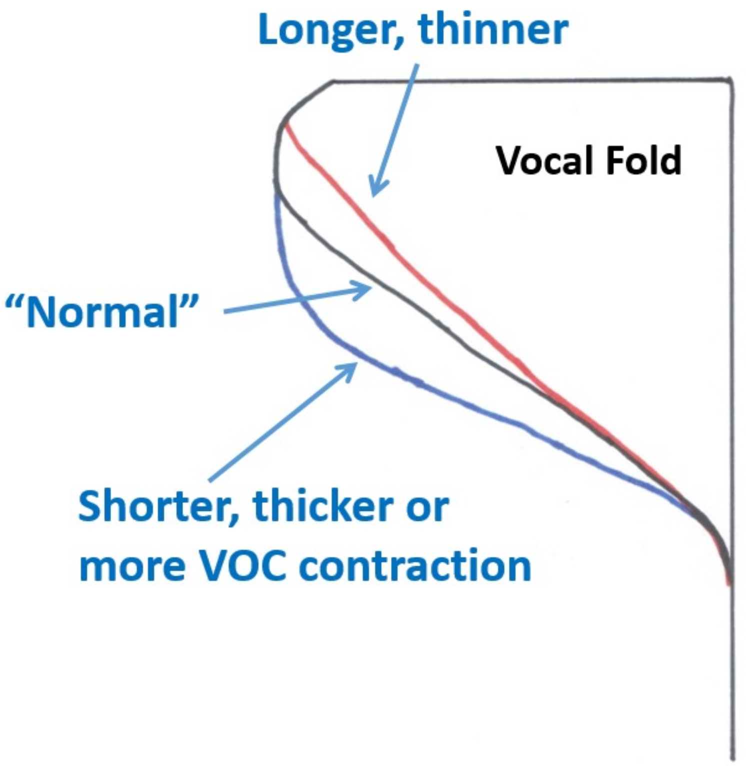
1. Vocal fold length increase

- CT vs. VOC antagonism, CT is "winning"
  - ***Increases passive tension*** of mucosa and vocalis
  - ***Decreases the amount of mass in motion*** (if Ps does not increase)



Medial Contour of the Vocal Folds

- Depends on
  - Lg, length of the folds
    - Lg longer → contour sharper
  - VOC contraction levels
    - More VOC contraction → contour less sharp & longer vertically
    - Contraction lateral to the VOC (i.e., of the lateral thyroarytenoid muscle) may also control the contour by adding some medial bulging



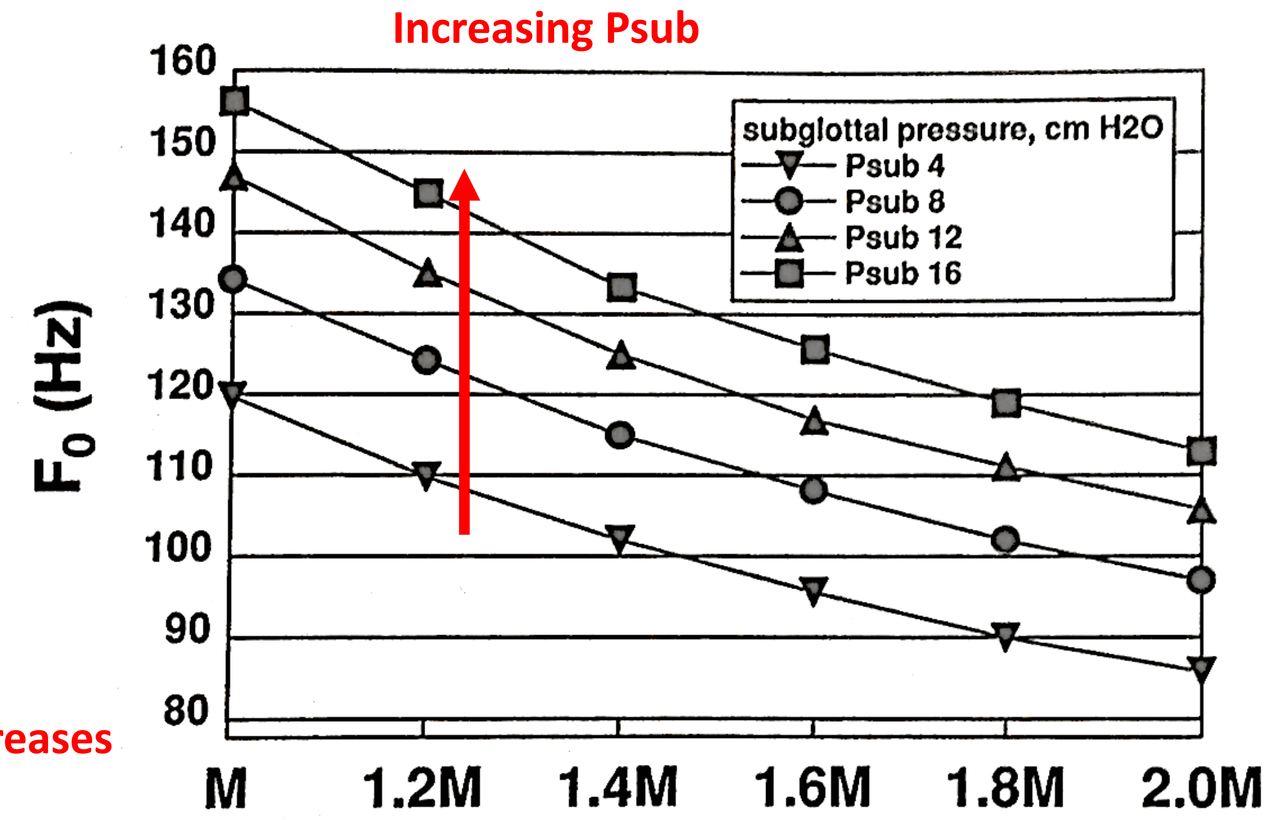
What Produces and Controls Fundamental Frequency (*f_o*)?

An **increase of *f_o*** during speech can be due to:

2. Subglottal pressure increase

- Higher subglottal pressure increases ***f_o*** by increasing the ***dynamic stretch*** of the vocal fold each cycle (VF goes out further, comes back faster)
- It's a small direct relationship b/c the increased lateral stretch of VF is counteracted by addition of more mass in vibration

Also note how *f_o* decreases as mass increases



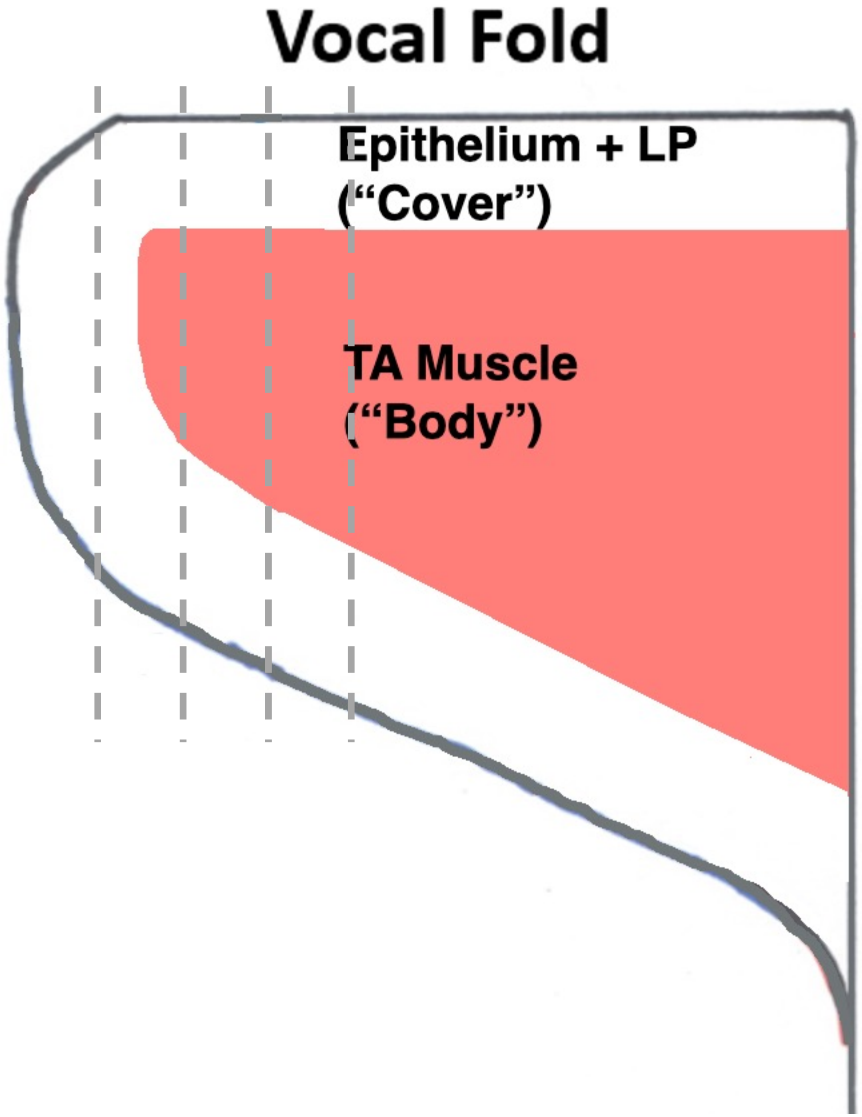
Scherer, R. C. (1991). Physiology of phonation: a review of basic mechanics. *Phonosurgery: Assessment and surgical management of voice disorders*, 77-93

What Produces and Controls Fundamental Frequency (f_o)?

An **increase of f_o** during speech can be due to:

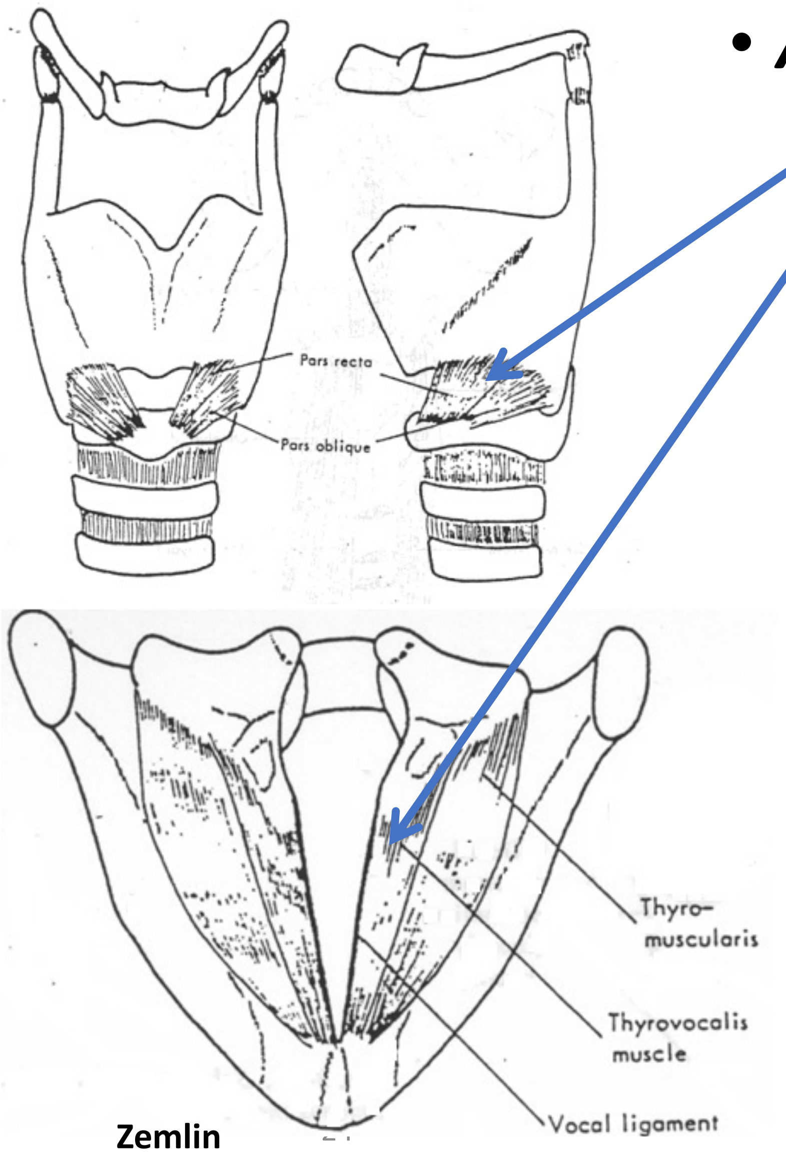
3. Contraction level increase of the vocalis muscle

- Greater contraction ***increases the stiffness*** (active tension of the VOC)
- The ***more vocalis muscle*** that is part of the tissue vibration (see *dashed lines*), the greater the increase in f_o

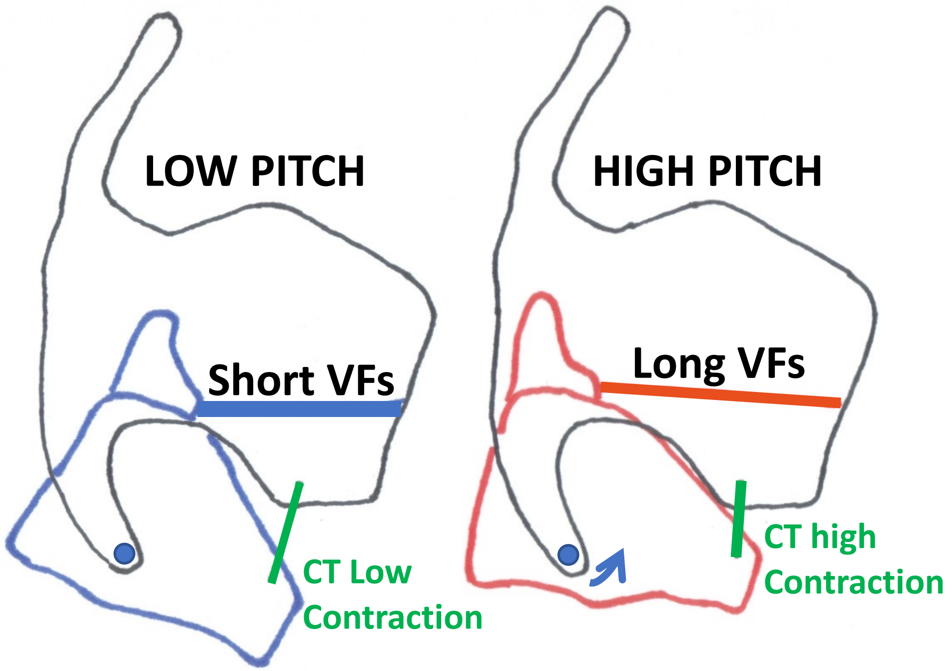


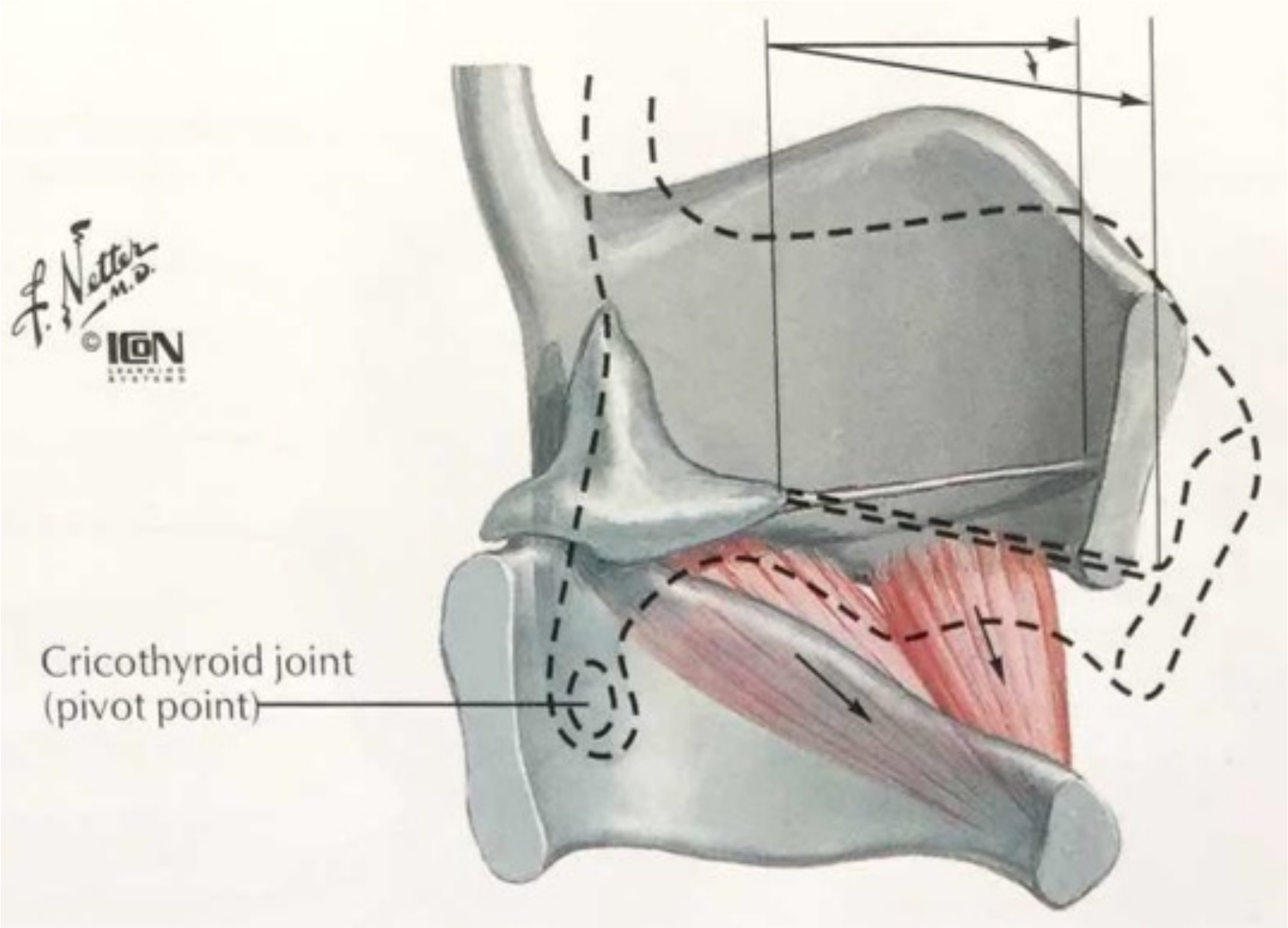
What determines Vocal Fold Length?

- ***Antagonistic Muscle Groups***
  - ***Cricothyroid muscles*** vs
  - ***Vocalis*** (medial thyroarytenoid) muscles

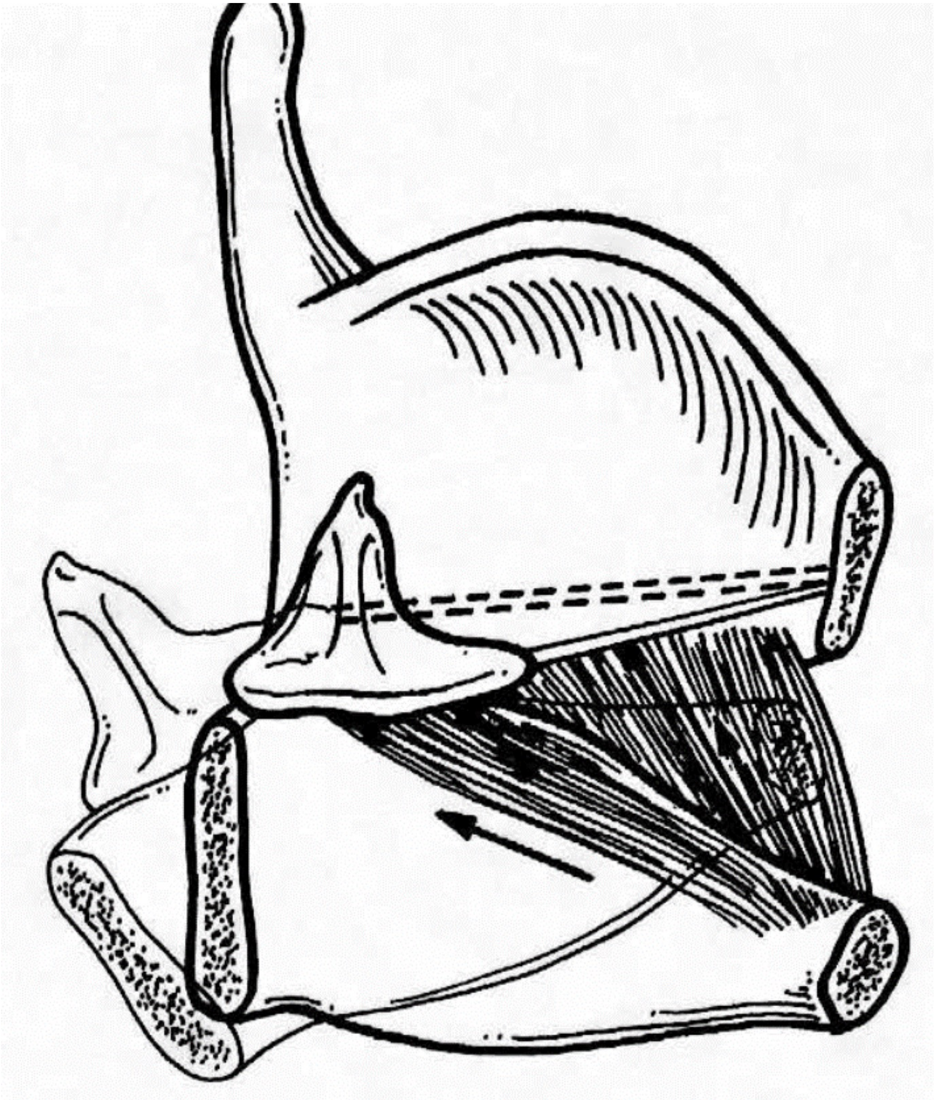


Zemlin





Netter, 2005, plate 75.

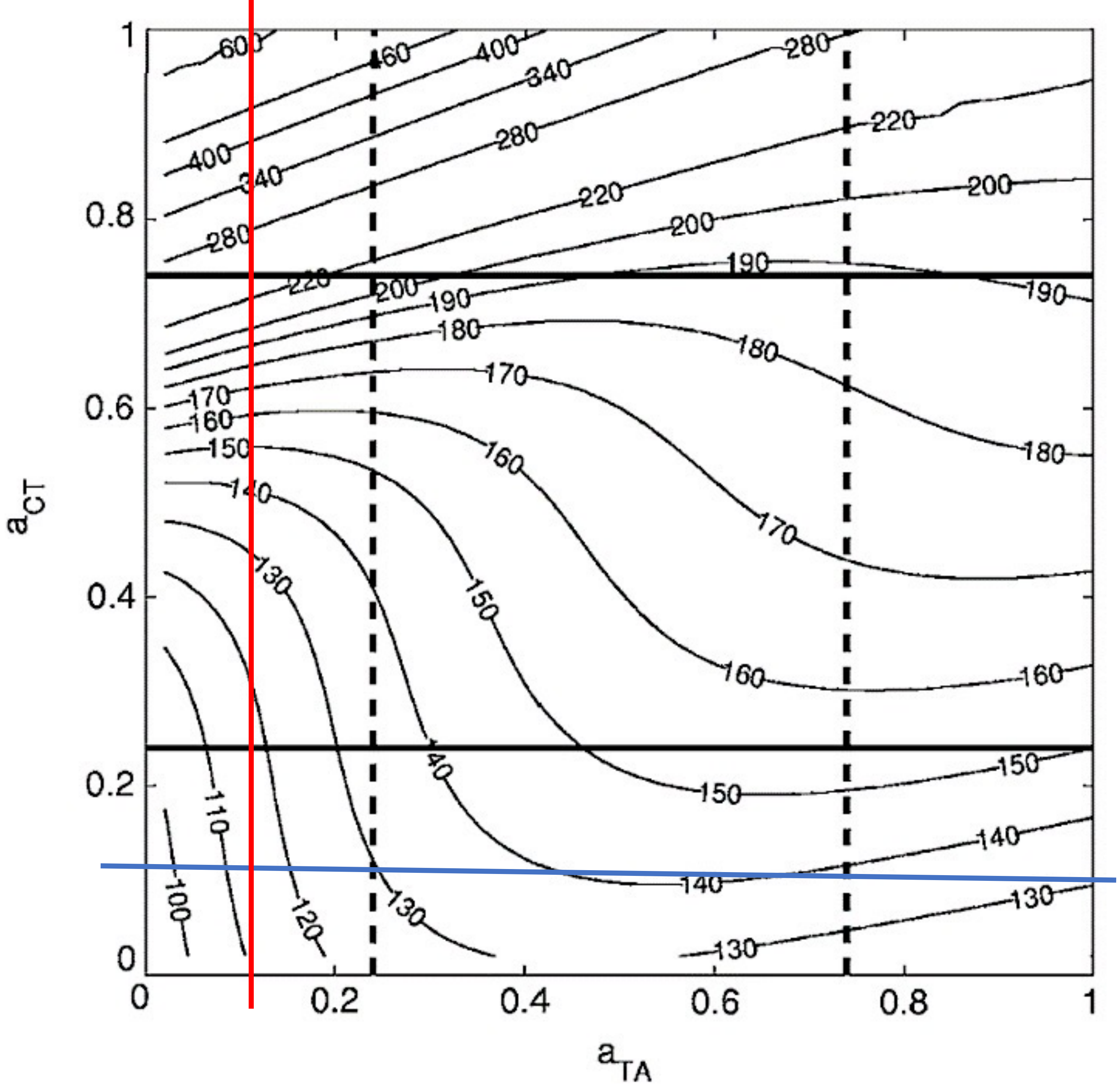


Sataloff, 2005, p. 157

This figure shows the relationship between:

CT muscle activation (aCT),
TA muscle activation (aTA), and fundamental frequency (F0)

Constant F0s are shown via the different curves



Main point: CT is the main pitch changing muscle

Lowell, S. Y., & Story, B. H. (2006). Simulated effects of cricothyroid and thyroarytenoid muscle activation on adult-male vocal fold vibration. *The Journal of the Acoustical Society of America, 120(1)*, 386-397.

What Produces and Controls Fundamental Frequency (f_o)?

Clinical importance:

- ***Monotonic low pitch***
  - CT (primarily; and VOC secondarily) not changing contraction levels?
    - ***Paralysis***, paresis?
  - ***Cricothyroid joint disease***? Can not rotate cricoid cartilage
  - ***Habit***?
    - Is used to having little prosodic variation (inflection)
    - Uses low level CT contraction
      - ***Will need to exercise CT – use high pitches, falsetto***
      - ***To alter pitch orientation, get larynx ready for normal pitch and pitch variation***
  - ***Little variation of subglottal pressure?***
    - Will need to exercise the respiratory system (***changing loudness***)

What Produces and Controls Fundamental Frequency (f_o)?

Clinical importance:

- Other situations
  - ***Vocal fry***
    - Vocal folds too short, too adducted, low Ps
    - <u>Do the opposite </u>at first:
      - (1) raise $\boldsymbol{f_o}$,
      - (2) abduct the folds (use a breathy voice),
      - (3) increase loudness with concept of “more air flow”,
      - (4) abduct vocal folds at the end of breath groups
  - ***Creaky voice***
    - This is like fry at a higher underlying pitch
    - <u>Do the opposite </u>at first:
      - (1) abduct the folds (use a breathy voice),
      - (2) increase loudness with concept of “more air flow”,
      - (3) abduct vocal folds at end of breath groups

What Produces and Controls Fundamental Frequency (f_o)?

Clinical importance:

- Other situations
  - ***Pitch too high*** – CT contracted too much
    - Do the opposite – practice low pitches, fry, growls, etc., to relax CT
  - ***Too much variation of f_o*** – train to recognize the situations, alter
  - ***Unstable pitch, tremor pitch*** – medical/neurological situation first

Summary

- **Subglottal Pressure Increases → Sound Intensity (loudness) and fundamental frequency (F0) (if muscle contractions are held constant)**
- **VF Stiffness Increases → Fundamental frequency (pitch) Increases**
- **VF Mass Increases → Fundamental frequency (pitch) Decreases**
- **Adduction increases → Spectral Slope (sound quality) Changes**
  - **Continuum: No phonation – Breathy – flow or normal – pressed no phonation**

Summary

- CT vs. VOC --------------------→ Lg --------------
- PCA vs LCA & INT & LTA ---→ Add -----------
- IntI vs ExtI & Diaph vs Abd M's → dV_L/dt --

| ⟶ **Ps**

- PCA vs LCA & INT & LTA
  - →Where the vocal processes are
- IA or INT
  - →Where the posterior arytenoids are and the size of the posterior glottis

| ⟶ **Add**

- CT vs VOC → vocal fold length | ⟶ **Lg**

- Lg & VOC contraction → | ⟶ **VF Tension**

What the client can control:

- ***Factors the client can control***
  - ***Ps***, subglottal pressure
  - ***Add***, glottal adduction
  - ***Lg***, vocal fold length
  - ***And thus most aspects of***
    - ***Pitch, quality [re: adduction], loudness***
- ***Factors the client does not control***
  - Total vocal fold mass
  - Tissue viscosity
  - Vocal fold contour at Speaking f_o (normal? bowed?)
  - Asymmetry of the vocal folds - mass, stiffness, viscosity, contour
- Clinical Importance:
  - Best to ***keep all these factors in mind*** when diagnosing and devising therapy to improve the voice.

A Note about the Variables

- What do we hear?
  - The ***acoustic signal***
- Where does the acoustic signal come from?
  - From the ***laryngeal sound source*** interacting with the ***vocal tract***.
- What is the laryngeal sound source for phonation?
  - The ***changing volume flow (the glottal flow)*** that exists the larynx

A Note about the Variables

- How is the glottal airflow created?
  - As an interaction between ***subglottal pressure (transglottal pressure)*** and ***vibration of the vocal folds***
- How is the vibration of the vocal folds created?
  - As an interaction of the
    - ***subglottal pressure*** (transglottal pressure)
    - ***vocal fold tissues*** (mass, tension, length, medial contour)
    - ***glottal adduction***

Myoelastic Aerodynamic Theory of Phonation

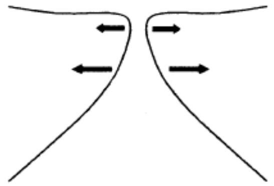
<u>Theory of vocal fold vibration that says VF vibration results from:</u>

1. Muscular contraction to control the gross position of the arytenoids (i.e., adduction),
2. Elastic properties of the VFs (recoil), and
3. Aerodynamic forces (air pressures and flows)

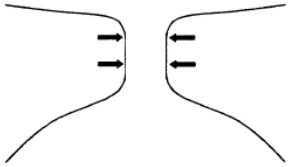
Physics based account of VF vibration (aeromechanical)

Glottal configuration during phonation

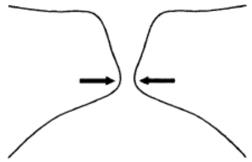
- The shape of the glottis is important for VF oscillation.
- During the opening phase, the glottis has a <u>**convergent**</u> shape.



- When the vocal folds are maximally separated, the glottis has a <u>**rectangular**</u> shape.

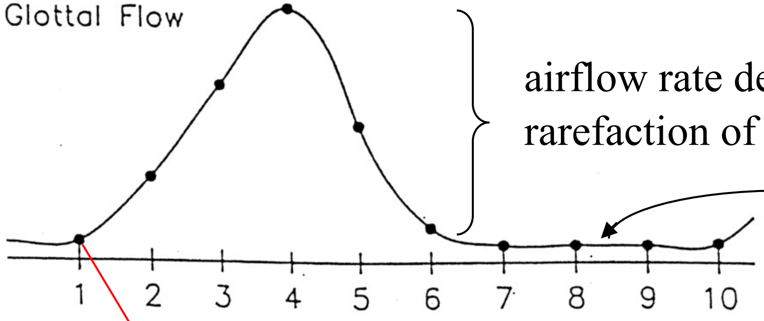


- During the closing phase, the glottis has a <u>**divergent**</u> shape.



- **The different glottal shapes correspond to different intraglottal pressures.**

airflow rate increasing; compression of air just above the glottis.



airflow rate decreasing; rarefaction of air just above glottis

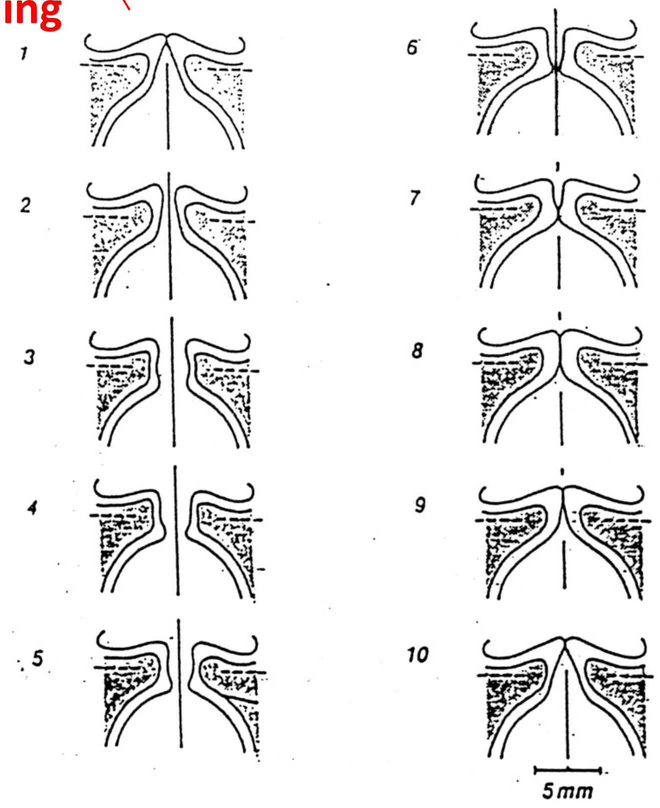
baseline

Scherer

Just before opening

glottal opening

glottal closing

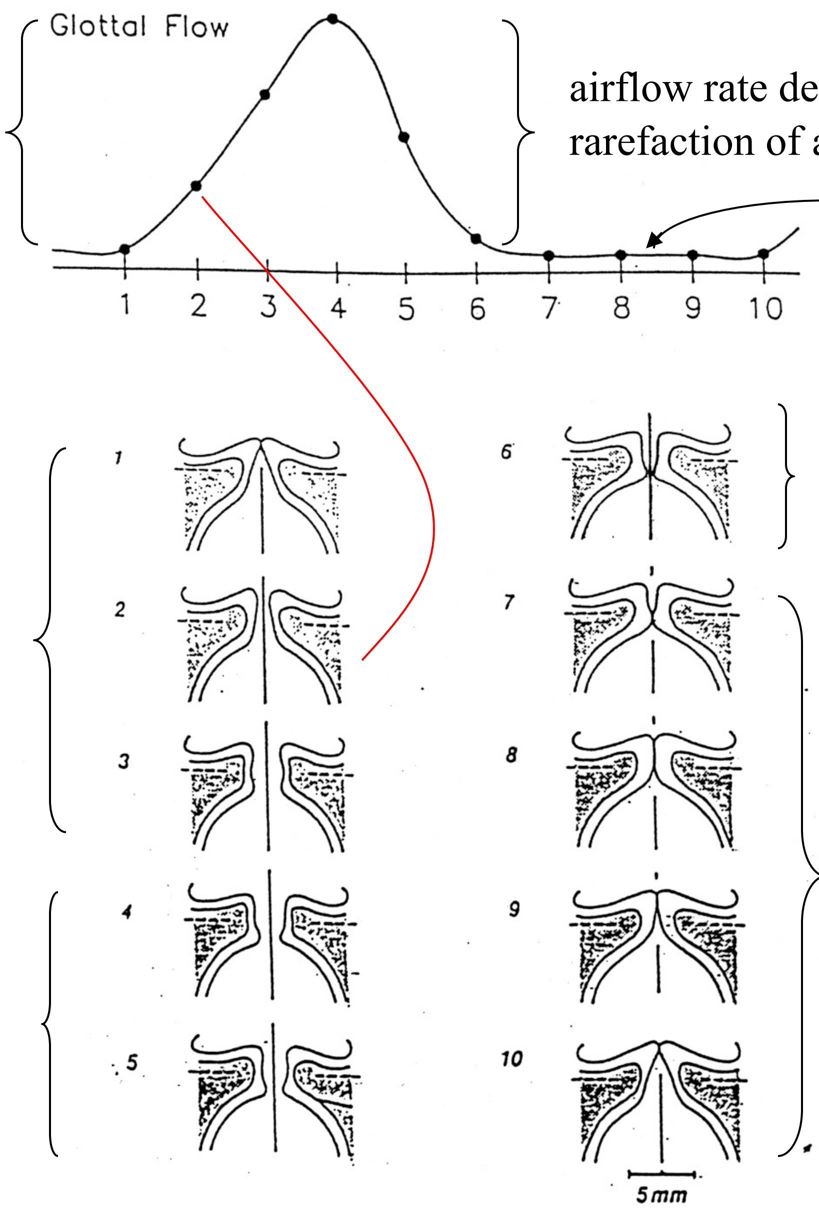


end of glottal closing

closed glottis

Hirano

airflow rate increasing; compression of air just above the glottis.



airflow rate decreasing; rarefaction of air just above glottis

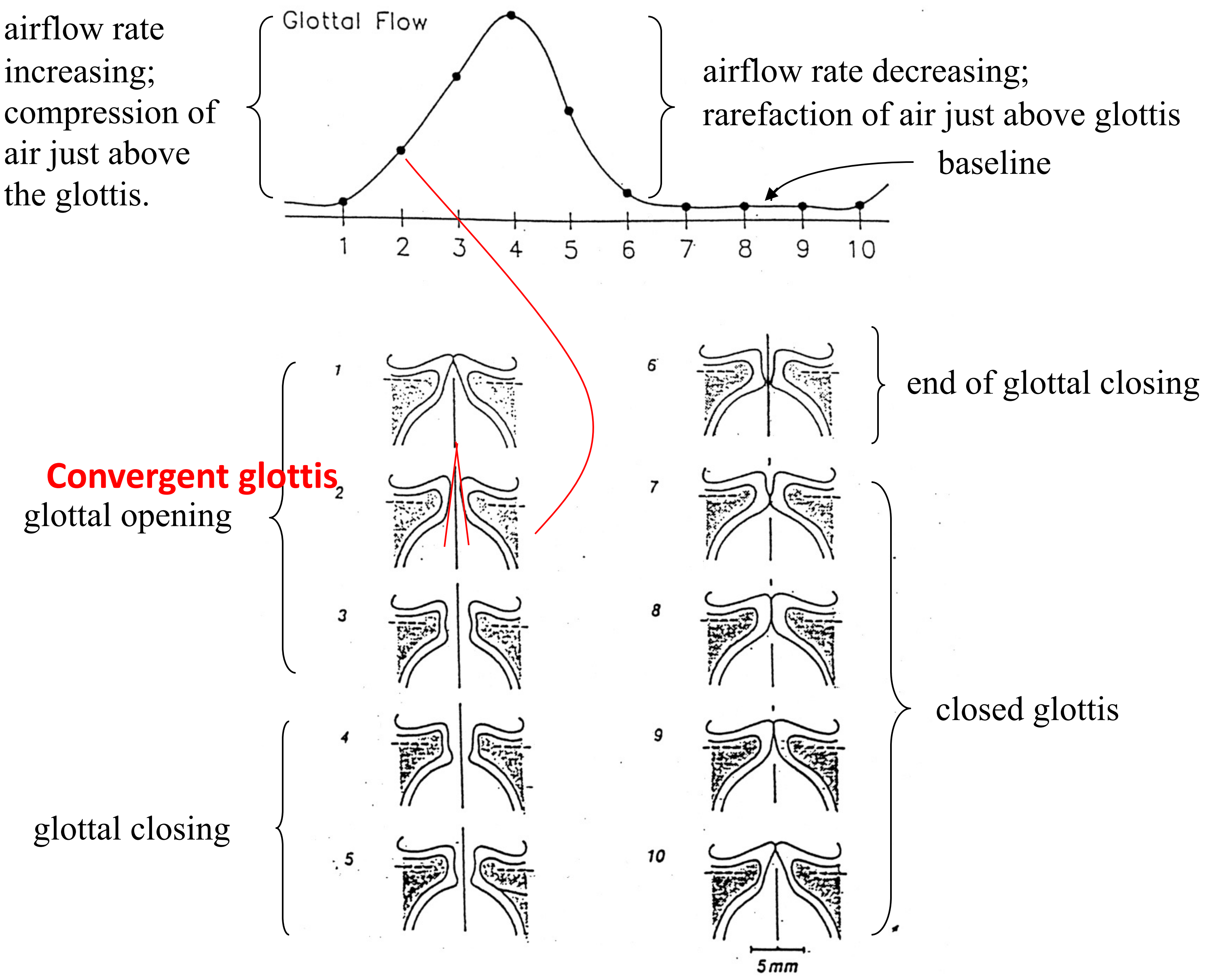
baseline

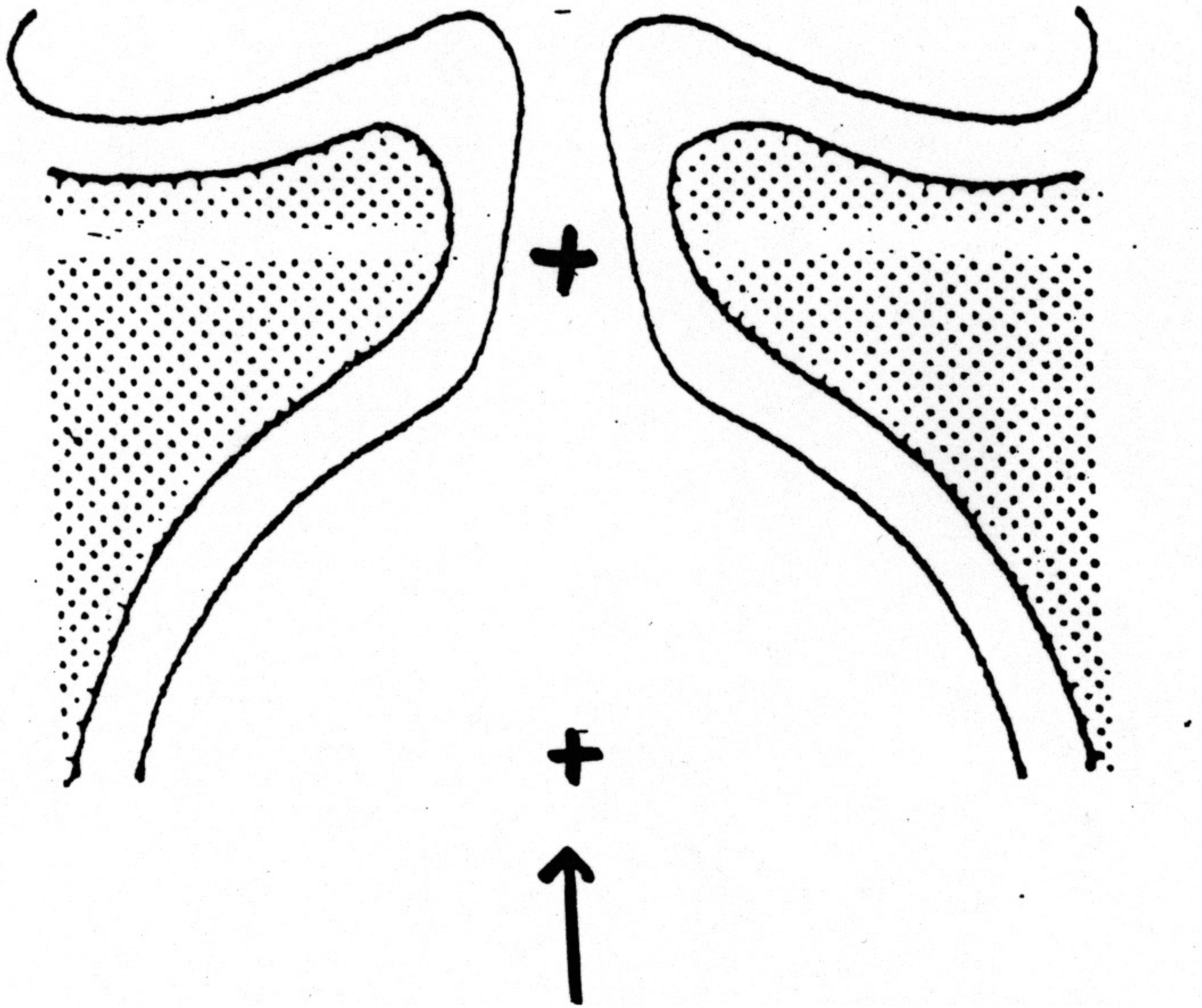
end of glottal closing

glottal opening

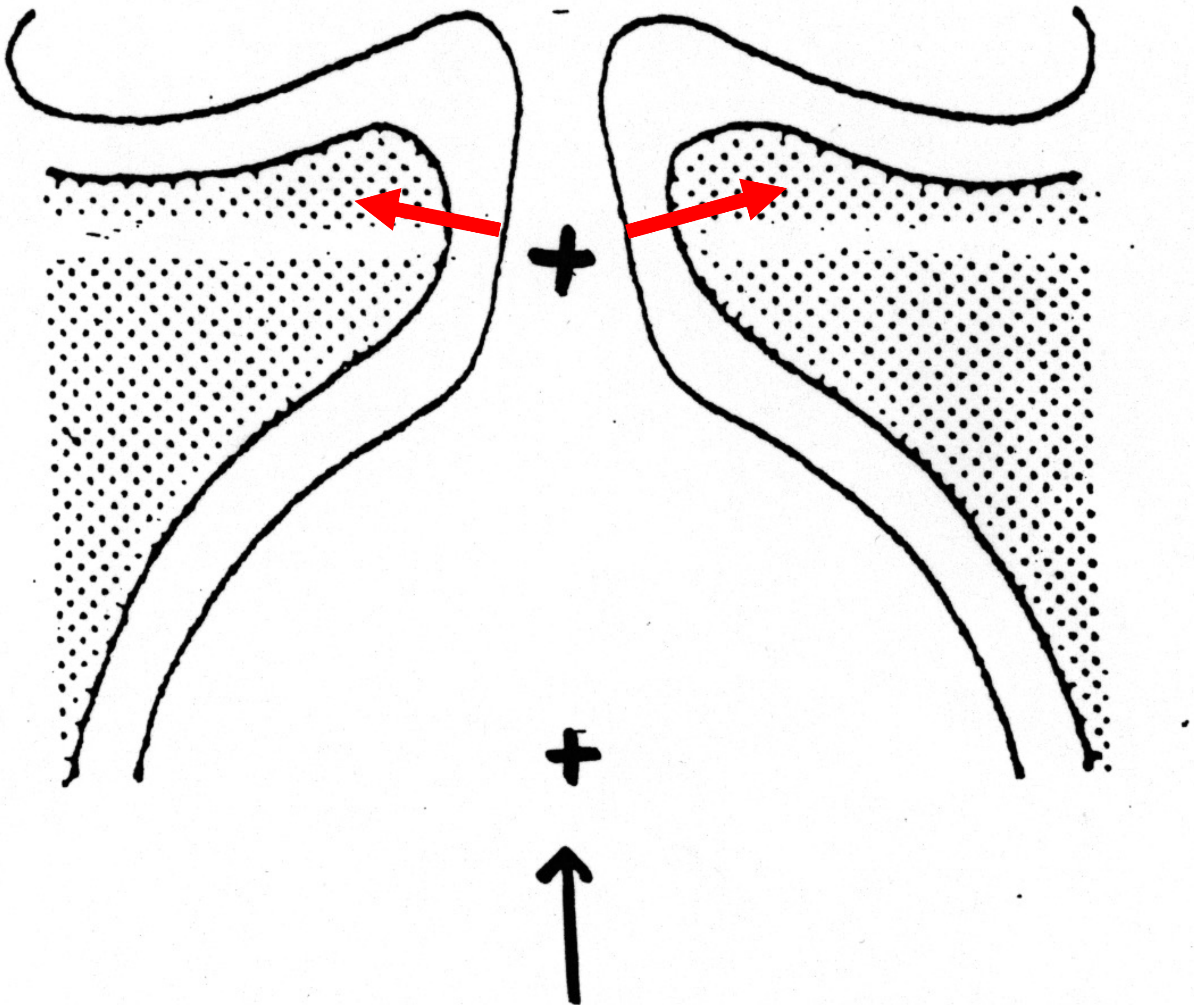
closed glottis

glottal closing


airflow rate increasing; compression of air just above the glottis.
Glottal Flow
airflow rate decreasing; rarefaction of air just above glottis
baseline
1
2
3
4
5
6
7
8
9
10
end of glottal closing
Convergent glottis
glottal opening
closed glottis
glottal closing
5mm



When the glottis has a convergent shape (during opening),
the intraglottal pressure is positive and pushes the folds outward.



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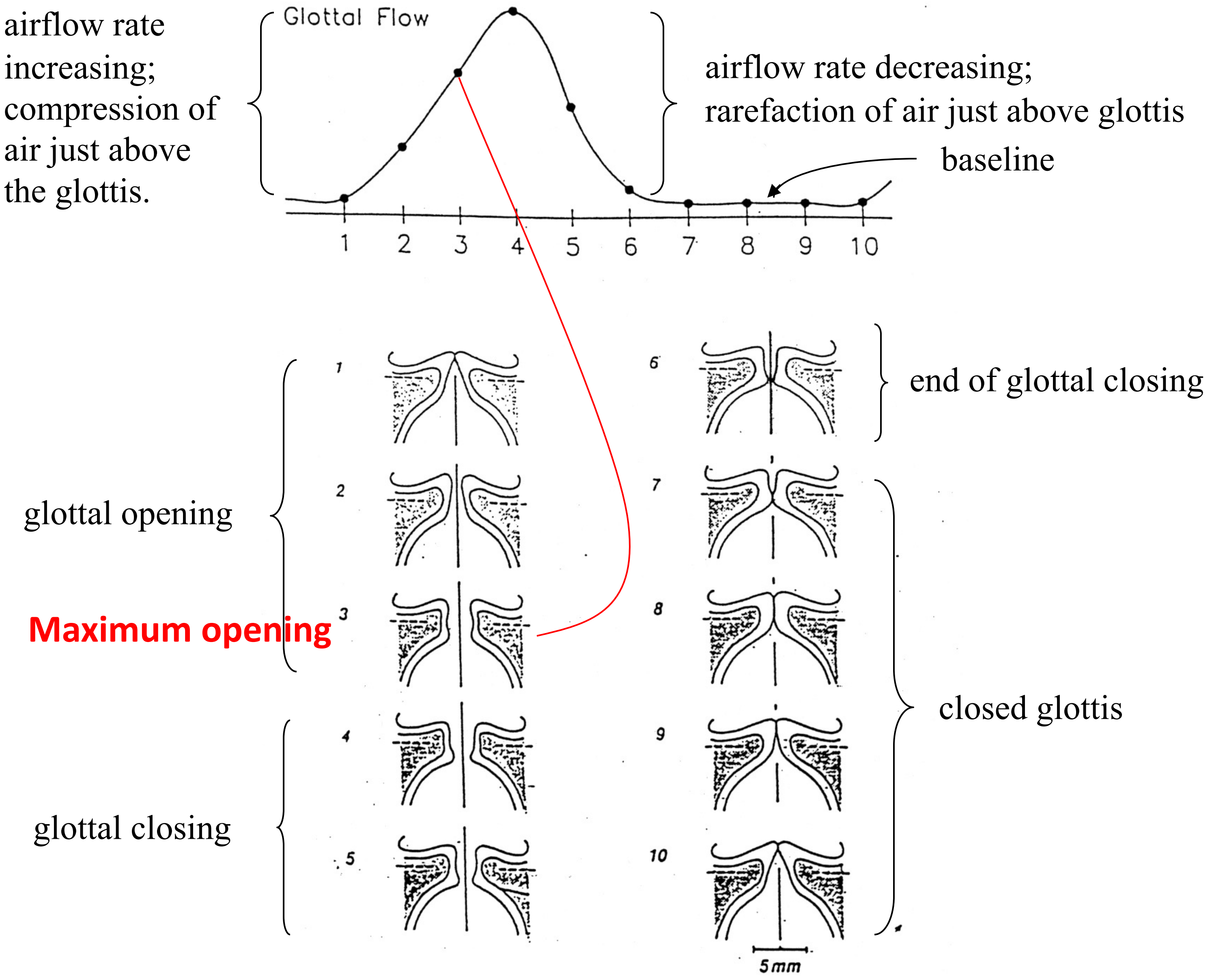
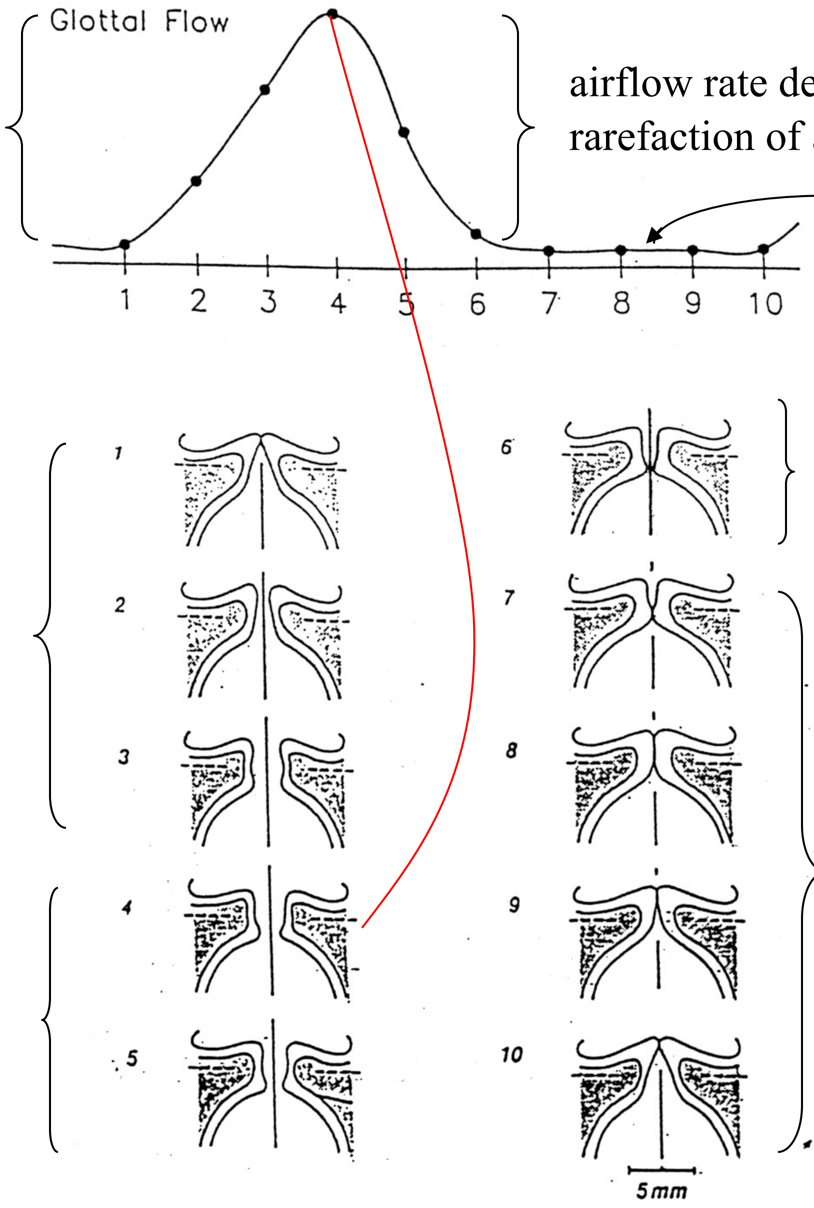

airflow rate increasing; compression of air just above the glottis.
Glottal Flow
airflow rate decreasing; rarefaction of air just above glottis
baseline
1 2 3 4 5 6 7 8 9 10
glottal opening
Maximum opening
glottal closing
end of glottal closing
closed glottis
5mm

airflow rate increasing; compression of air just above the glottis.

airflow rate decreasing; rarefaction of air just above glottis

baseline

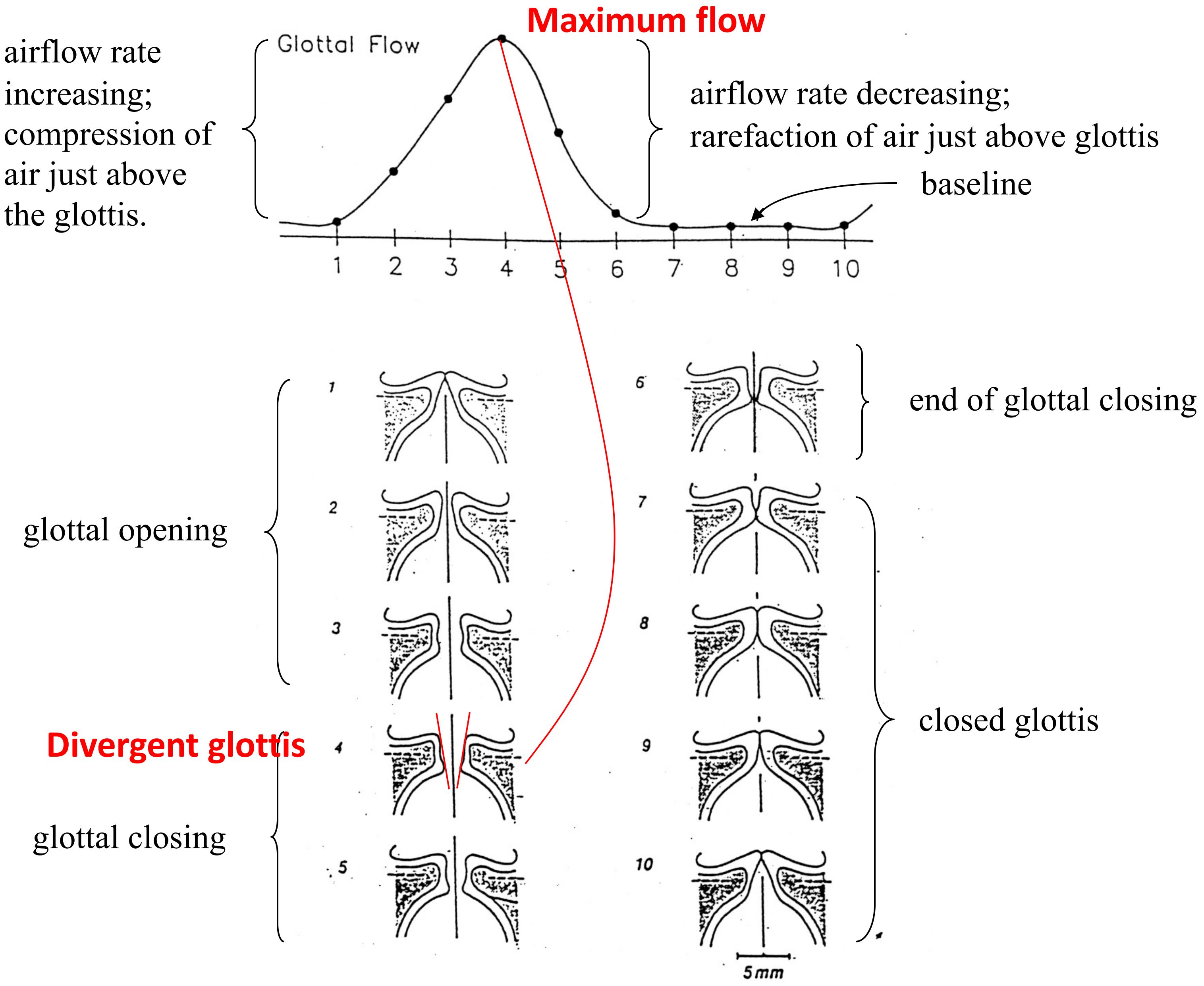


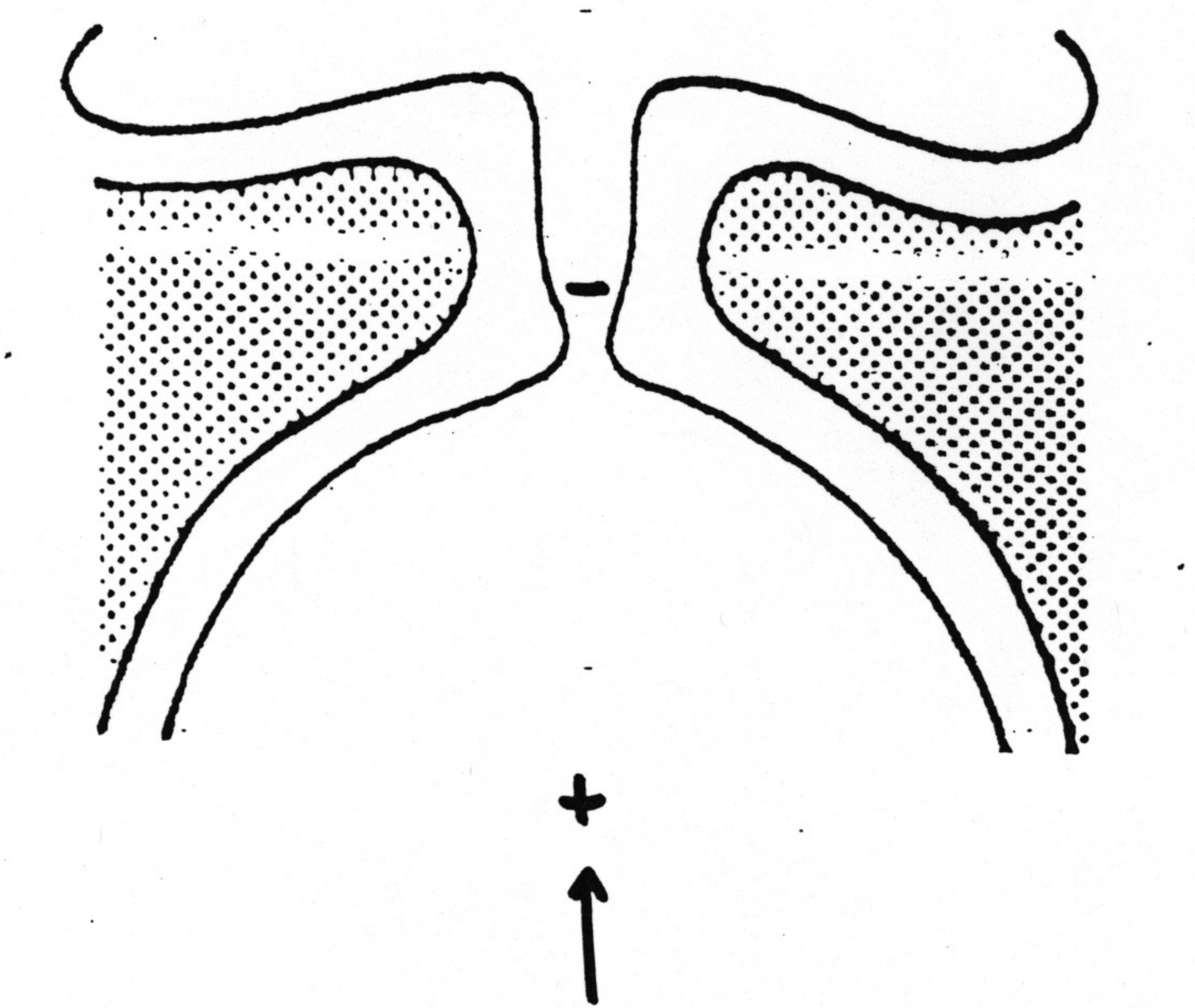
glottal opening

glottal closing

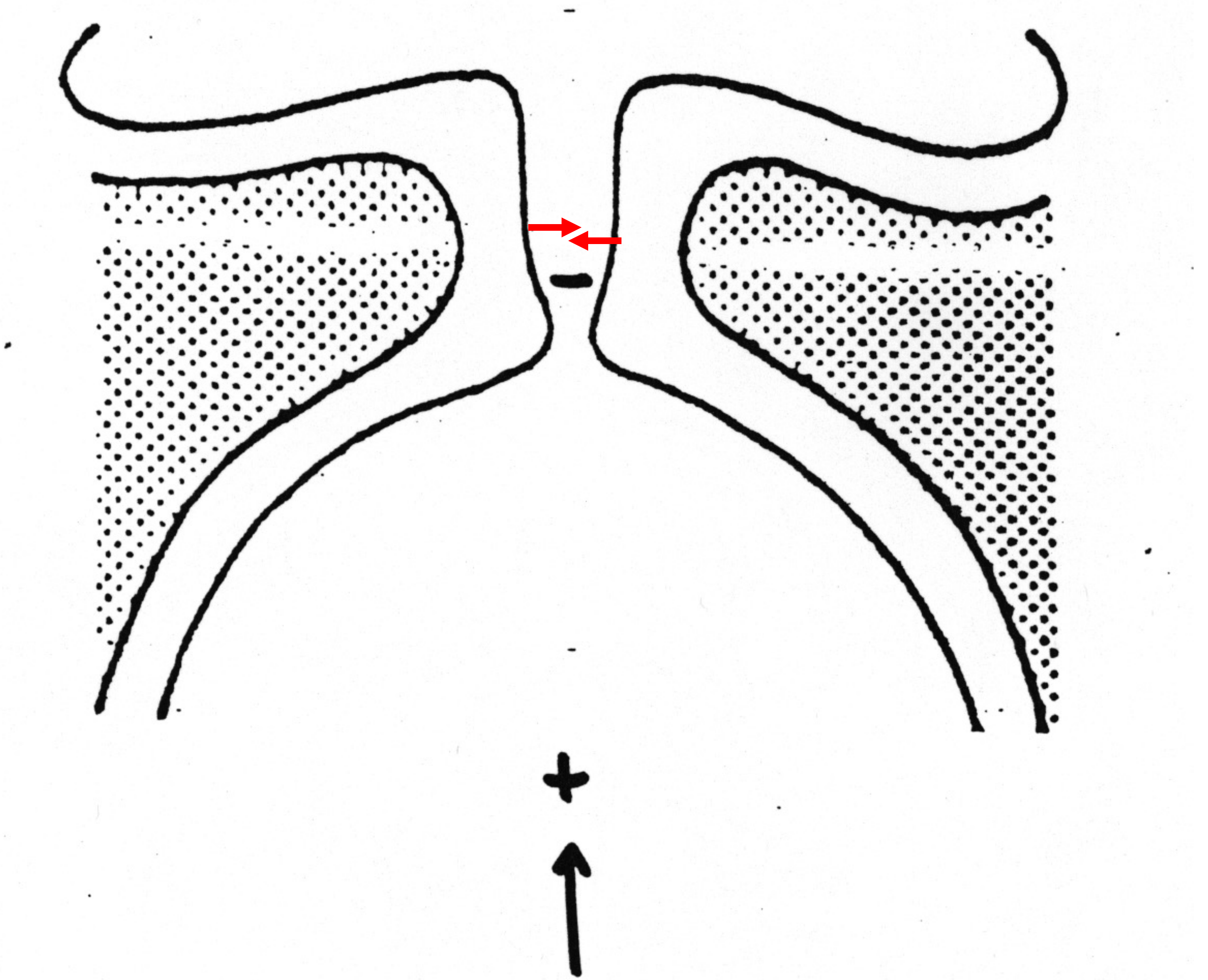
end of glottal closing

closed glottis


Maximum flow
Glottal Flow
airflow rate increasing; compression of air just above the glottis.
airflow rate decreasing; rarefaction of air just above glottis
baseline
1 2 3 4 5 6 7 8 9 10
end of glottal closing
glottal opening
closed glottis
Divergent glottis
glottal closing
5mm



When the glottis has a divergent shape (during closing), the intraglottal pressure is negative to help pull the folds inward.



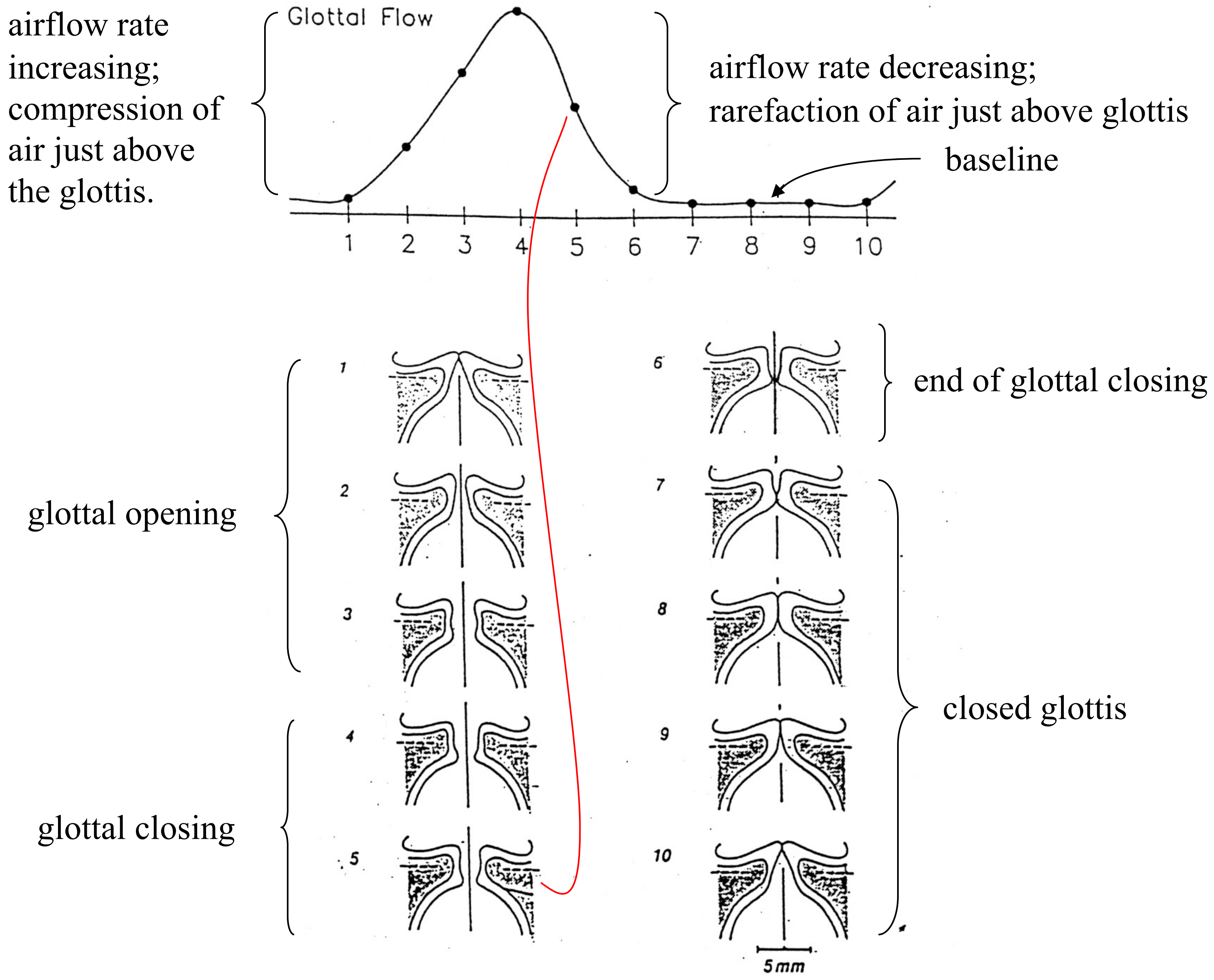
When the glottis has a divergent shape (during closing), the intraglottal pressure is negative to help pull the folds inward.

Pressures in glottis are *negative* during *glottal closing [only!]*:

- Due to:
  - 1. ***Bernoulli equation***: a divergence means the pressure rises, and here the pressure must rise from negative to atmospheric or less (the ***Bernoulli effect***)
  - 2. ***Rarefaction***: when the air is being shut off, the air further above is going faster → particles separate just above the glottis → negative rarefaction pressure → communicates into the glottis
  - 3. Possibly also due to ***vortical structures*** near the top of the glottis that increase the negative pressure there.

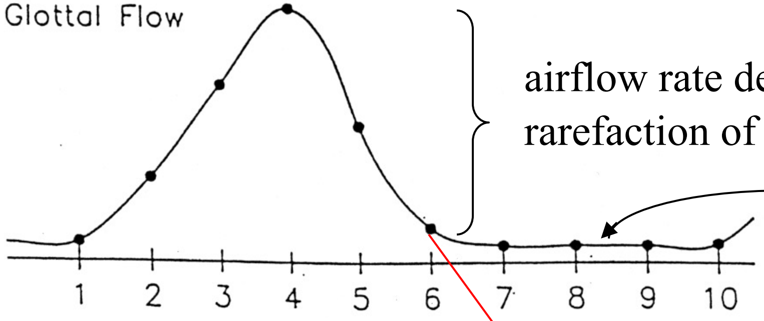
During *glottal closing*:

- Also, the vocal fold tissue is **recoiling back toward midline**
  - It was pushed out laterally during glottal opening, like a mass on a spring.
  - It must come back, or recoil back, toward its home position.



airflow rate increasing; compression of air just above the glottis.
Glottal Flow
airflow rate decreasing; rarefaction of air just above glottis
baseline
1 2 3 4 5 6 7 8 9 10
glottal opening
glottal closing
end of glottal closing
closed glottis
5mm

airflow rate increasing; compression of air just above the glottis.

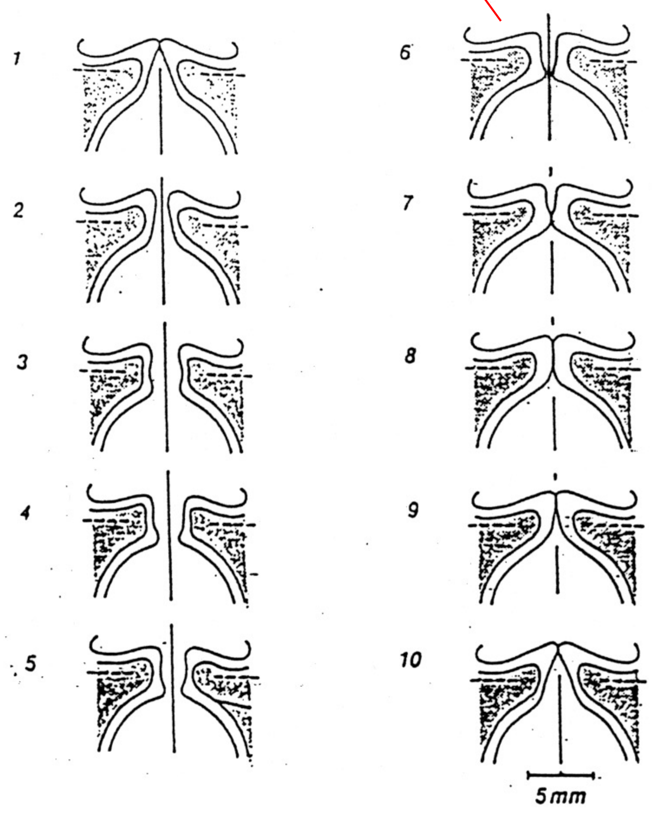


airflow rate decreasing; rarefaction of air just above glottis

baseline

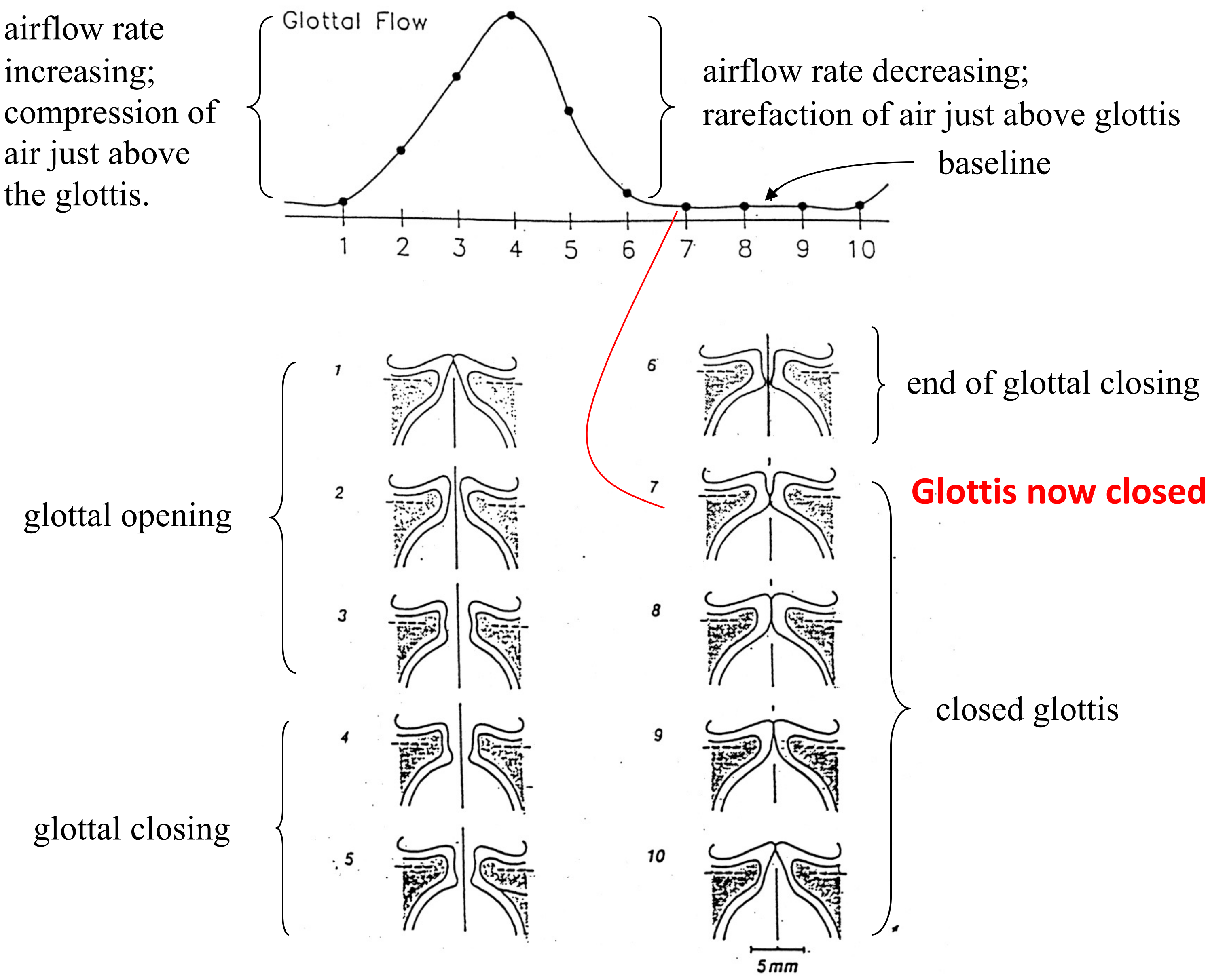
glottal opening

glottal closing



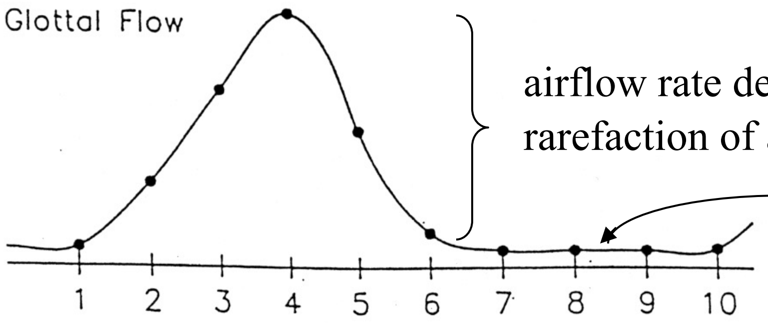
end of glottal closing

closed glottis



airflow rate increasing; compression of air just above the glottis.
Glottal Flow
airflow rate decreasing; rarefaction of air just above glottis
baseline
1
2
3
4
5
6
7
8
9
10
glottal opening
glottal closing
end of glottal closing
Glottis now closed
closed glottis
5mm

airflow rate increasing; compression of air just above the glottis.

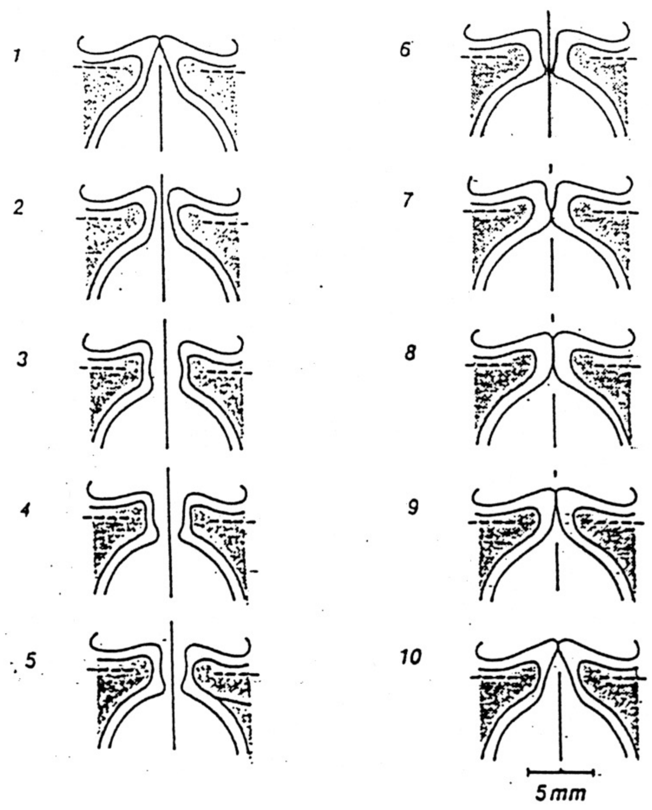


airflow rate decreasing; rarefaction of air just above glottis

baseline

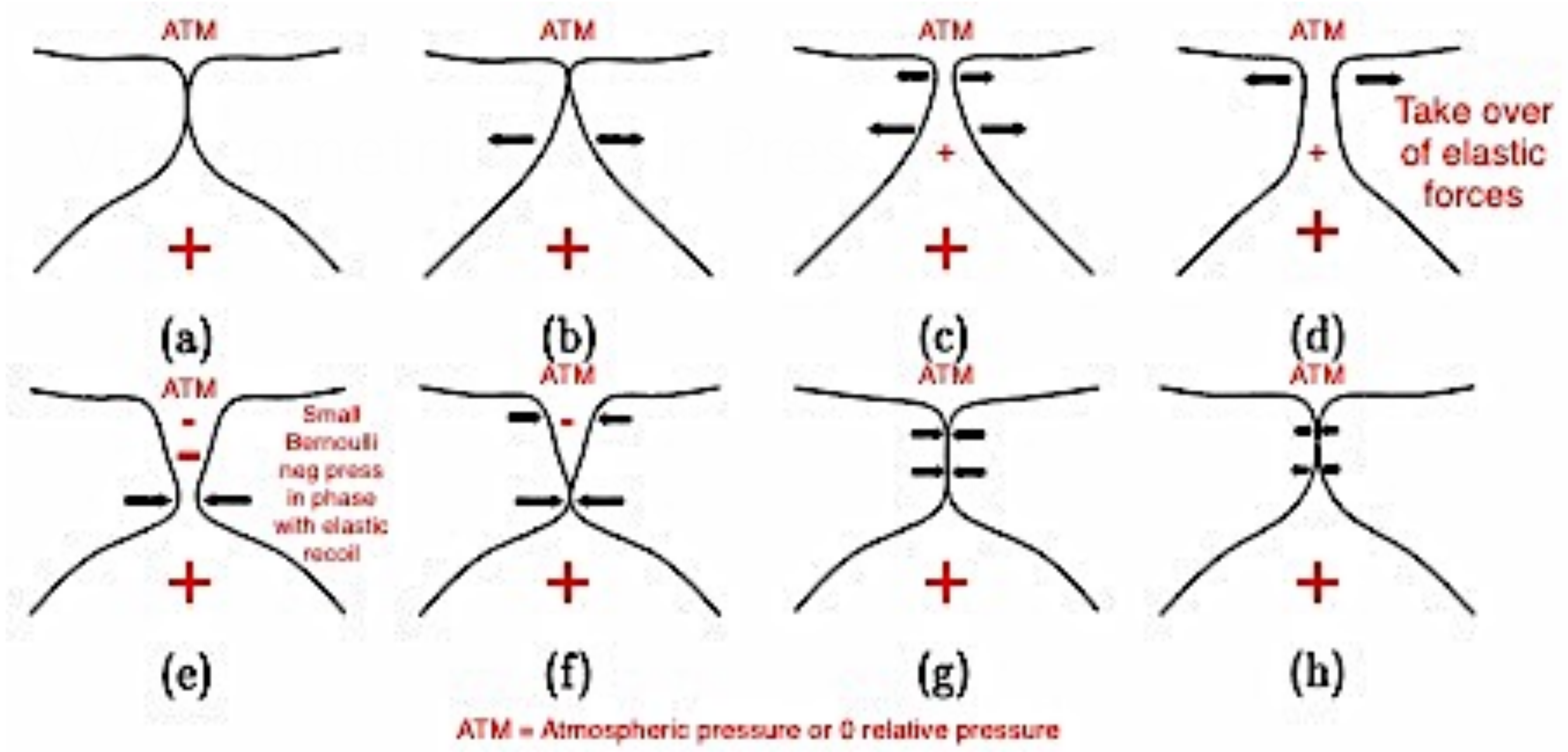
glottal opening

glottal closing



end of glottal closing

closed glottis

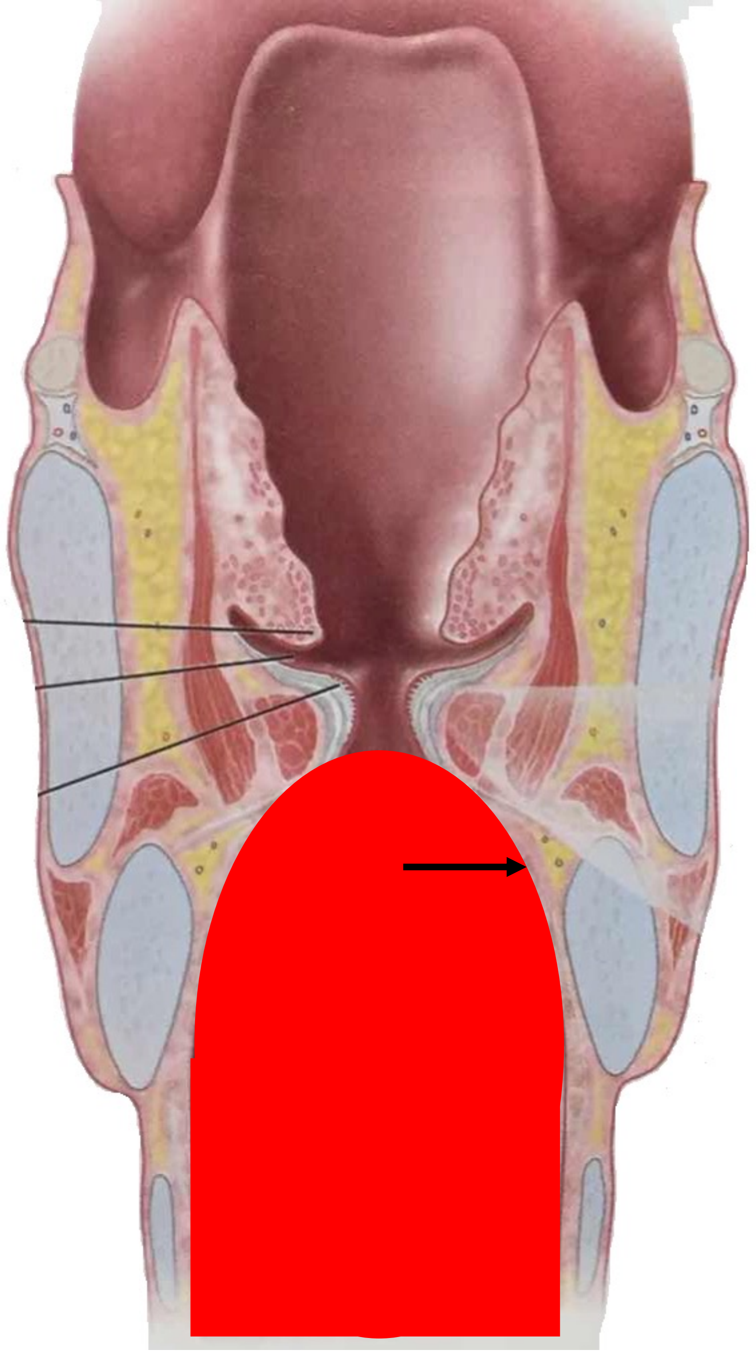


Modified from Story, B. H. (2002). An overview of the physiology, physics and modeling of the sound source for vowels. *Acoustical Science and Technology, 23(4),* 195-206.

https://www.youtube.com/watch?v=BPqx3GqAcmM → start at 5:00

Glottal Pressures

- ***Subglottal pressure:*** the air pressure created by the respiratory system below the larynx with dependence on degree of glottal adduction.
- *Supraglottal pressure:* the air pressure within the vocal tract above the level of the glottis.
- *Transglottal pressure* (a.k.a. driving pressure): the difference between the subglottal and supraglottal pressures (i.e., $\Delta P_{glottis} = P_{subglottal} - P_{supraglottal}$) or as the pressure drop across the glottis.
- *Intraglottal pressure:* the pressure within the glottis acting upon the surfaces (walls) of the vocal folds.
  - These pressures along with elastic recoil forces are the primary external and internal forces, respectively, that drive the vocal folds into oscillation during phonation (Scherer at al., 2001)



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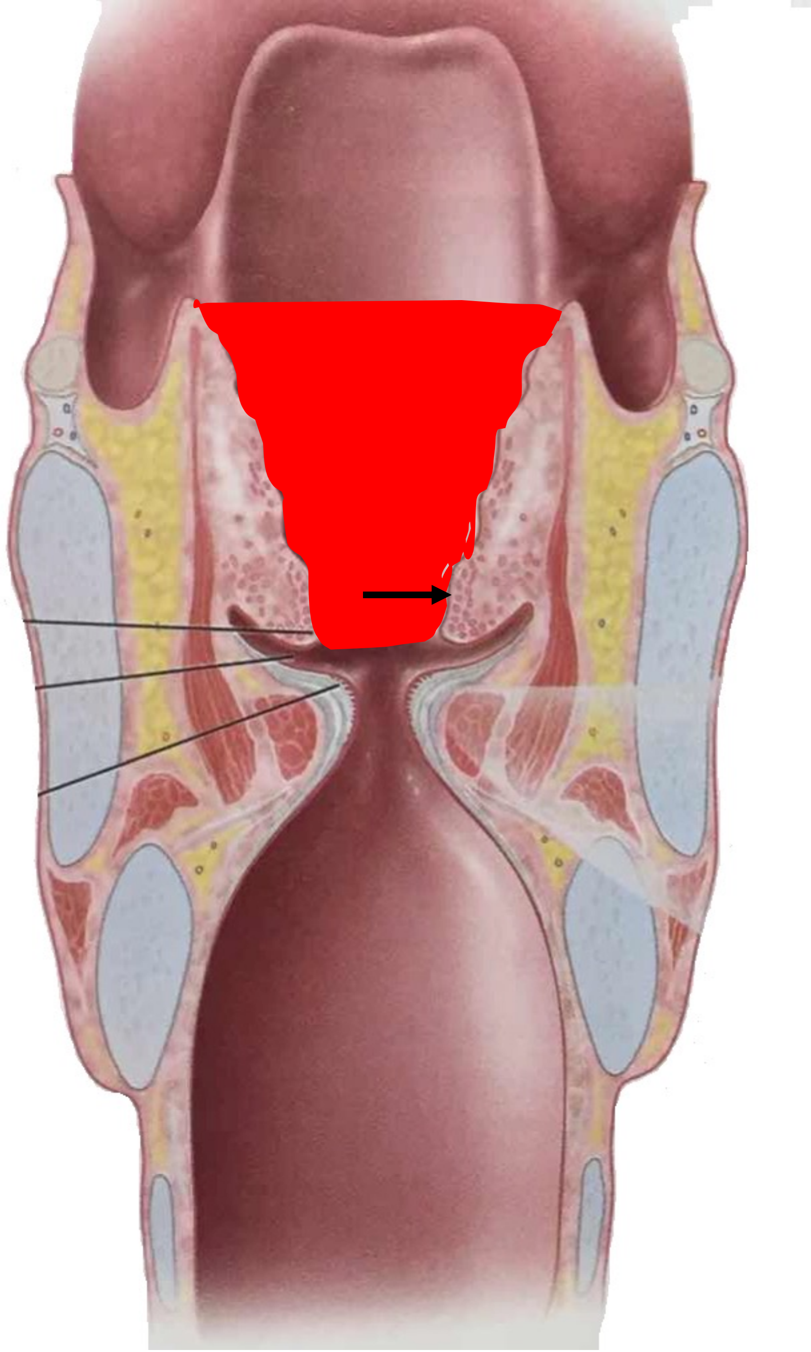

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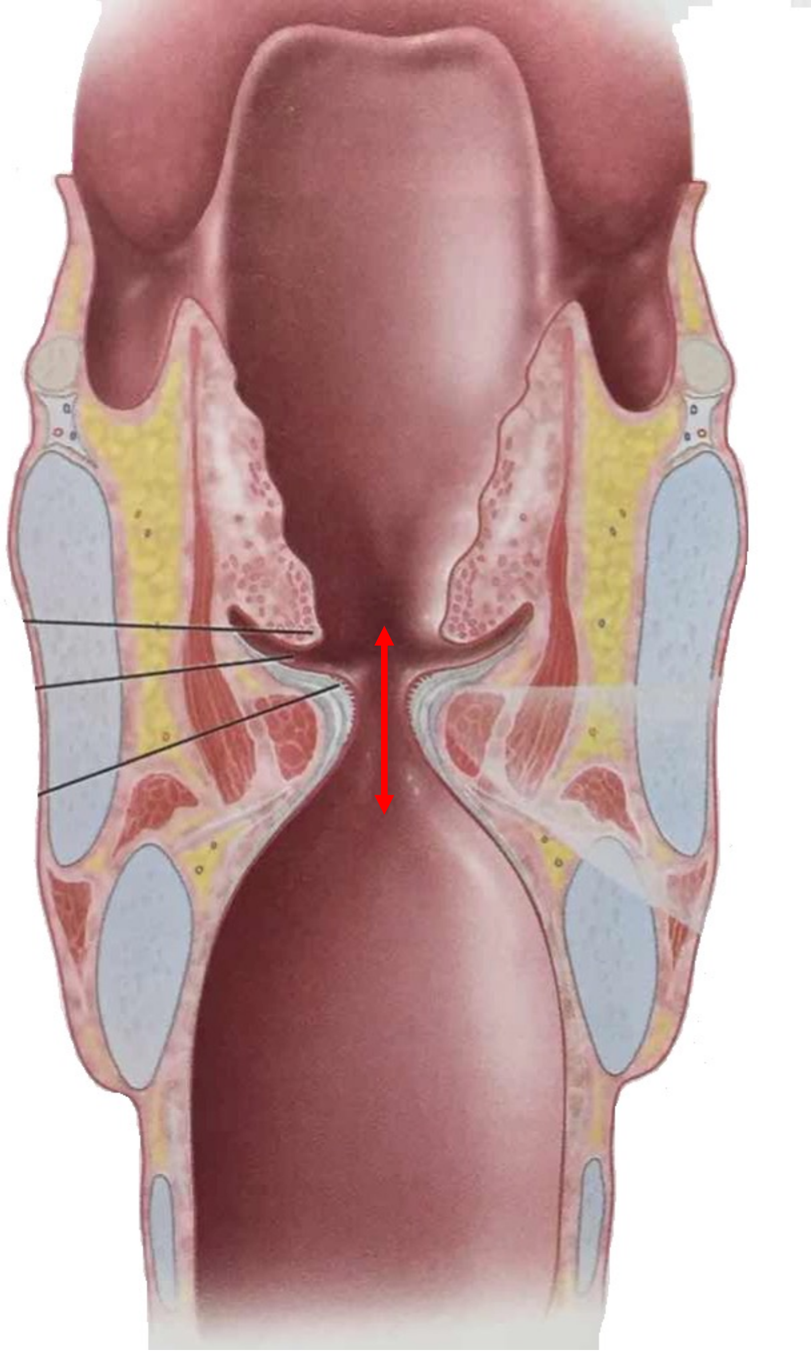

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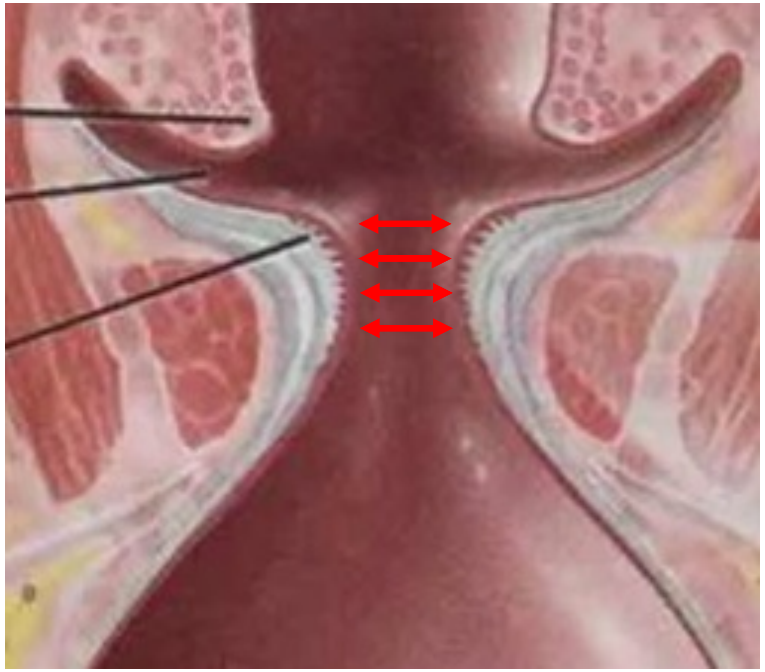


Ohm's Law (aerodynamic version)

$$\uparrow\downarrow U_T = \frac{P_S \uparrow}{Z_T \uparrow}$$

U_T is the total airflow through the system,

P_S is the source pressure or the total pressure drop across all resistances within the system (generally synonymous with ΔP_g), and

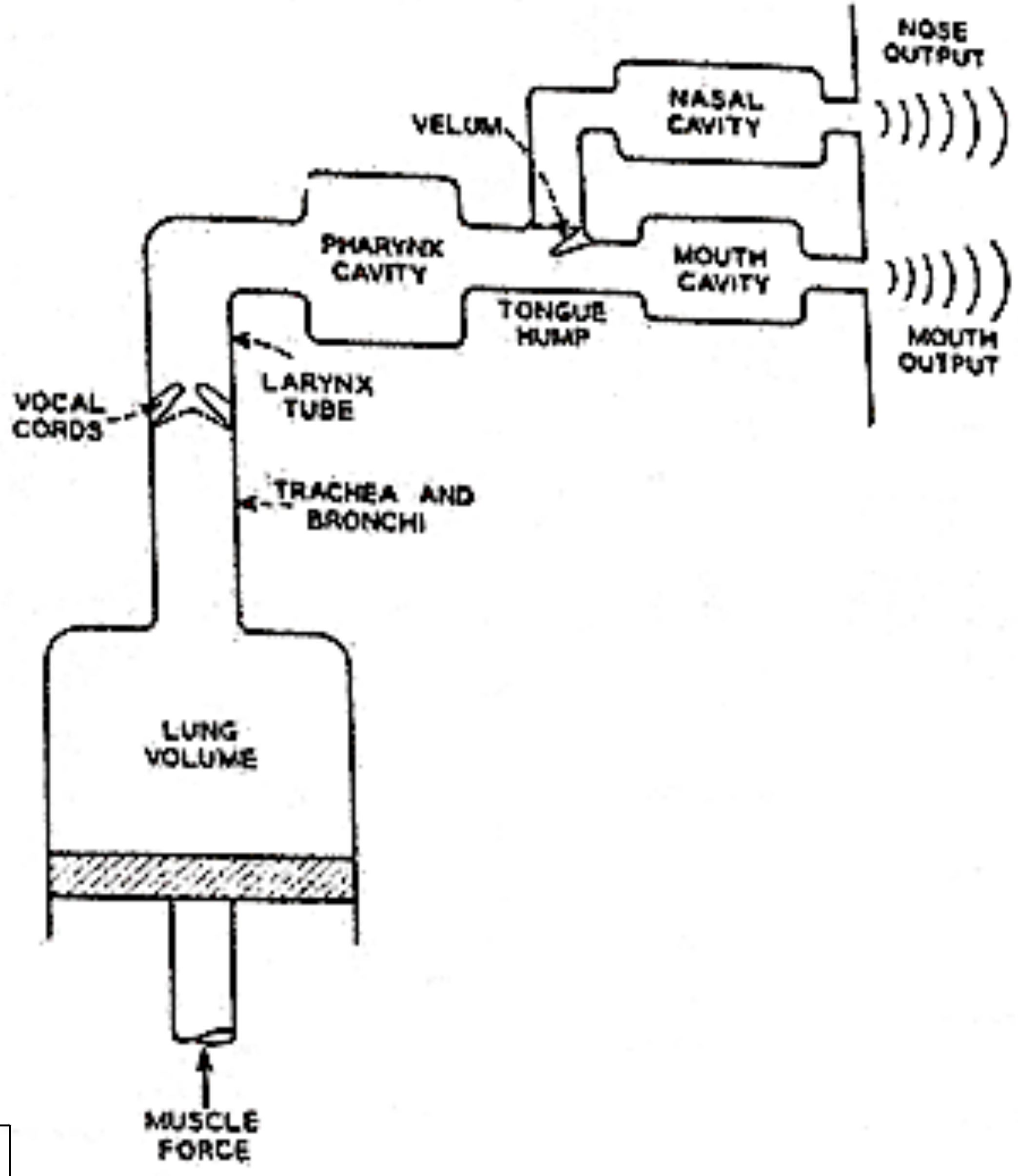
Z_T is the total airflow *impedance** of the system

**Impedance* is a measure of lack of response to an applied stimulus (Titze & Verdolini, 2012)

This equation implies that:

1. **Total airflow decreases as total airflow impedance increases,**
2. **Total airflow increases as source pressure increases, and**
3. **Source pressure increases as either total flow or total impedance increase.**

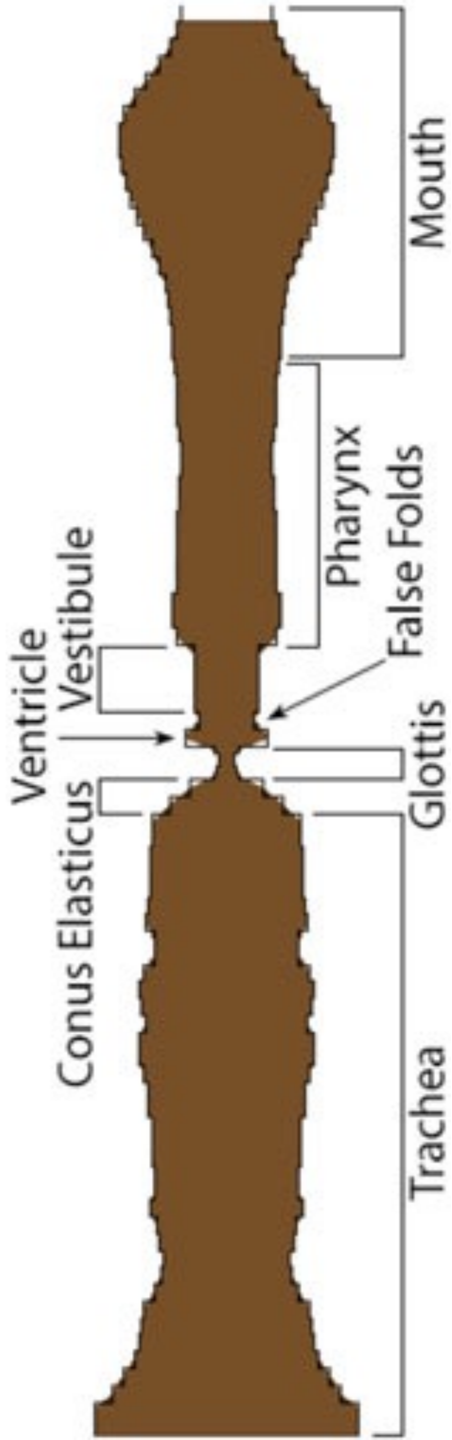
$$\boxed{P_S = U_T * Z_T}$$



Flanagan, 1968, p. 24

Note that a significant downstream airflow resistance acts analogously as a downstream resistor in a series circuit, which would increase the pressure drop across this resistor.

This relationship is given by the aerodynamic version of the <u>voltage divider rule for series circuits</u>…



<u>Voltage divider rule for series circuits:</u>

$$\uparrow P_n = P_s \frac{R_n}{R_t} \uparrow$$

where P_n is pressure drop across a downstream resistance,
R_n is the value of the downstream airflow resistance,

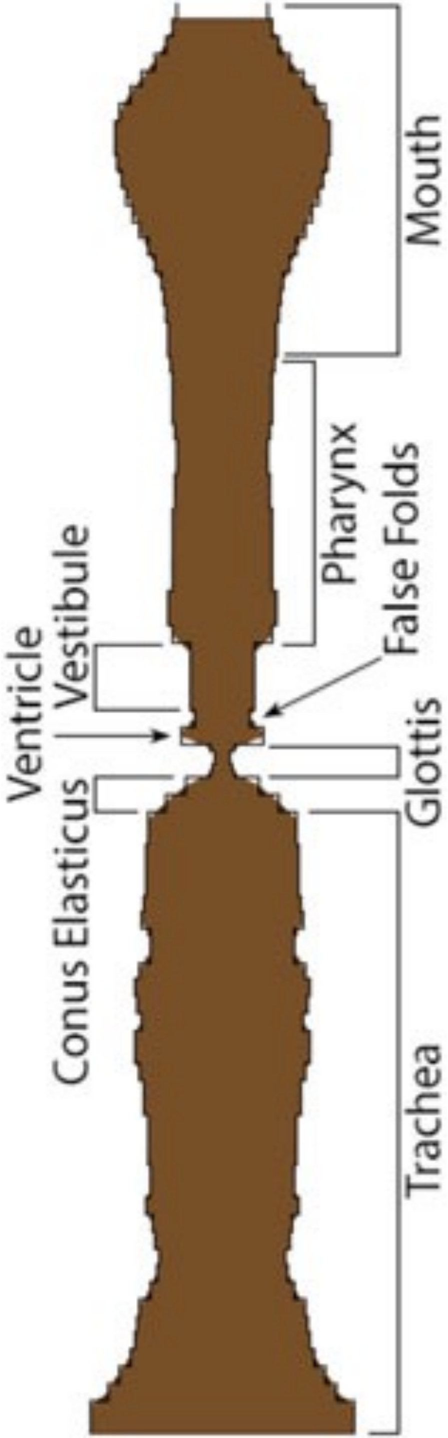
R_t is the total resistance (source resistance plus downstream resistance), and

P_s is a constant pressure source from the lungs.

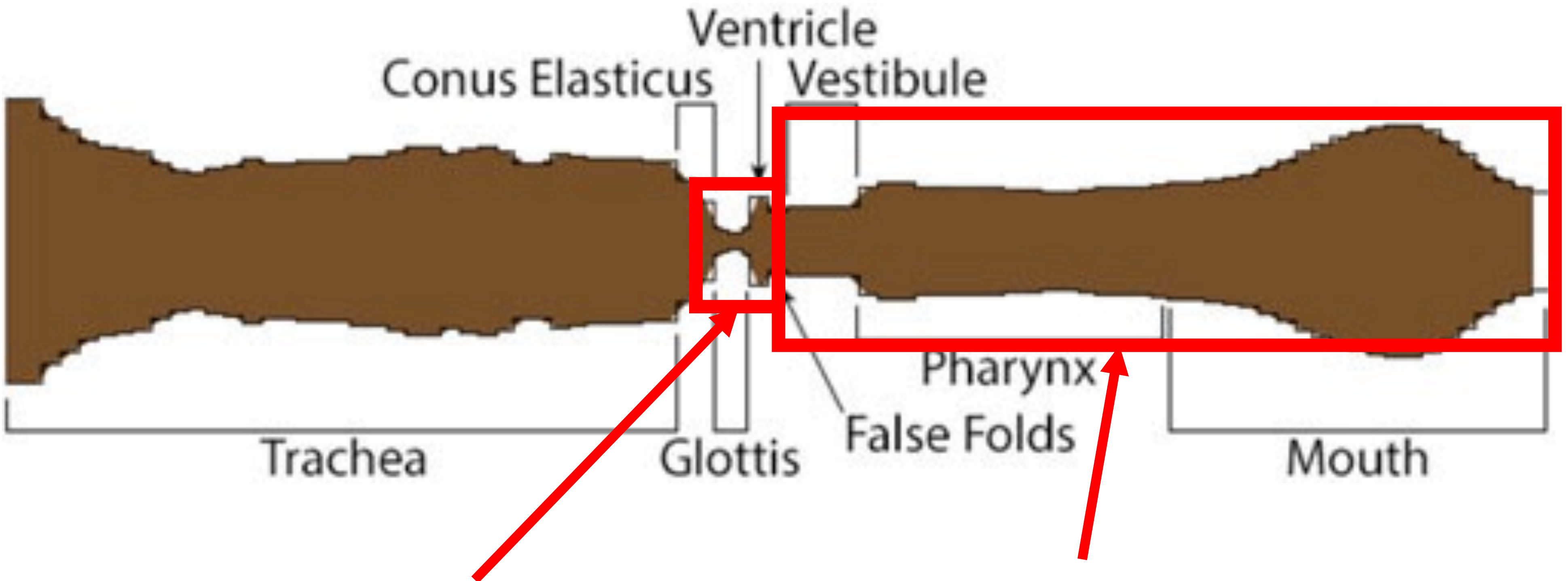
This equation implies that:

given a constant source pressure (P_s), the static pressure drop across the downstream resistor (P_n), which is equivalent to oral pressure just upstream of the constriction, should increase given an increase in downstream airflow resistance (R_n).

- *Example: /a/ to /u/ to super closed /u/*



Source Filter Theory



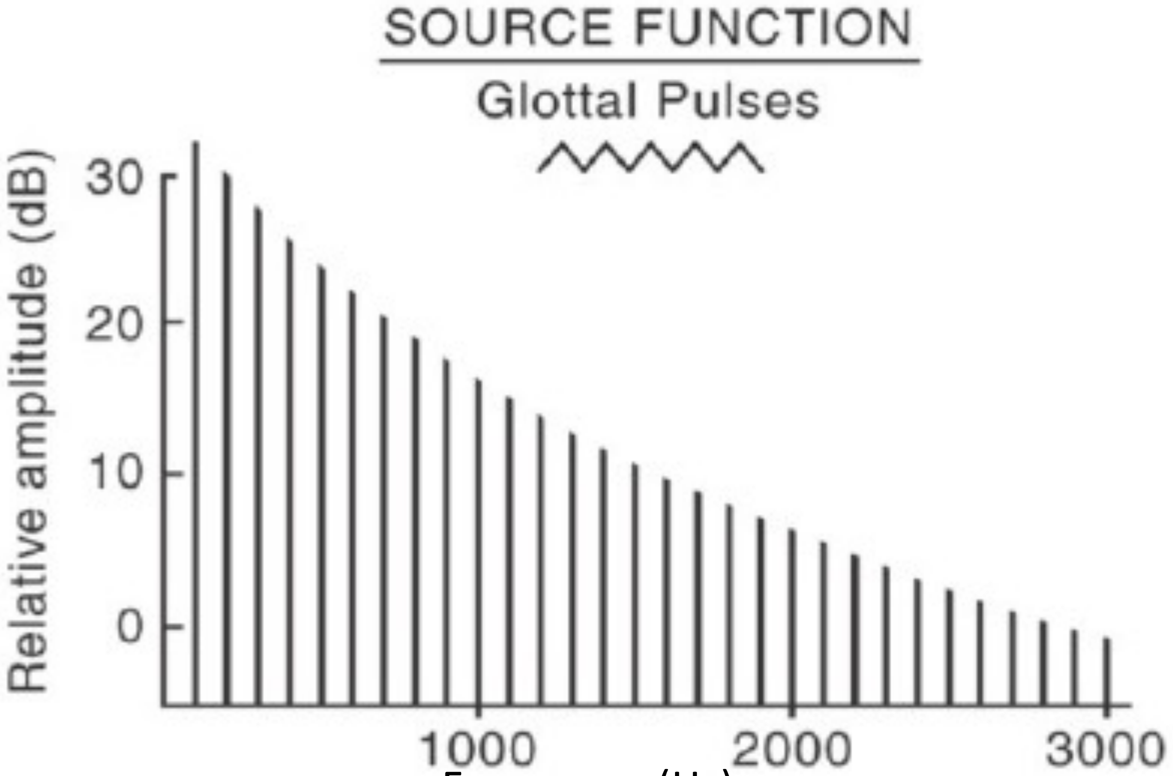
Source

(changing glottal airflow creates harmonic structure)

Filter

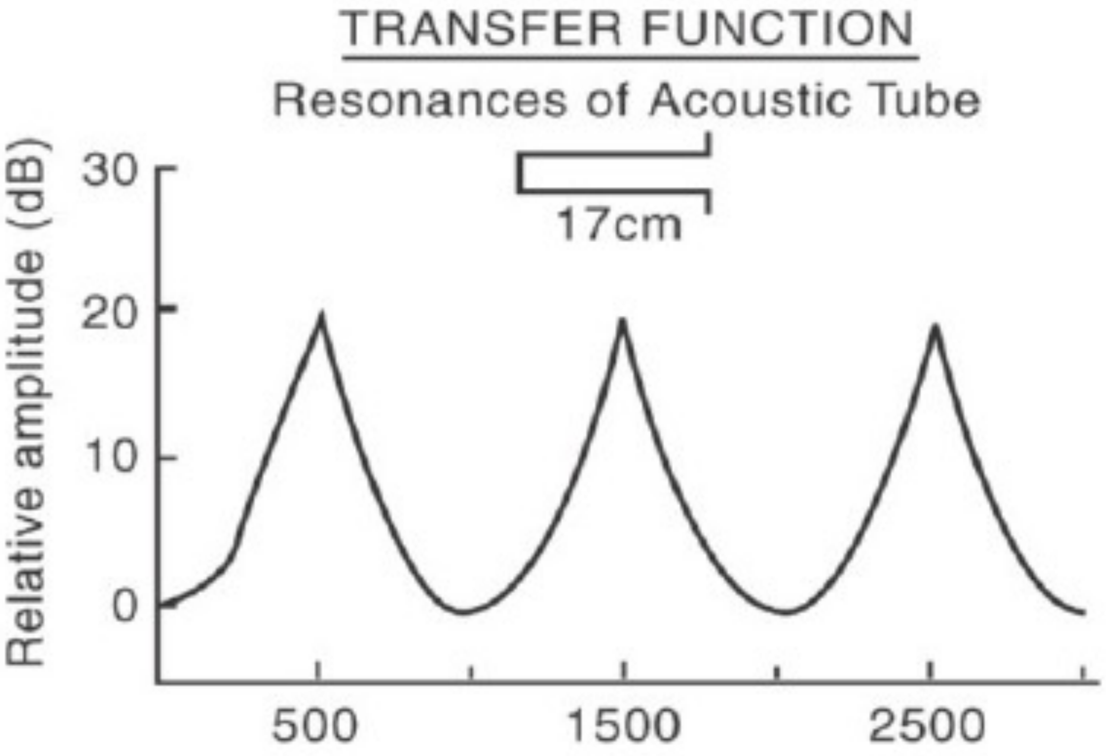
(vocal tract length and cross sectional area from glottis to lips creates formant structure)

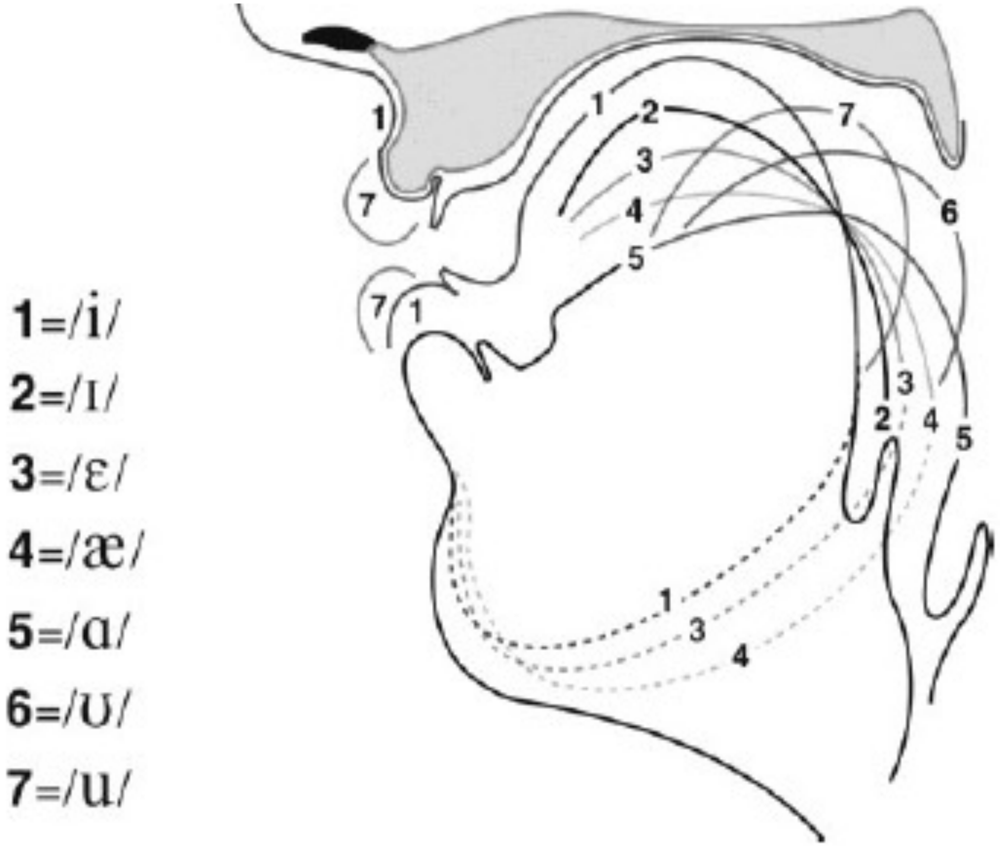
Source Filter Theory



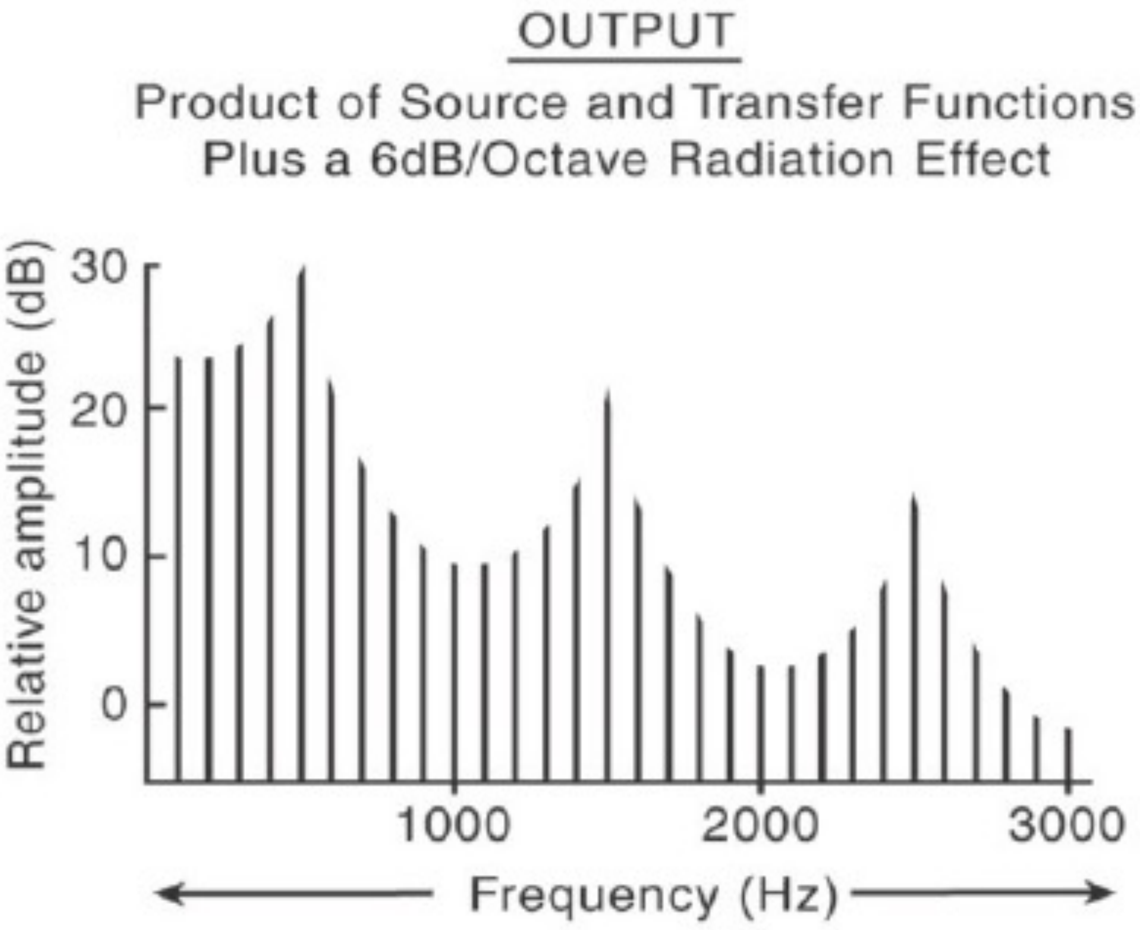
Frequency (Hz)

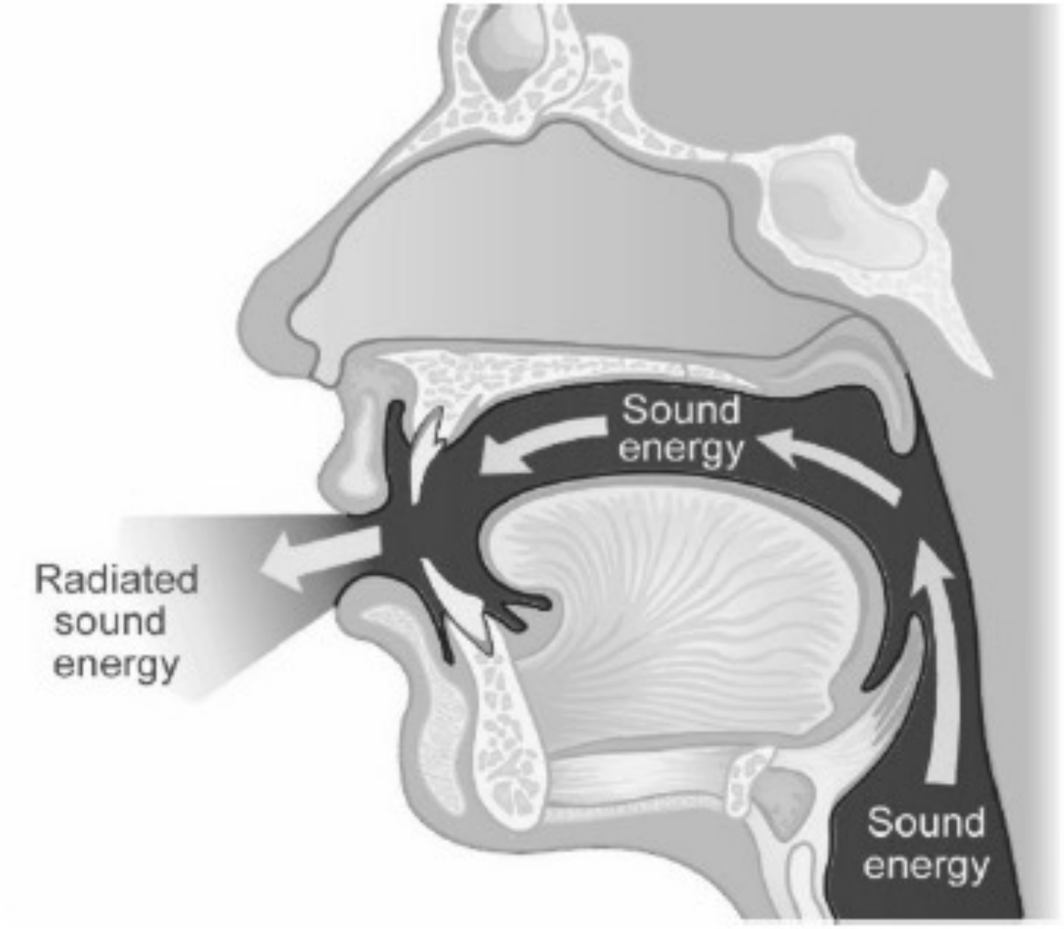
Source Filter Theory





Source Filter Theory





Source-filter theory for vowel production

Never changes, always present.

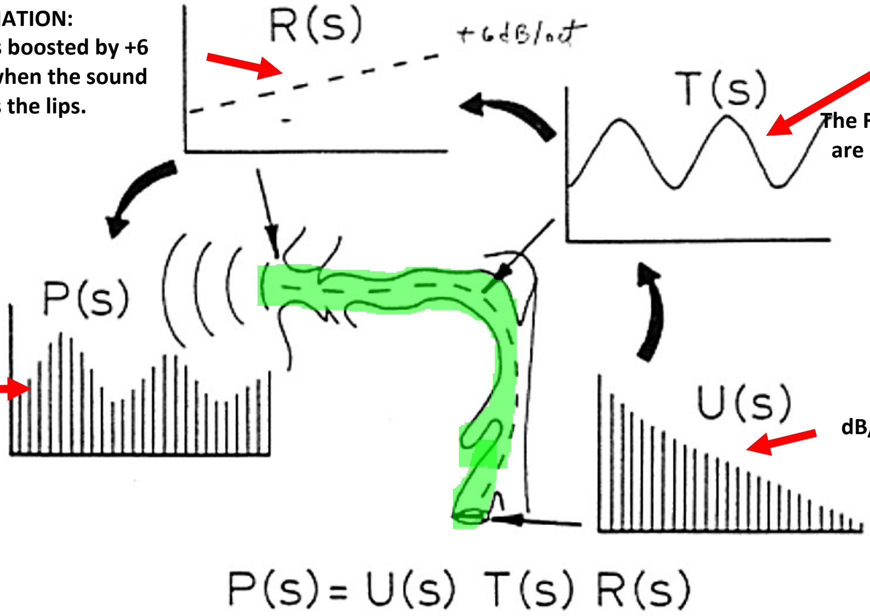
RADIATION:
The sound is boosted by +6 dB/octave when the sound leaves the lips.

Depends on the vowel!

FILTER:
The FILTER of the vocal tract. The humps are resonance frequencies, the valleys are between the resonances.

The resulting output sound

Goes to your ears.

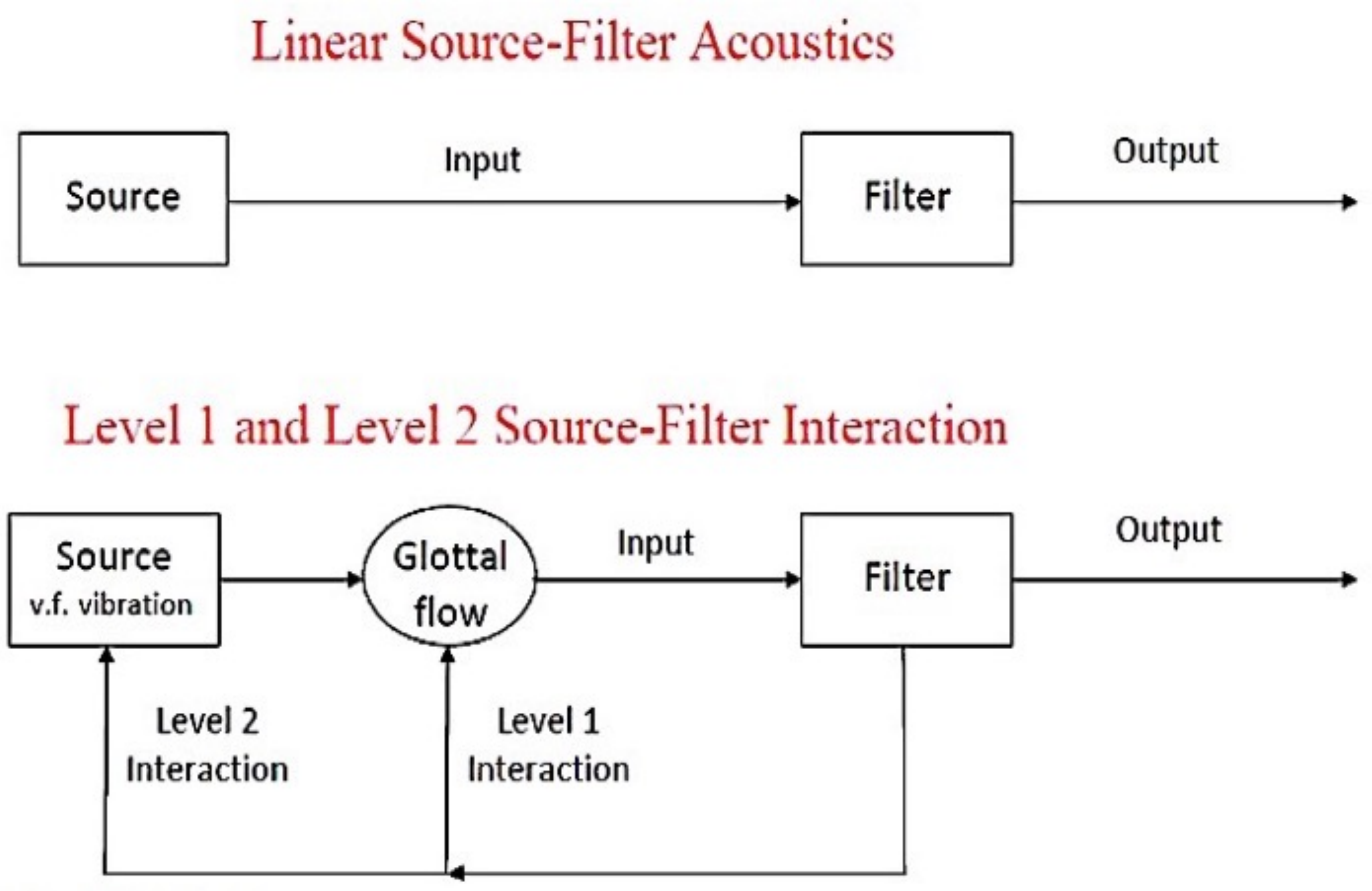


SOURCE:
Laryngeal source (about -12 dB/octave) = spectrum of the glottal flow

Depends on vocal fold adduction, length, tissue health, subglottal pressure

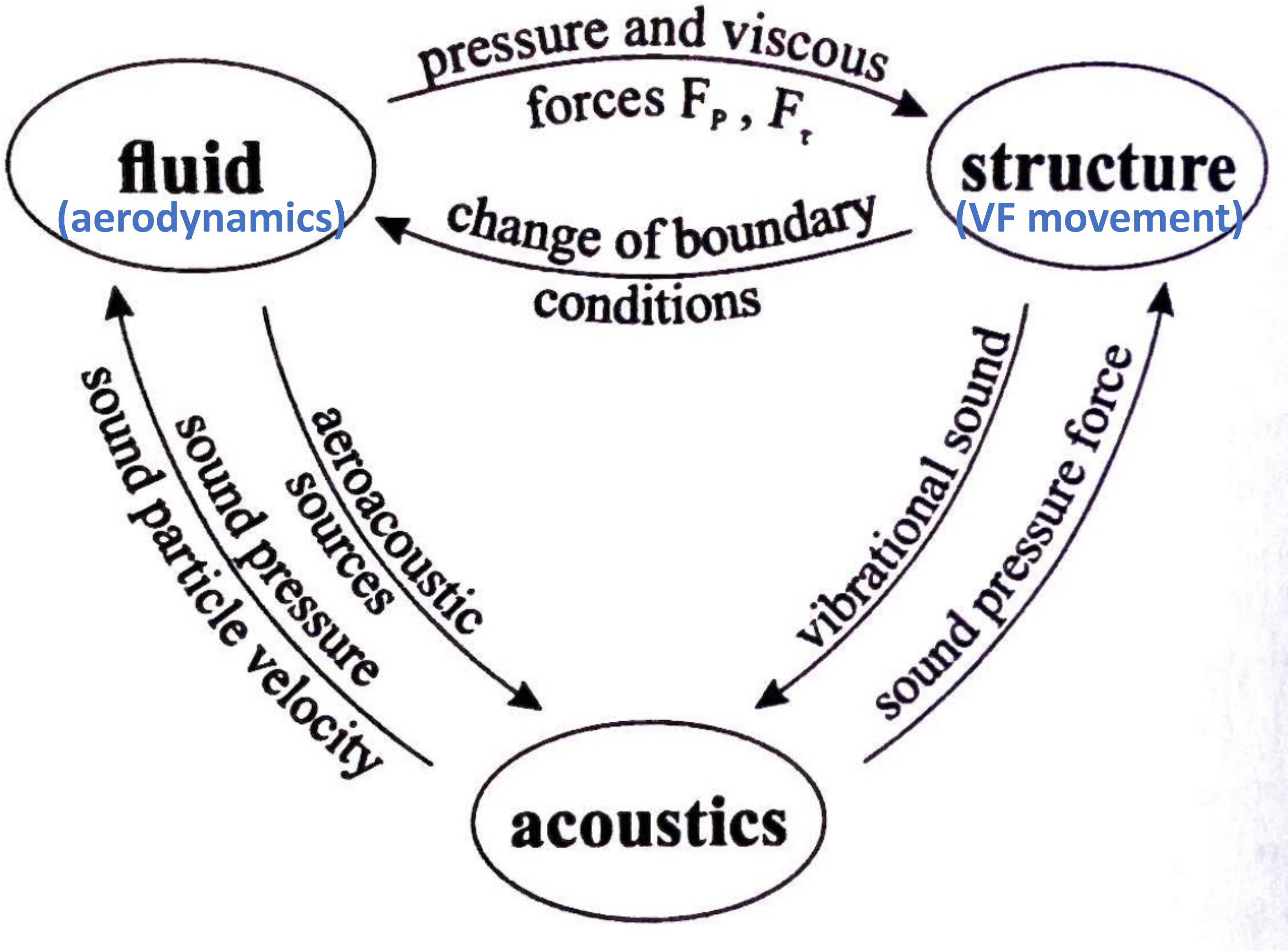
FIGURE 2-5. Diagrammatic representation of the source-filter concept for vowels. The laryngeal source spectrum, U(s), is filtered by the vocal tract transfer function, T(s), and the radiation characteristic, R(s), to yield the output spectrum, P(s). Mathematically, P(s) is a coproduct of U(s), T(s) and R(s) where s = frequency.

Sundberg 1987, p. 20, “The Science of the Singing Voice”



Maxfield et al., 2017, p. 150

Fluid-Structure-Acoustic Interaction



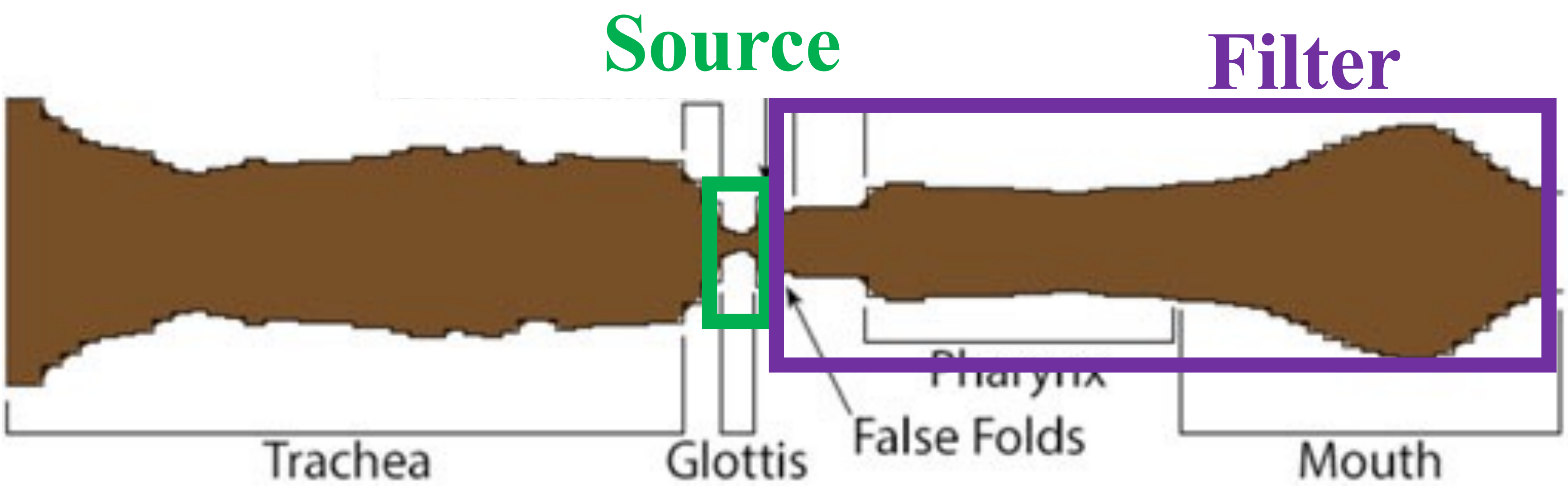
Kniesburges, 2014

Nonlinear Source-Filter Theory of Speech Production

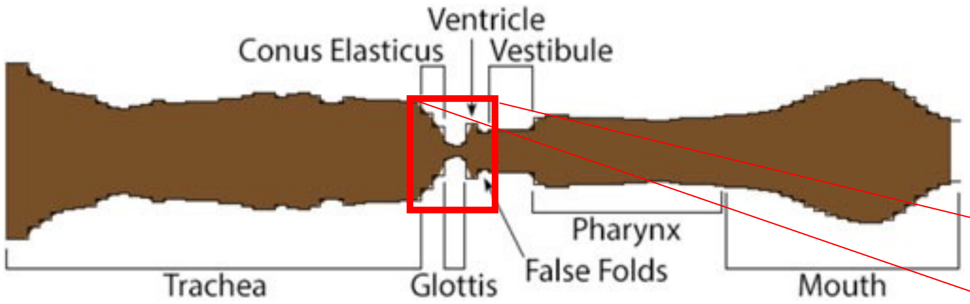
(Flanagan & Meinhart, 1964; Flanagan, 1968; Rothenberg, 1981; Titze, 2004a, 2008)

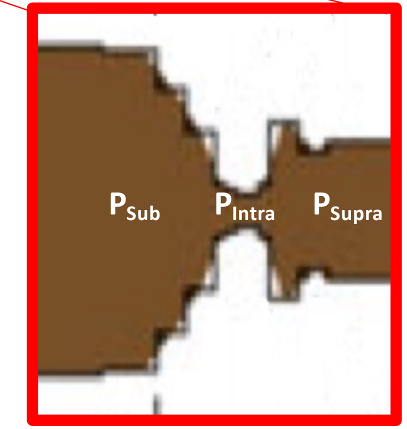
Assumption:

Changes to the geometry of the vocal tract (e.g., constricting the tube) can cause changes in glottal airflow and vocal fold vibration.



This follows from theory:



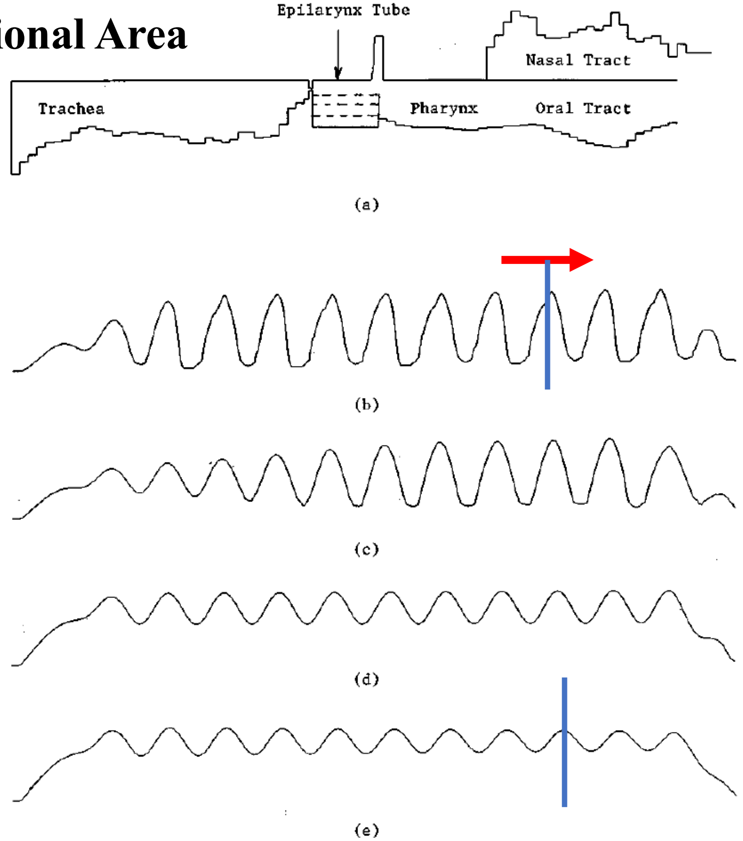


- $\boldsymbol{P_{Transgl}} = P_{Subgl} - P_{Supragl} = k\frac{1}{2}\rho V_2^2 + \boldsymbol{I\frac{dU}{dt}}$
  - Vocal tract inertance, $\boldsymbol{I} = \boldsymbol{\frac{\rho L}{A}}$
- Since $\boldsymbol{P_{Transgl}}$ drives glottal airflow
- And since **during the open glottal phase, $\boldsymbol{I}$ and $\boldsymbol{\frac{dU}{dt}}$ are not zero**
- **Therefore, $\boldsymbol{I}$ should affect the transglottal pressure and therefore the glottal airflow to some extent…**

Titze & Story, 1997

Vocal Tract Cross sectional Area

Glottal Flow



A_e = 0.2 cm²

A_e = 0.5 cm²

A_e = 1.1 cm²

A_e = 2.0 cm²

FIG. 10. The effect of a widening the epilarynx tube. Dashed lines in part (a) show the equivalent diameters for A_e=0.2, 0.5, 1.1, and 2.0 cm^2 and correspond to the glottal flow waveforms shown in (b)–(e). The waveform amplitudes are normalized to show the shape differences only. The pharynx areas vary around 2.0 cm^2 and the mouth area reaches a maximum of about 4.1 cm^2.

Note the decrease in glottal airflow pulse skewing (MFDR becomes less negative) with an increase in epilaryngeal tube cross sectional area (due to decreased inertive reactance).

$$I = \frac{\rho L}{A}$$

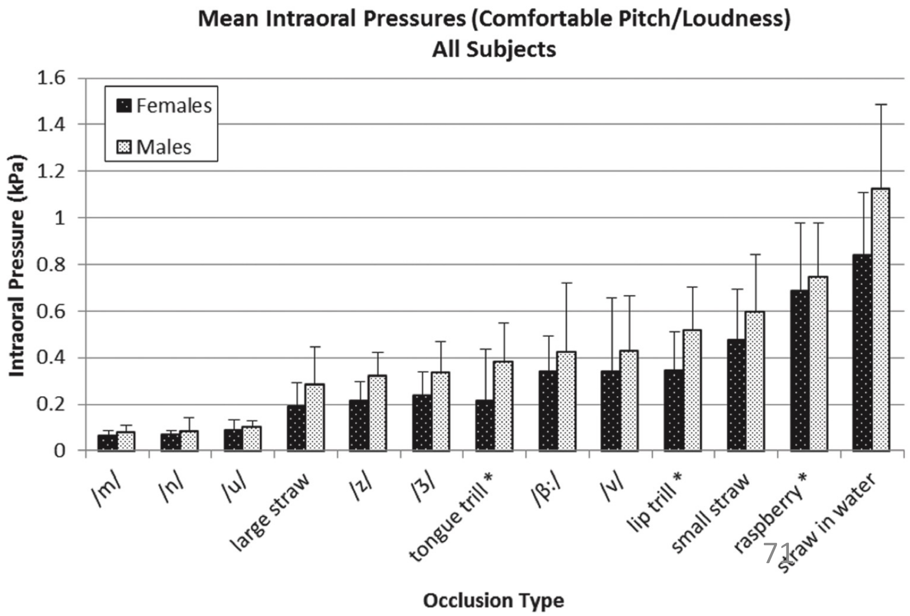
Semi-occluded vocal tract exercises (SOVTEs):

- **Exercises introducing a constriction near the distal end of the vocal tract or via some constricted extension to the vocal tract (Titze, 2006).**

  - Sustained
    - Straw/tube phonation exercises (phonation through flow-resistance straws or tubes of various diameters with the free end in air or submerged in water at various depths);
    - Voiced fricatives /ð/, /v/, /z/, and /ʒ/ in English;
    - Nasal consonants /m/, /n/, and /ŋ/ in English;
    - “Y-buzz” created by sustaining the beginning posture of the semivowel /j/,
    - Vocal Function Exercises /o/ (as in “knoll”),
    - Voiced bilabial /β/ in Finnish;
    - “Hand over mouth” or “standing wave” exercises.

  - Oscillatory
    - Lip trills or lip buzzes,
    - Tongue trills (i.e., rolled /r/s),
    - Raspberries

Maxfield et al., 2015



More on SOVTEs

- SOVTEs heighten interaction between the source and the filter, which can increase vocal intensity, efficiency, and economy.
- For interaction to be maximally useful, some impedance matching needs to take place between the source (via glottal adduction/abduction) and the filter (via epilaryngeal tube narrowing/widening).
- VF vibration during SOVTE has been demonstrated to have small amplitude (Titze, Finnegan, Laukkanen, & Jaiswal, 2002); therefore, there is little concern about damage to the vocal folds.

Titze, 2006

More on SOVTEs

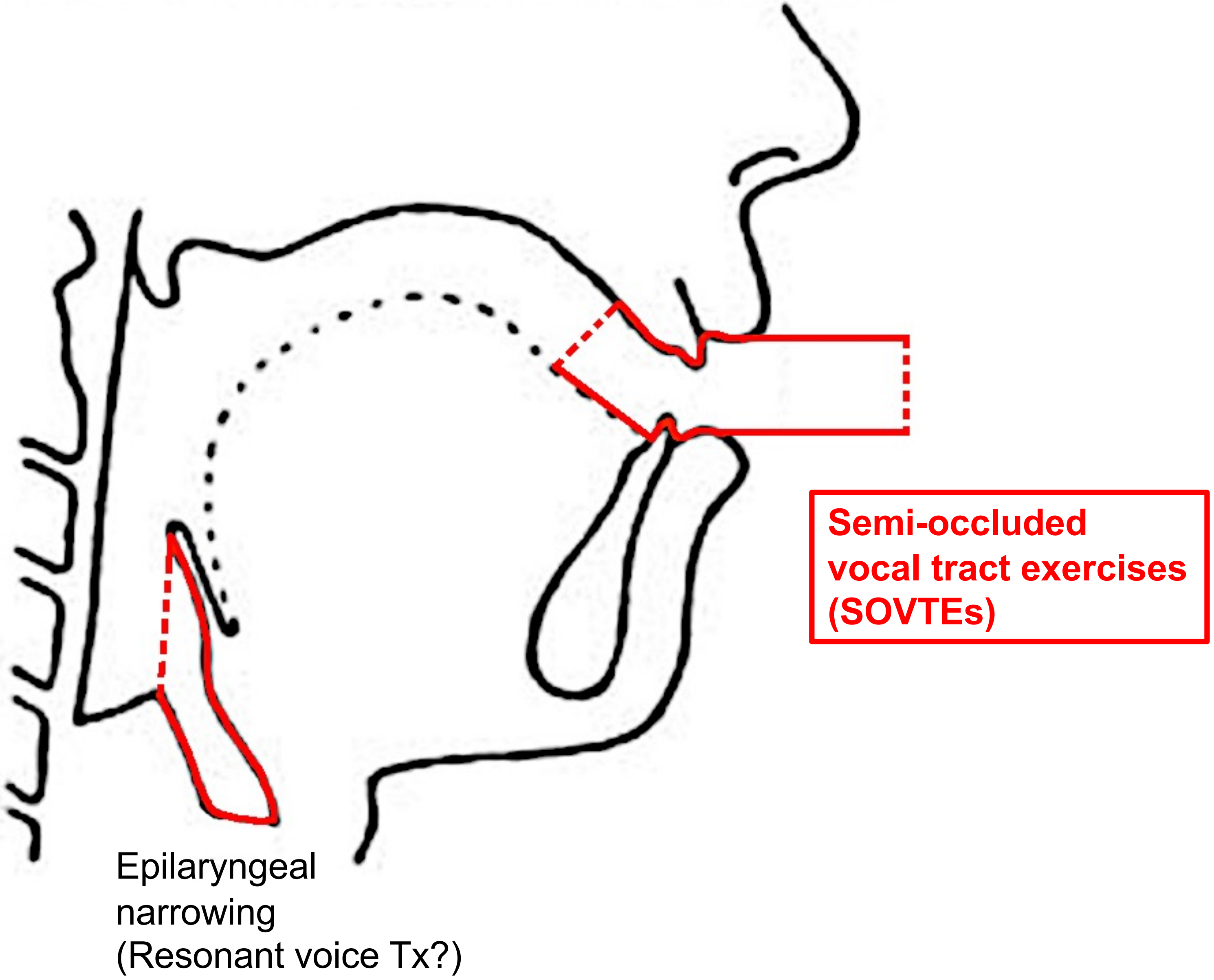
- Some internal sensations are helpful to facilitate a client’s awareness of this impedance-matching requirement:
  - Sensation of a back pressure (yields perception of a light resistance to sound emission from the vocal tract?) → purpose of the semi-occlusion, in front of VT due to ease of control
  - Efficient sound production then leads to sensations of tissue vibration in the front of the facial structures (maxilla behind the nose). This could be due to heightened acoustic pressures in the mouth.
  - Clients must become comfortable using large lung pressures over large pitch ranges while only a small amount of sound is being emitted from a small orifice.
  - After client is familiar with this resistance sensation, lung pressures can safely be taken up to large values without concern for injury (due to the small amplitude of vibration). Thus, SOVTEs can also function as a safe phonatory–respiratory warm-up.

Titze, 2006

More on SOVTEs

- Trade-off between lip narrowing and epilarynx tube narrowing?
  - Titze (2006) proposed the following: epilaryngeal tube narrowing may occur when the mouth opens after SOTVE training to preserve the sensation of resistance to sound release (the goal being increased efficiency). That is, a front articulation is replaced or augmented by a back articulation.
  - Progression could be from "wide" (epilarynx) – "narrow" (lips) to "narrow–narrow" to "narrow–wide"

Titze, 2006


Semi-occluded
vocal tract exercises
(SOVTEs)
Epilaryngeal
narrowing
(Resonant voice Tx?)

More on SOVTEs

- More "rectangular" (parallel glottis)
  - Titze (2006) further proposed that SOVTEs may facilitate equal top-to-bottom adduction, which would "square up" the glottis and reduce PTP. That is hyperadduction of the vocal processes with loose adduction at the bottom of the folds (potentially caused by LCA activity) may be traded for more TA activity. → *This hypothesis still needs to be empirically tested.*
- As the mouth is gradually opened, a vocal "ring" may also be detected indicating the contribution of a epilaryngeal tube resonator.

Titze, 2006

2. SOVTE Literature Review

Summary of information regarding the effect of SOVTEs

Evidence suggests that **narrowing the vocal tract** tube can affect **aerodynamics, kinematics, and acoustics** in vocal fold/tract models.

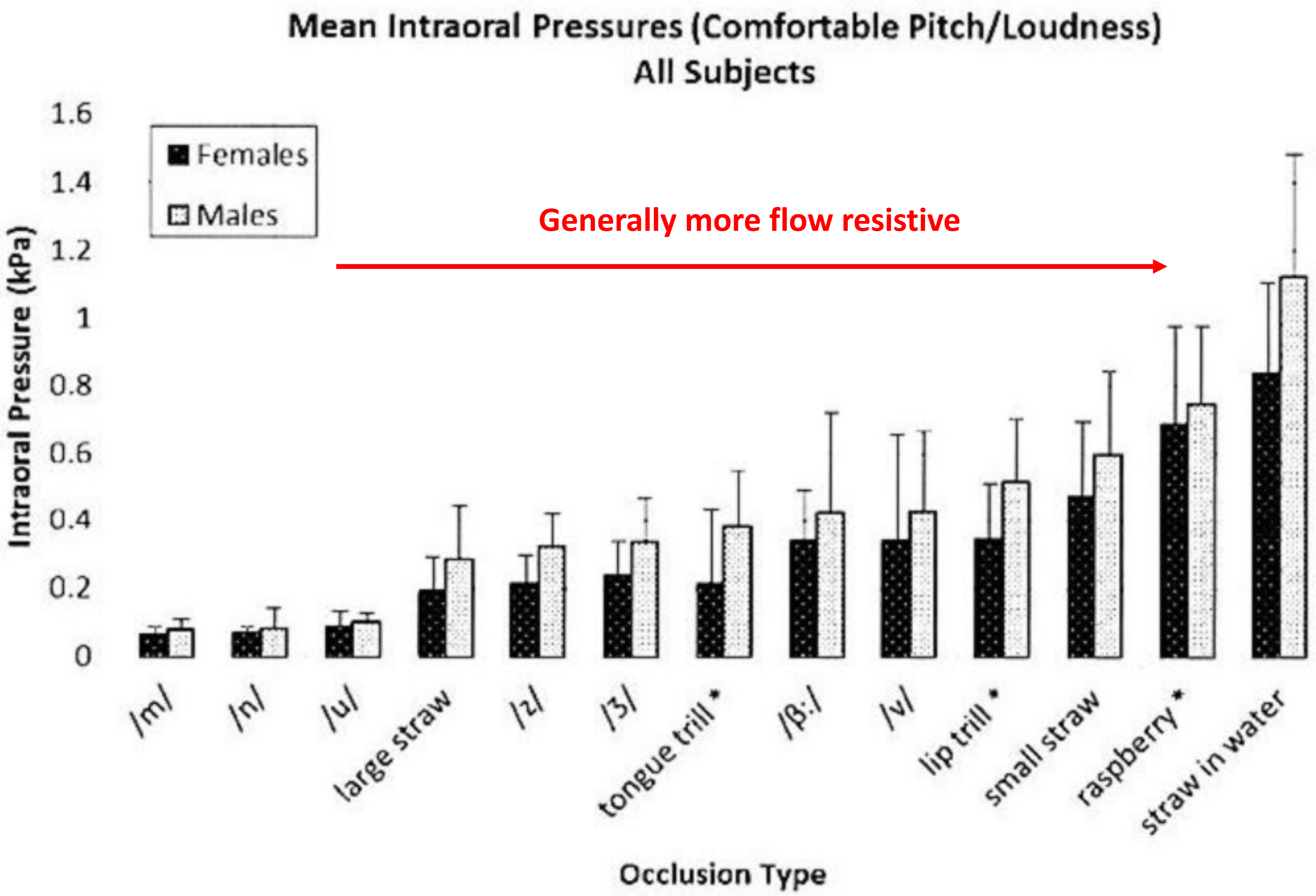
Adding a semi-occlusion to the vocal tract should:

- **Reduce transglottal pressure** by increasing intraoral pressure
- Facilitate resonance that may be associated with increasing **sensory feedback sensations**
- Presumably reduce the risk of phonotrauma by **minimizing vocal fold impact forces** during phonation

Titze, 2006

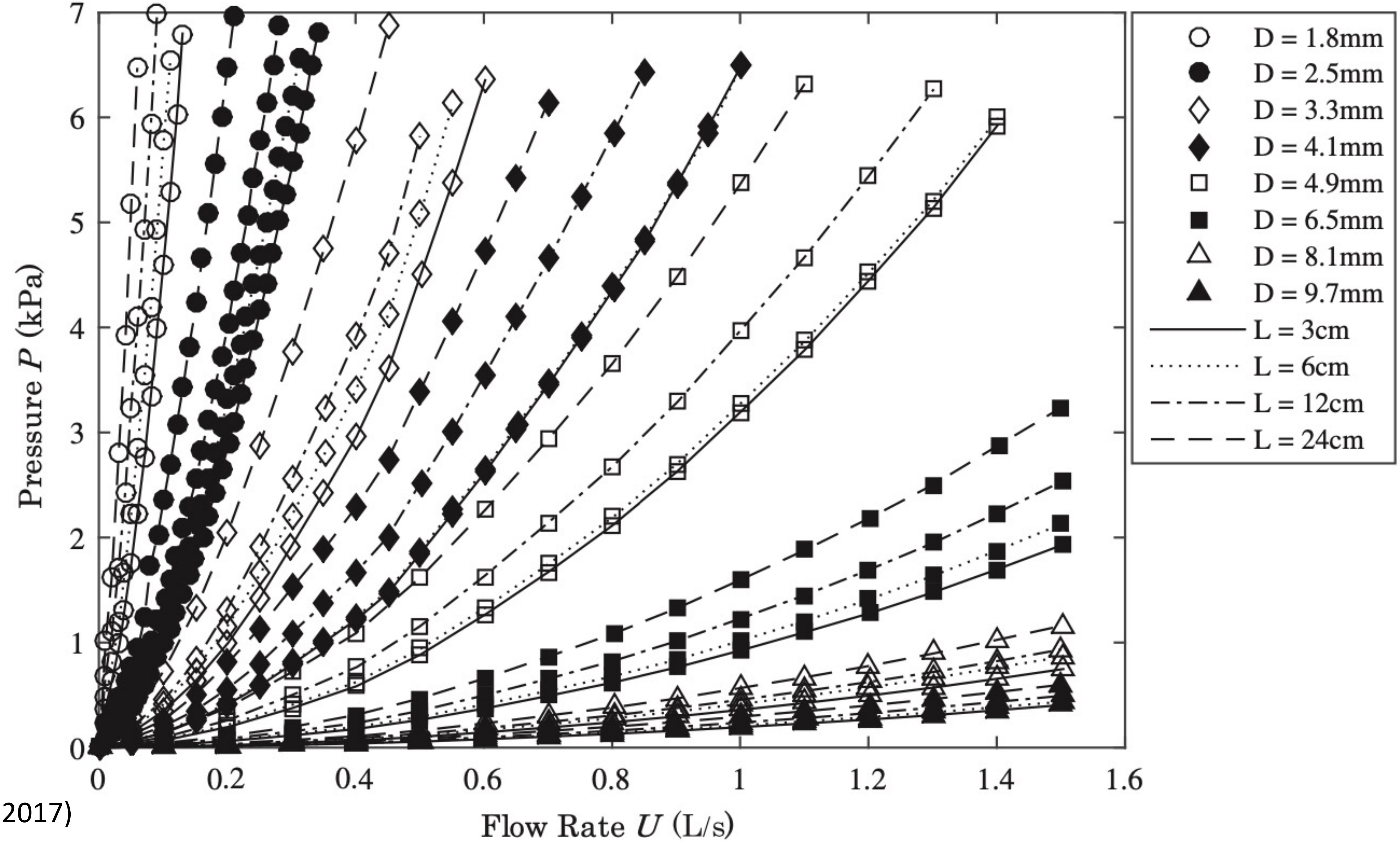
- Each SOVTE has a slightly different oral pressure associated with it and thus affects transglottal pressure differently

- Thus, you will want to tailor the exercise to the needs of the client.



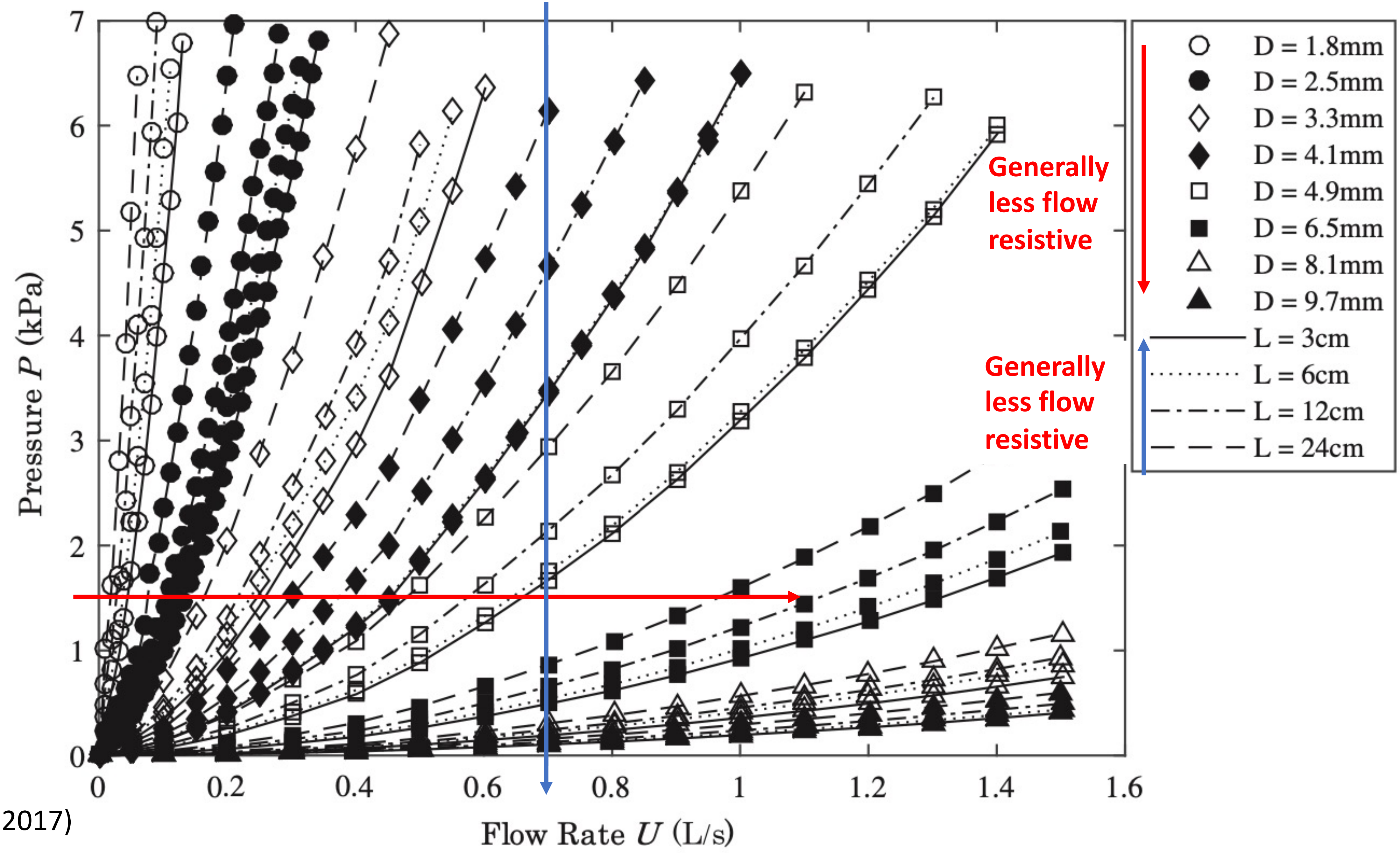
Maxfield et al., 2015, p. 9

Pressure-Flow Relationships for Various Tubes



(Smith & Titze, 2017)

Pressure-Flow Relationships for Various Tubes

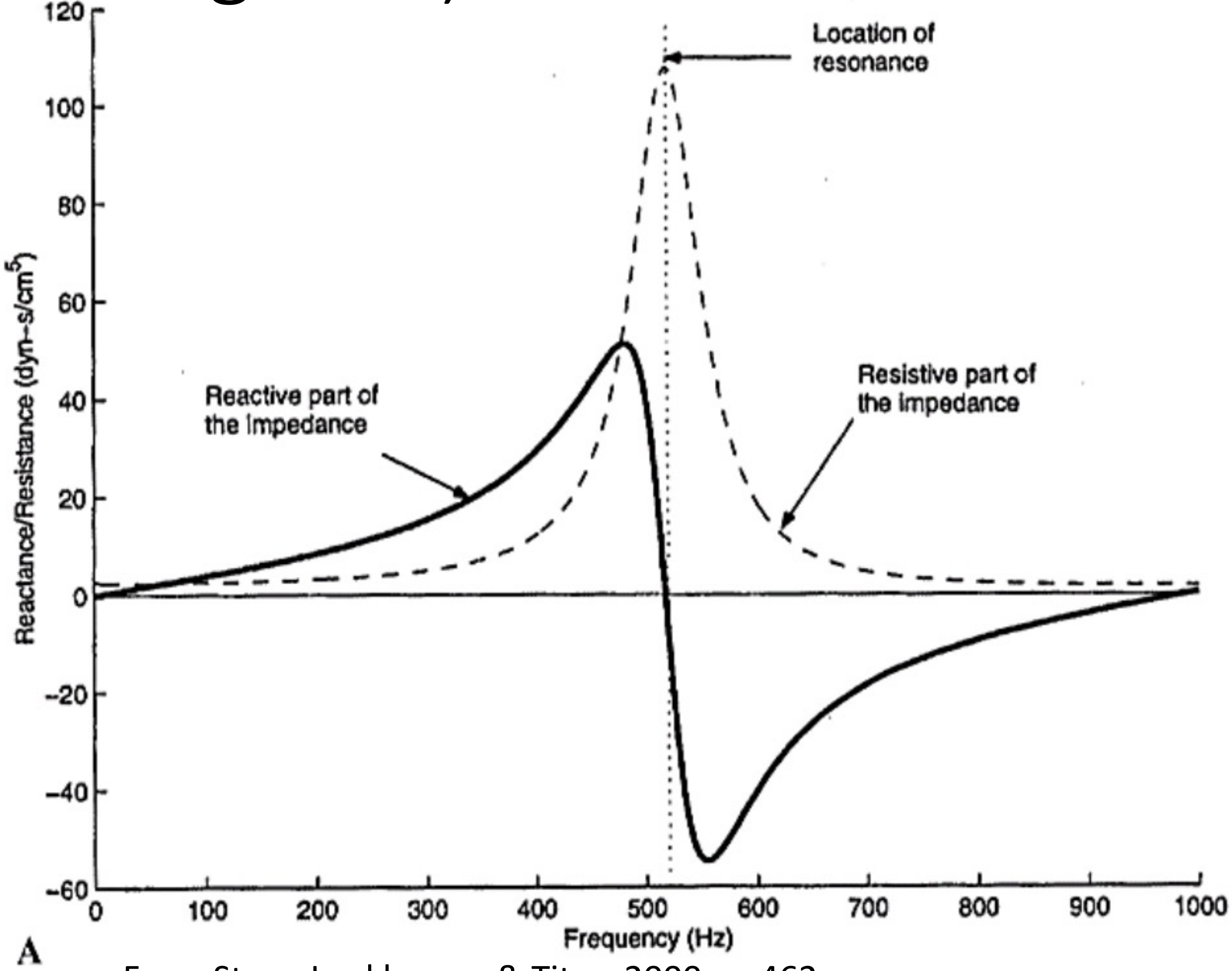


(Smith & Titze, 2017)

Reactance Curves(Inertograms)

$$Z = R + iX_L - iX_C$$

- **Impedance curves calculated for a uniform tube with length 17.5 cm and cross- sectional area 3 cm².**
- The solid line represents the reactance and the dashed line represents the resistance.
- The resonant frequency is shown at approximately 501 Hz where resistance is maximum, inductance and capacitive are equal (and therefore reactance is zero), and impedance in minimal.
- The portion of the reactance curve to the left of the resonance frequency (the positive section) is inductive and the portion of the reactance curve to the right of the resonance frequency (the negative section) is capacitive.



From Story, Laukkanen, & Titze, 2000, p. 462.

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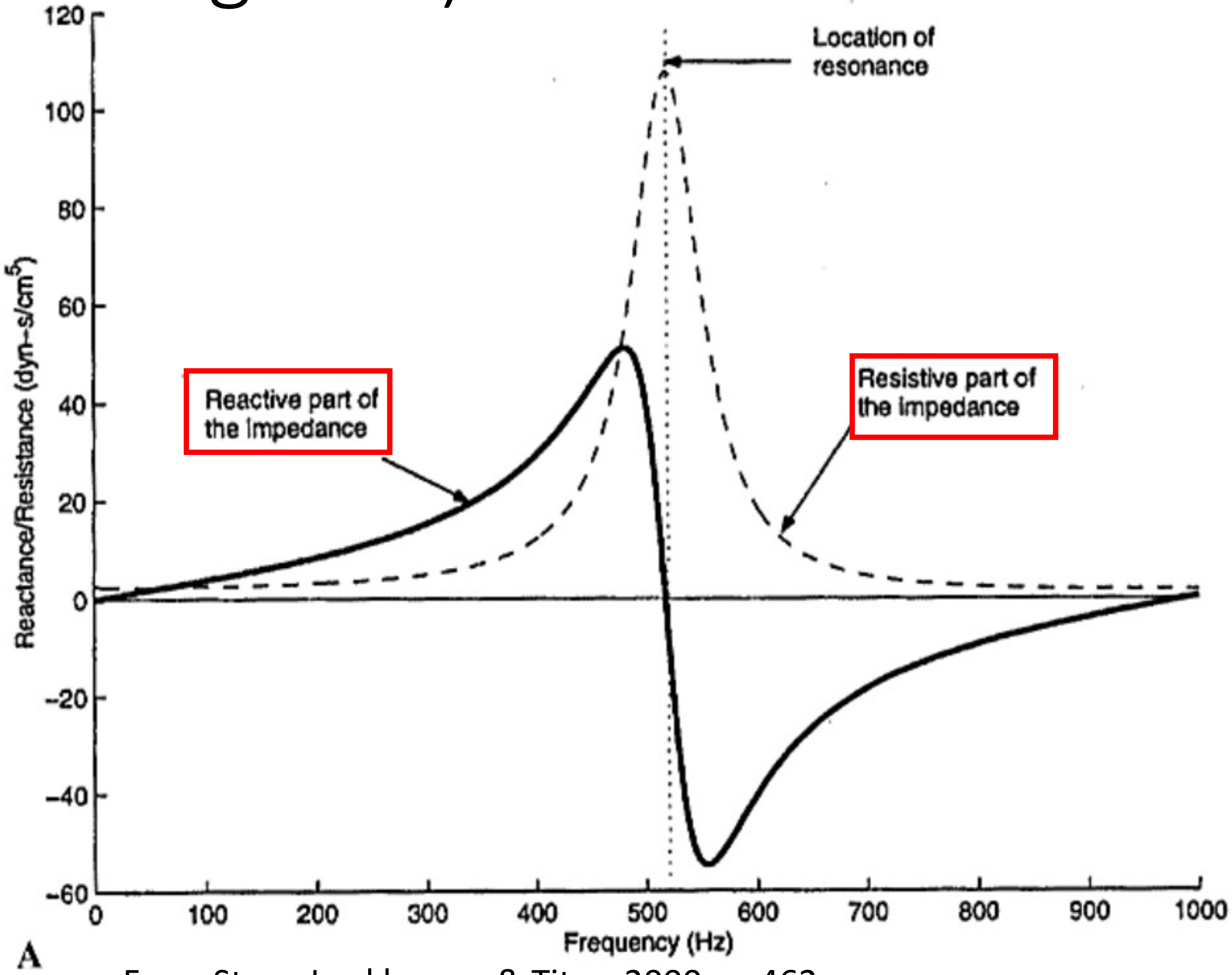
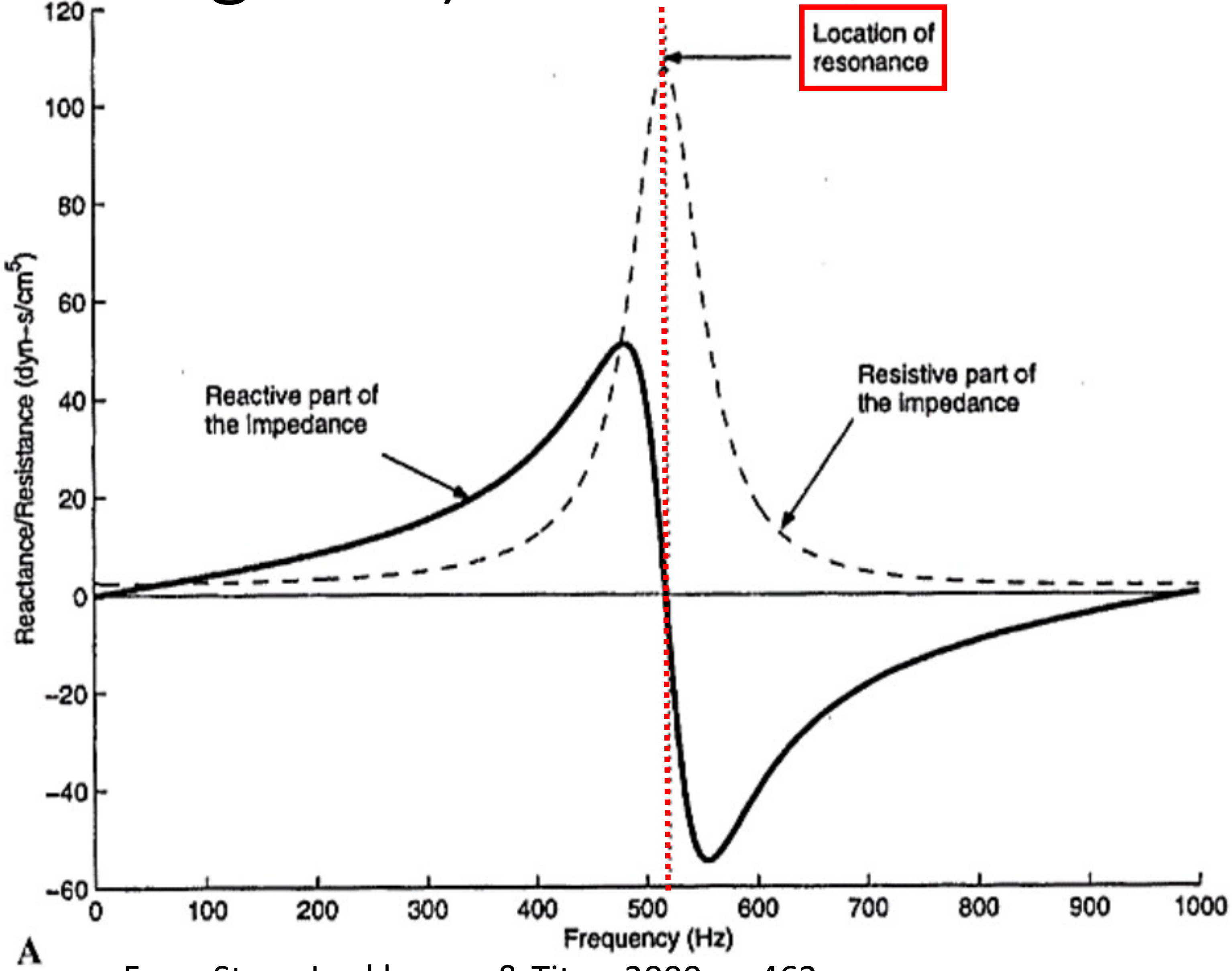


From Story, Laukkanen, & Titze, 2000, p. 462.

Reactance Curves(Inertograms)

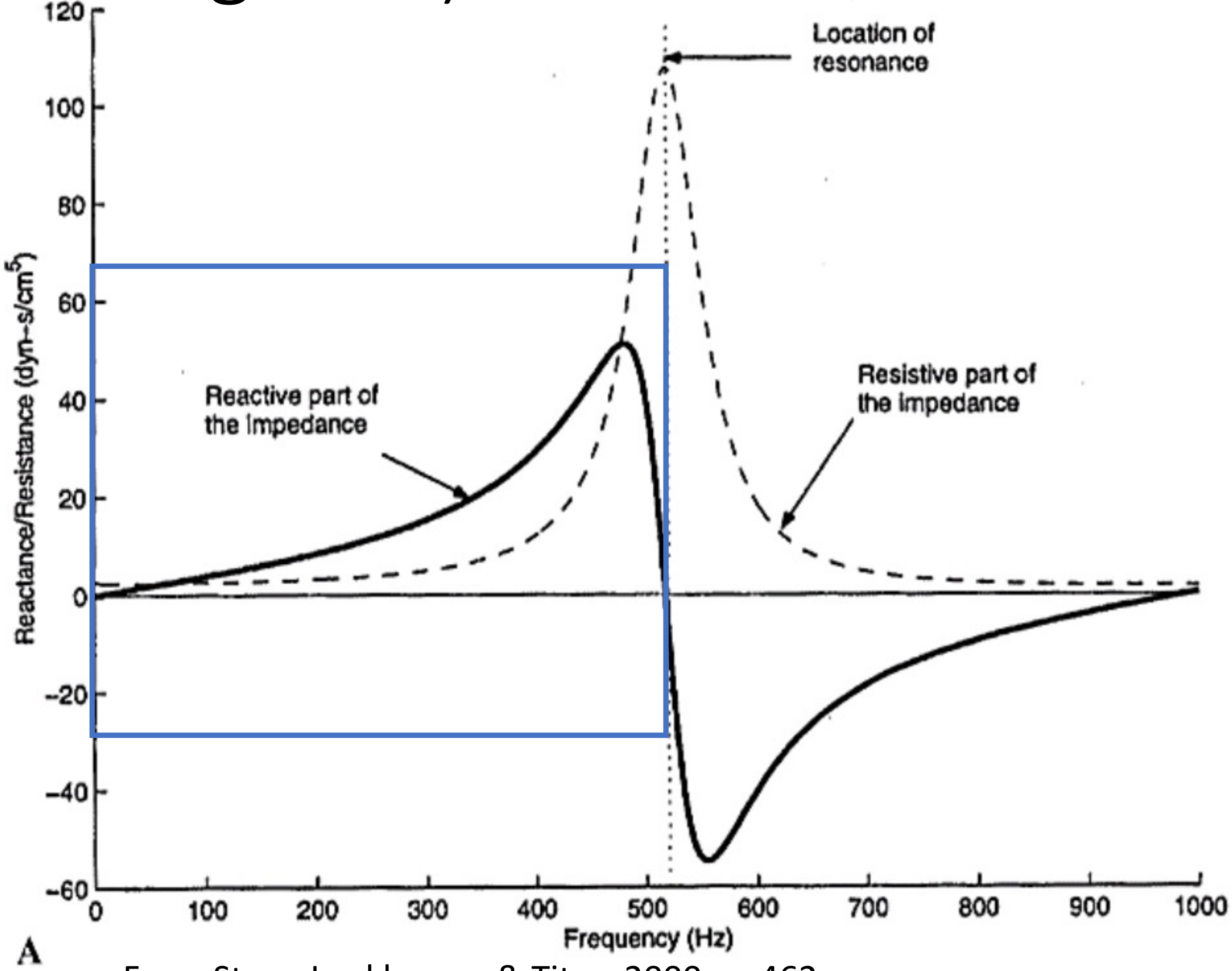
- Impedance curves calculated for a uniform tube with length 17.5 cm and cross- sectional area 3 cm^2.
- The solid line represents the reactance and the dashed line represents the resistance.
- **The resonant frequency is shown at approximately 501 Hz where resistance is maximum, inductance and capacitive are equal (and therefore reactance is zero), and impedance in minimal.**
- The portion of the reactance curve to the left of the resonance frequency (the positive section) is inductive and the portion of the reactance curve to the right of the resonance frequency (the negative section) is capacitive.



From Story, Laukkanen, & Titze, 2000, p. 462.

Reactance Curves(Inertograms)

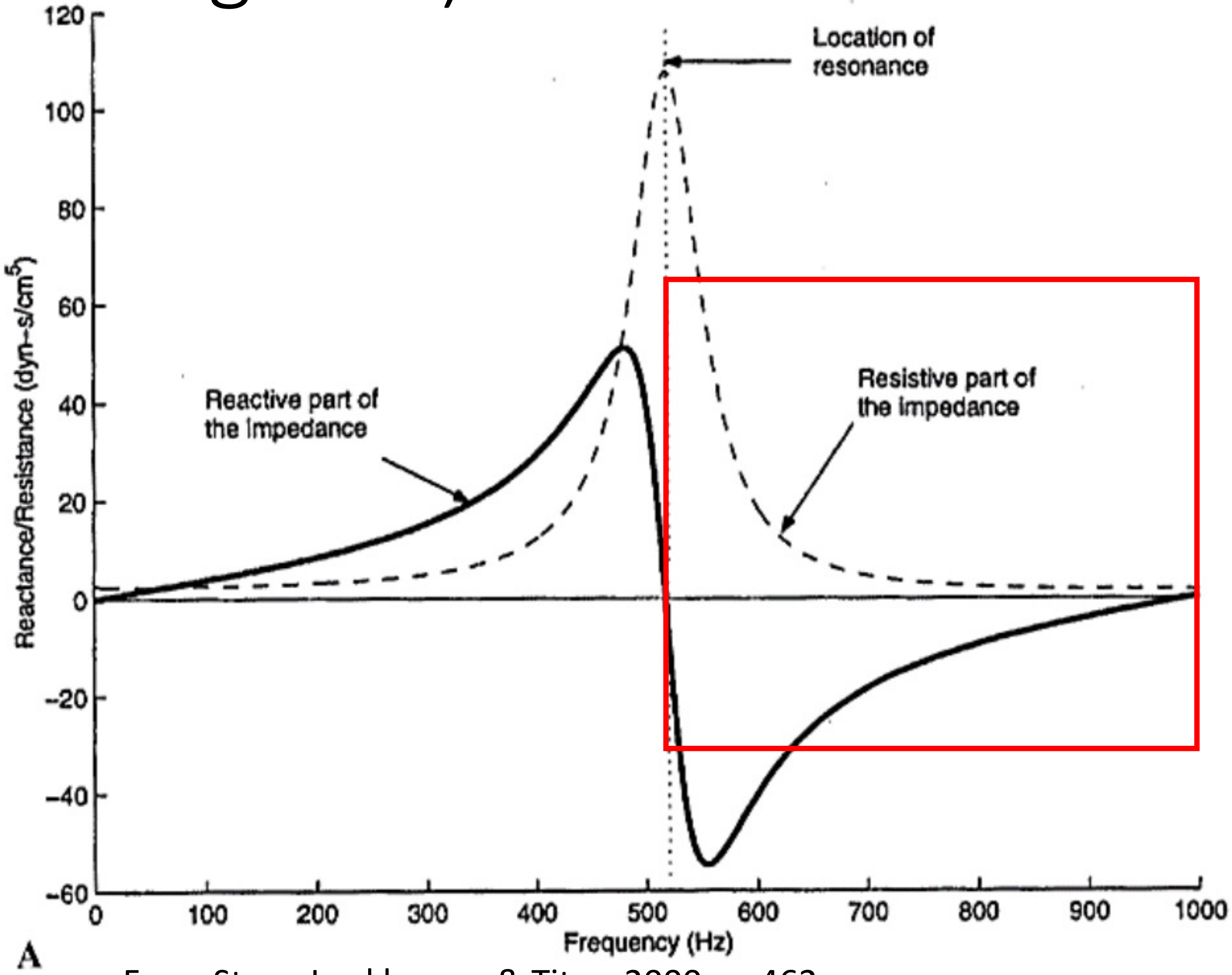
- Impedance curves calculated for a uniform tube with length 17.5 cm and cross- sectional area 3 cm^2.
- **The solid line represents the reactance and the dashed line represents the resistance.**
- The resonant frequency is shown at approximately 501 Hz where resistance is maximum, inductance and capacitive are equal (and therefore reactance is zero), and impedance in minimal.
- **The portion of the reactance curve to the left of the resonance frequency (the positive section) is inertive (inductive)** and the portion of the reactance curve to the right of the resonance frequency (the negative section) is capacitive.



From Story, Laukkanen, & Titze, 2000, p. 462.

Reactance Curves(Inertograms)

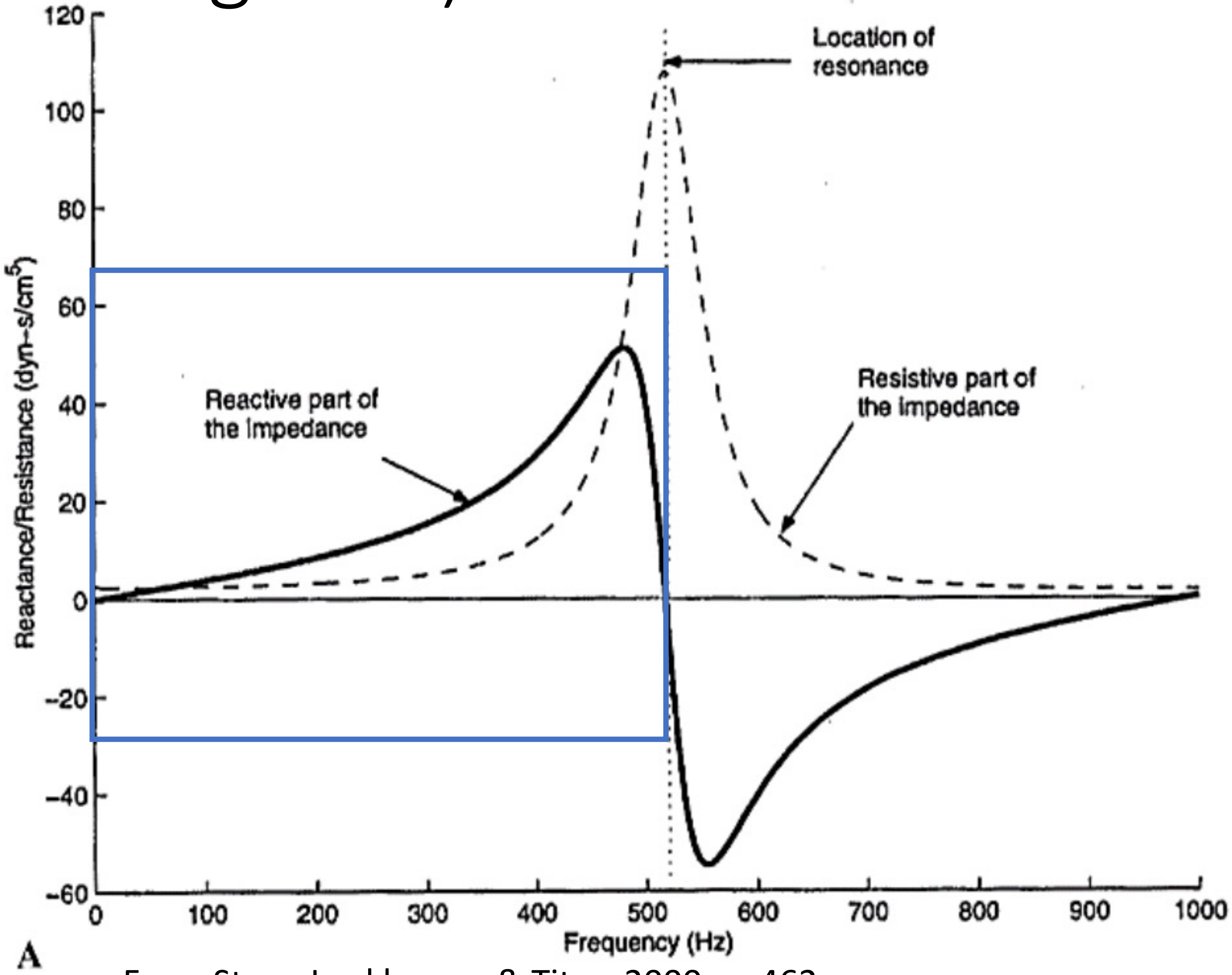
- Impedance curves calculated for a uniform tube with length 17.5 cm and cross- sectional area 3 cm^2.
- The solid line represents the reactance and the dashed line represents the resistance.
- The resonant frequency is shown at approximately 501 Hz where resistance is maximum, inductance and capacitive are equal (and therefore reactance is zero), and impedance in minimal.
- The portion of the reactance curve to the left of the resonance frequency (the positive section) is inductive **and the portion of the reactance curve to the right of the resonance frequency (the negative section) is compliant (capacitive).**



From Story, Laukkanen, & Titze, 2000, p. 462.

Reactance Curves(Inertograms)

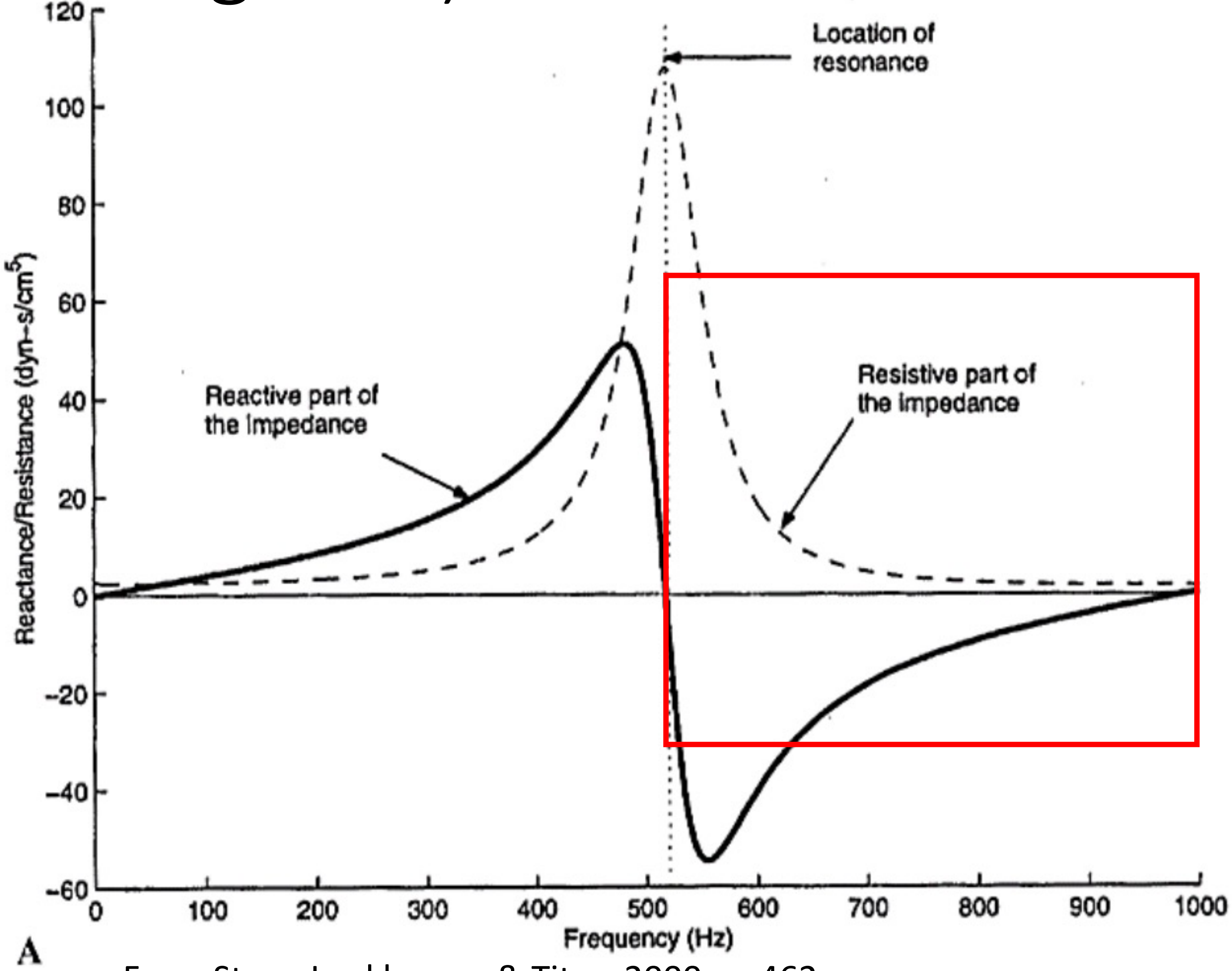
- **Inertive reactance occurs when the sound source converts aerodynamic energy efficiently into acoustic energy, resulting in more resonant voice production**
  - **So, having a source harmonic within this region is desirable**



From Story, Laukkanen, & Titze, 2000, p. 462.

Reactance Curves(Inertograms)

- **Compliant reactance can hinder vocal fold vibration, resulting in a non-resonant voice (i.e., the sound source does not efficiently convert aerodynamic into acoustic energy, resulting in sensation of vibration in the laryngeal region with a non-resonant quality)**
    - **So, having a source harmonic within this region is NOT desirable**
    - Harmonic – formant crossing can lead to unfavorable phonatory ***bifurcations*** (Maxfield, Palaparthi, & Titze, 2017; Titze, 2003; Titze, 2008**):**
        - Unexpected f_0 jumps,
        - Quenching (aphonic segments),
        - Subharmonics (f_0/n),
        - Diplophonia, chaotic VF vibration)

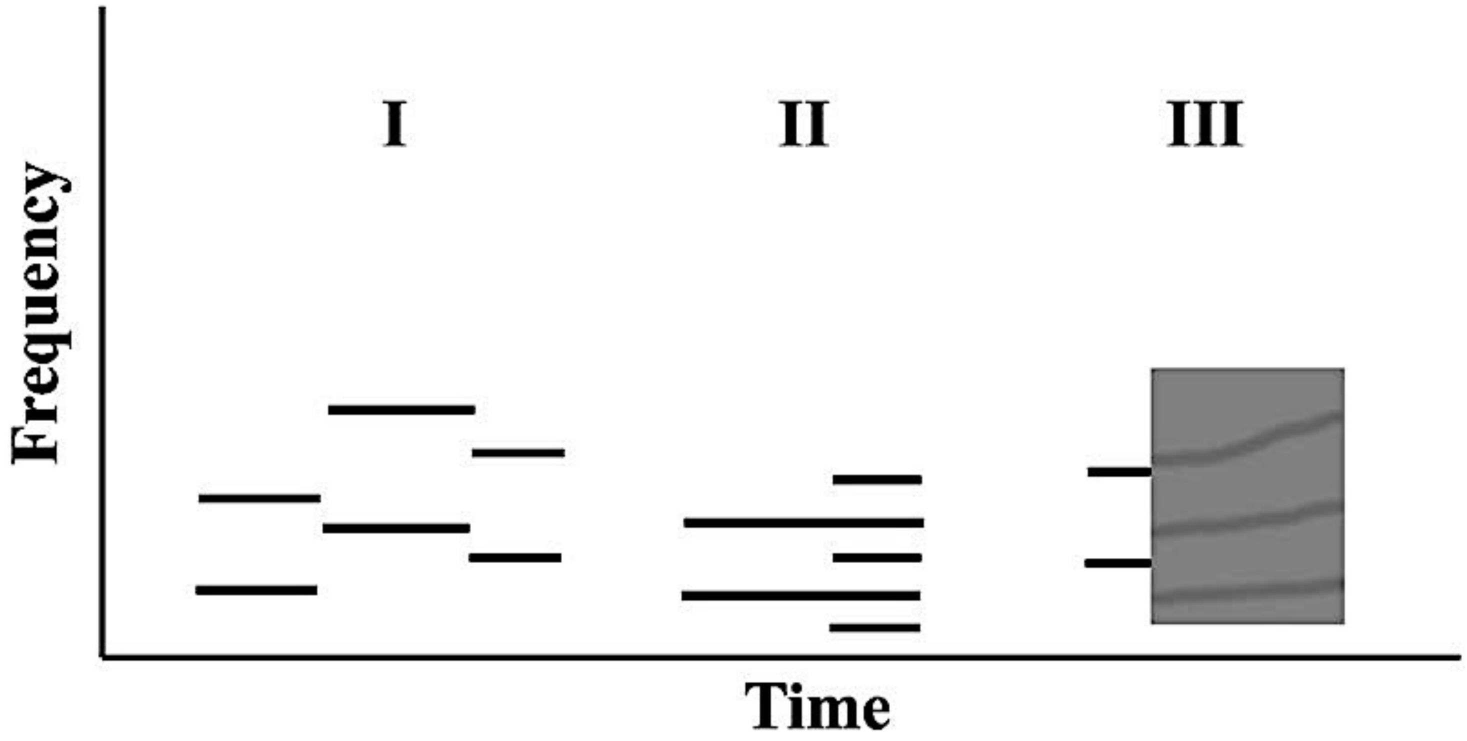


From Story, Laukkanen, & Titze, 2000, p. 462.

Bifurcations

Harmonic – formant crossings from an inertive formant region (on the left side) to a compliant region (on the right side) can lead to unfavorable phonatory ***bifurcations*** (Maxfield, Palaparthi, & Titze, 2017; Titze, 2003; Titze, 2008**):**

- Unexpected f_0 jumps,
- Quenching (aphonic segments),
- Subharmonics (f_0/n),
- Diplophonia, chaotic VF vibration)



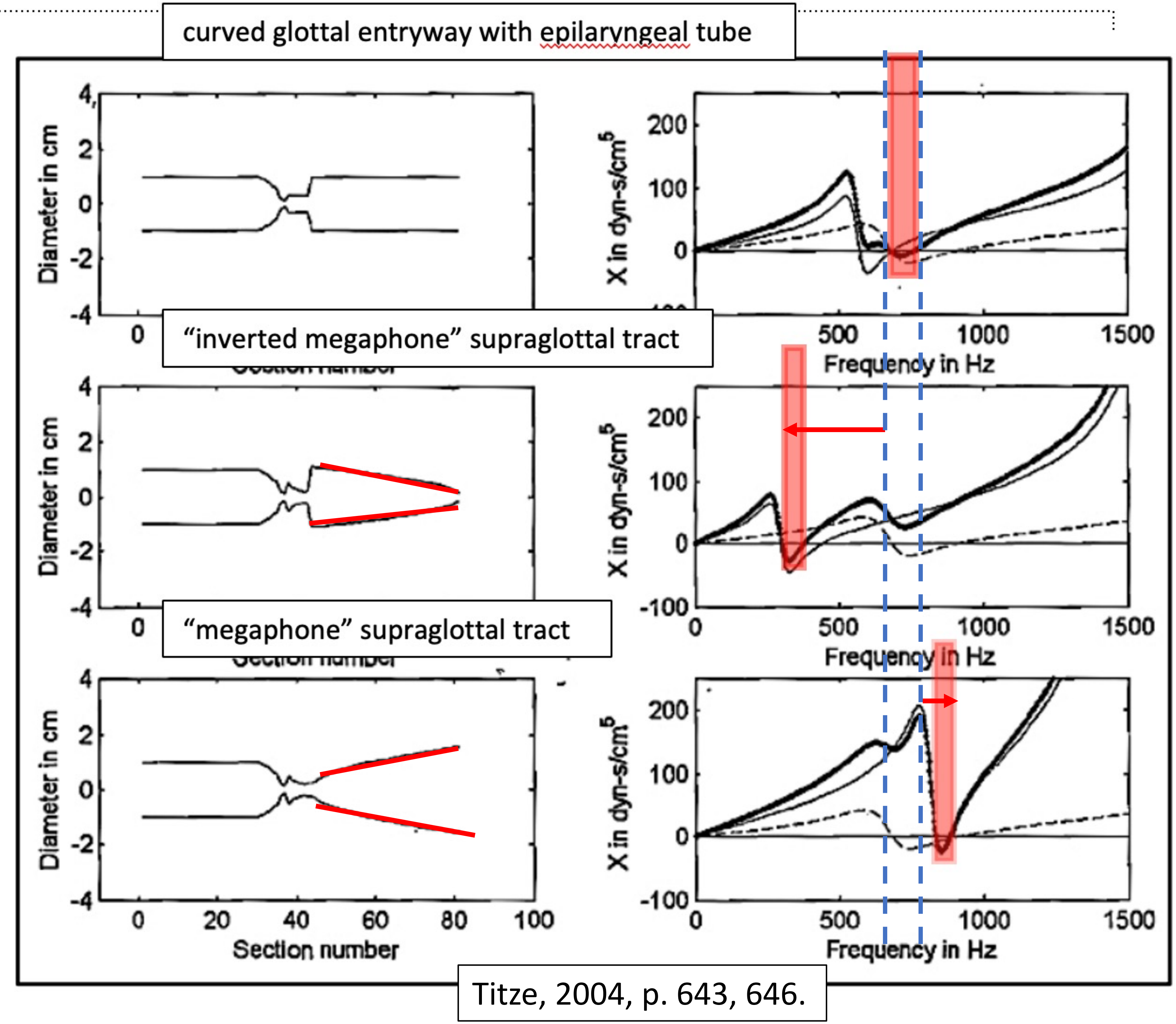
Bifurcation types. Sketches of narrow-band spectrograms of sudden frequency jumps (I), subharmonics (II), and chaotic VF vibration (deterministic chaos, III).

From Titze, et al., 2008, p. 1905.

The goal then is to increase the inertive frequency region(s) (and avoid compliant regions) by modifying the vocal tract geometry.

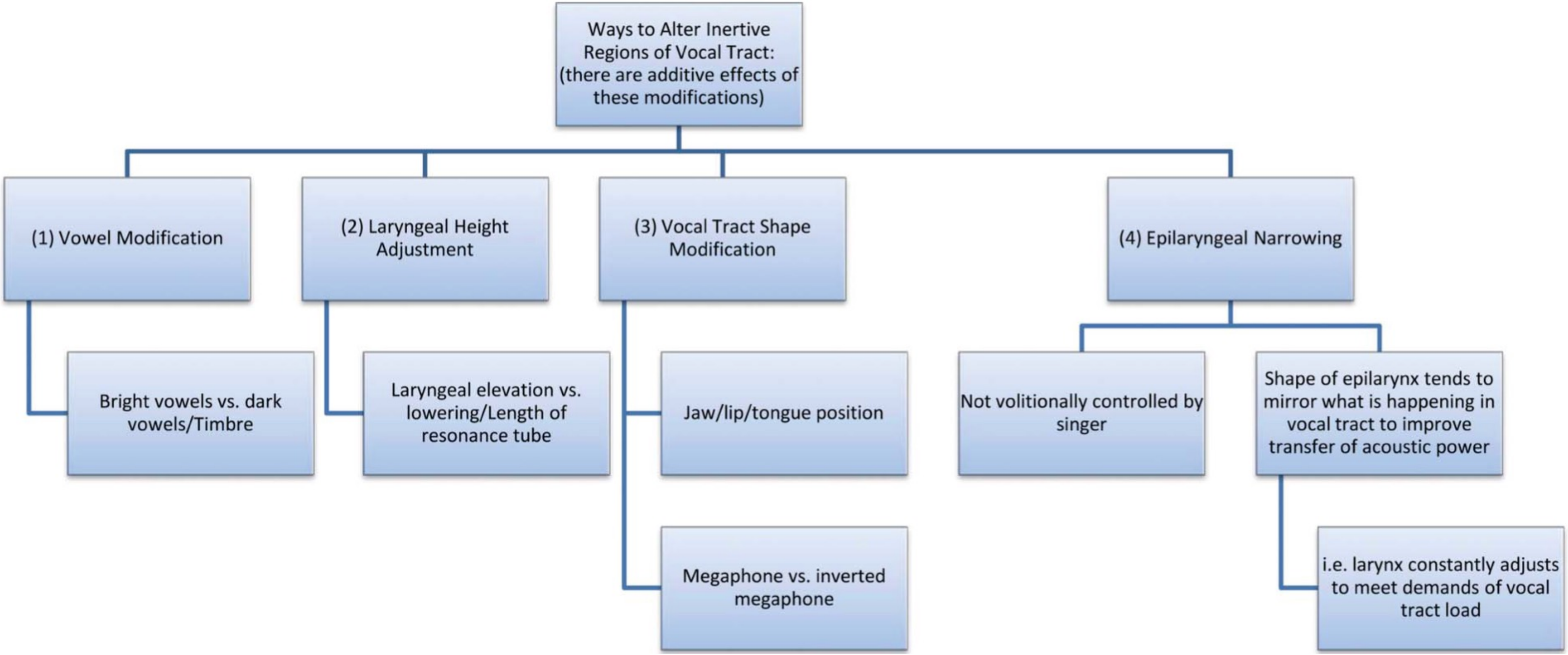
<u>This can be accomplished by:</u>

1. Adjusting the shape of the vocal tract (e.g., tongue position, megaphone vs. inverted megaphone),
2. Adjusting vocal tract length (e.g., straws, tubes, lip protrusion, laryngeal height adjustment),
3. Epilaryngeal narrowing



- "Reverse megaphone" VT shifts compliant region to the left (lower freq. region)
- "Megaphone" VT shifts compliant region to the right (higher freq. region)

- thin solid line = supraglottal reactance,
- dashed line = subglottal reactance,
- **thick solid line = combined supra- and sub-glottal reactance**



Rosenberg, 2014; Rosenberg & LeBorgne, 2014

VOCAL FOLDS – TYPES OF MODELS

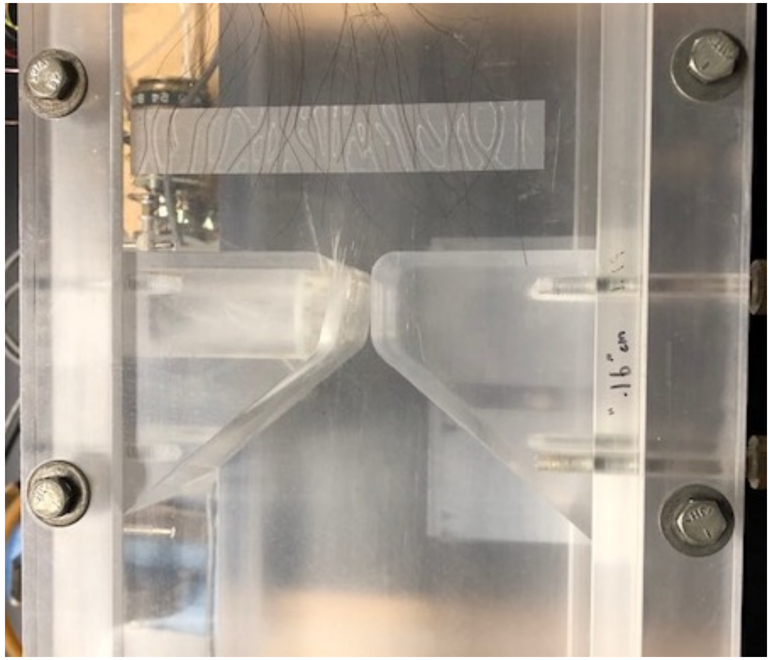
- Studies of voice production often utilize models in order to examine aerodynamic phenomena that would be difficult, impossible, or too invasive to access *in vivo*.

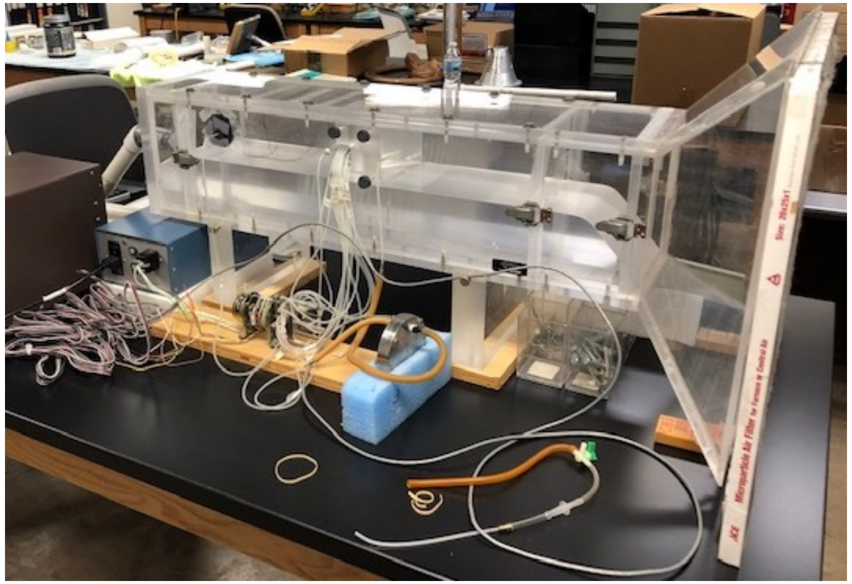
- **Static vocal fold models** (e.g., M5 – Scherer et al., 2001; M6 – Scherer et al., 2010)
- **Dynamic vocal fold models** (e.g., fluid-filled balloon – Titze et al., 1995; homogenous silicone M5 – Thomson et al., 2004; two layer silicone M5 – Murray and Thomson, 2012; multilayered silicone M5 – Murray and Thomson, 2012)
- **Excised animal and human laryngeal models** (e.g., van den Berg, 1968; Baer, 1975; Alipour & Scherer, 2000)
- **Computational laryngeal models** (e.g., one-mass model – Flanagan & Landgraf, 1968; two-mass model – Ishizaka & Flanagan, 1972; three-mass model – Story & Titze, 1995; 16-mass model – Titze 1973 & 1974; finite element model – Alipour et al., 2000)

Methods – TYPES OF Laryngeal MODELS

- **<u>Static models</u>**
  - Pros: precise control over geometric parameters, aerodynamic detail
  - Cons: cannot study dynamic motion, acoustics, or biomechanics

M5, Scherer et al., 2001
BGSU Physical Modeling Lab

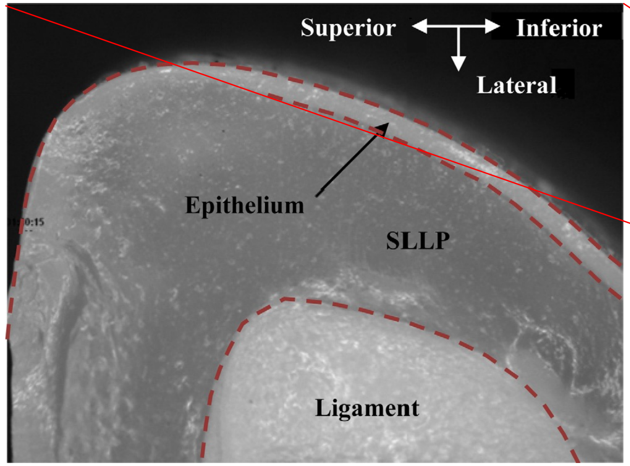


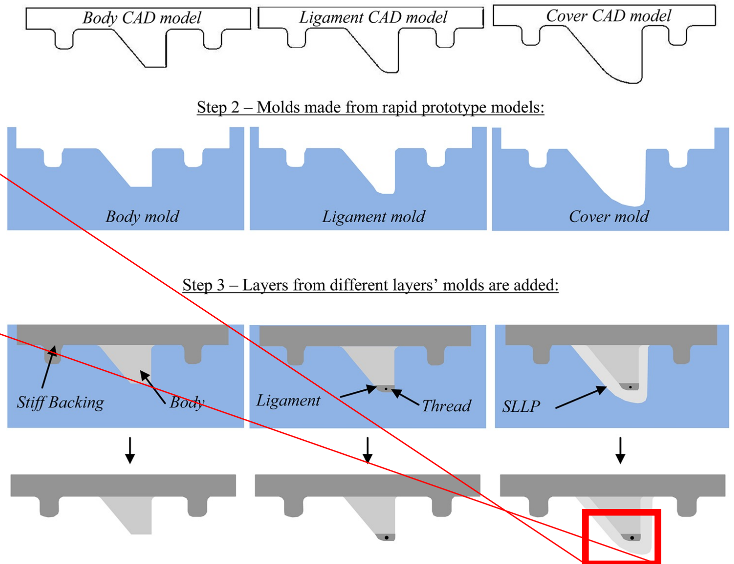


Methods – TYPES OF Laryngeal MODELS

- **Dynamic/synthetic models (driven or self-oscillating)**
  - Pros: precise control over geometric parameters; can study dynamic motion (kinematics), acoustics, and mechanical properties of synthetic material; fabrication is relatively straightforward and inexpensive; better repeatability than excised; shelf-life is longer than excised (can be used for several hours at a time and over several months with reasonable reliability)
  - Cons: lacks perfect ecological validity (e.g., lacks neuro innervation), unable to study intraglottal aerodynamics with great resolution; change in a parameter requires creation of a new model; reliability over time in question

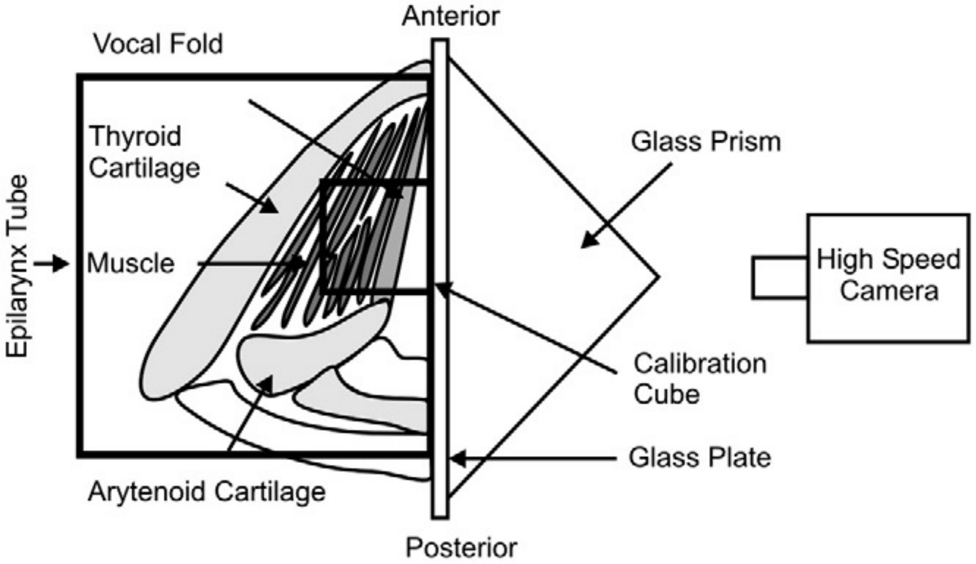
Murray, 2011; Murray & Thomson, 2011 & 2012



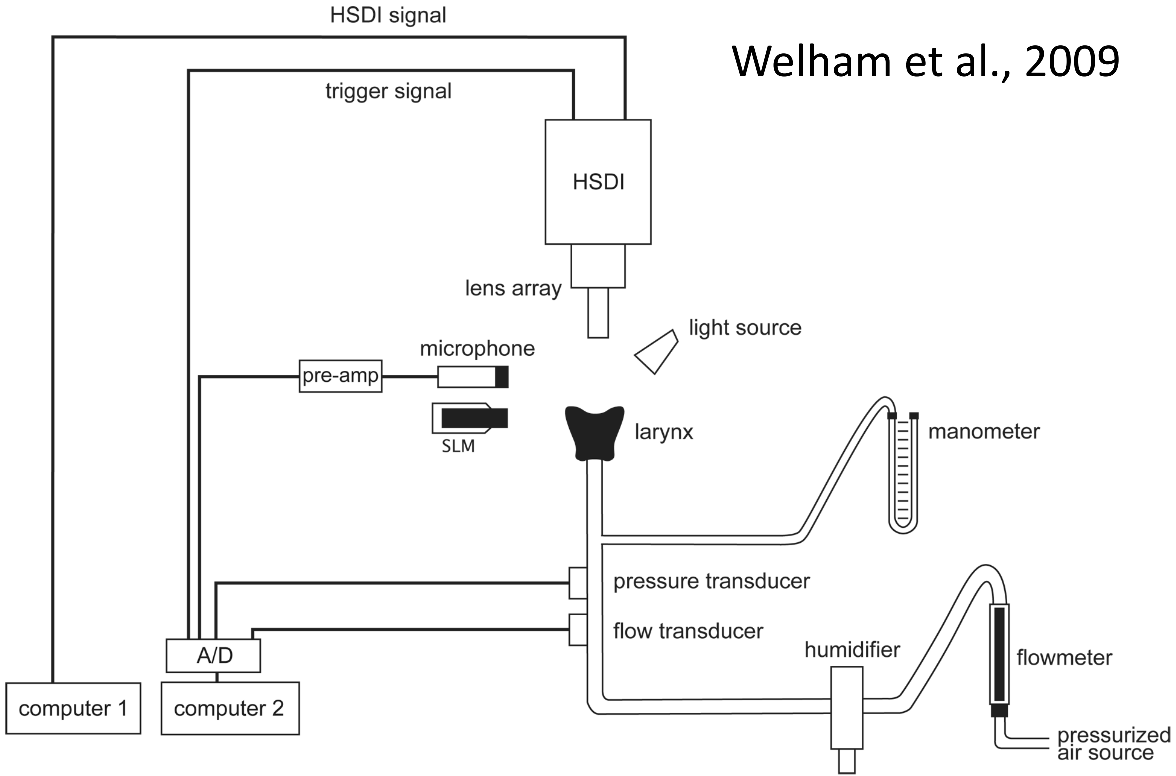


Methods – TYPES OF Laryngeal MODELS

- **Excised animal and human laryngeal models**
  - Pros: passive biomechanical properties ecologically valid (more so with human than with other animals); can study dynamic motion, acoustics, and biomechanics
  - Cons: lacks neuro innervation, unable to study intraglottal aerodynamics with great resolution



Döllinger et al., 2006 & 2012



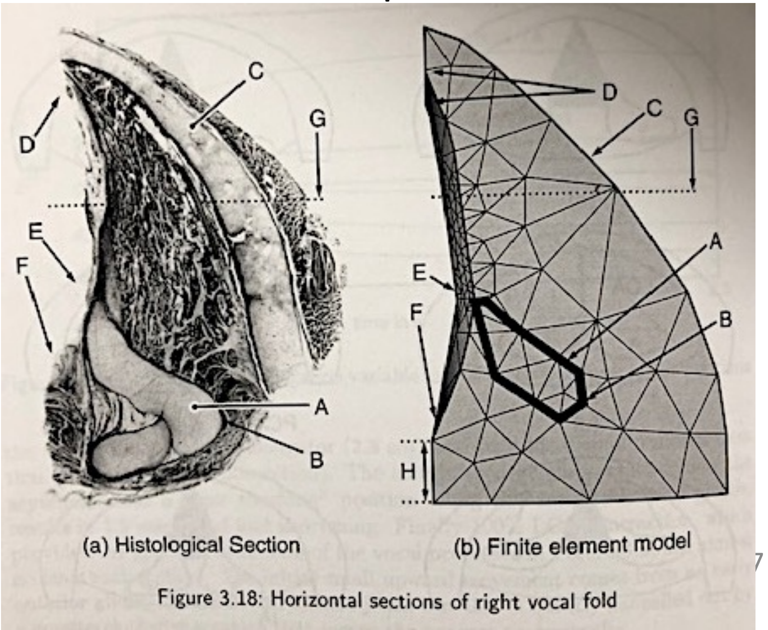
Welham et al., 2009

Methods – TYPES OF Laryngeal MODELS

- **<u>Computational/numerical models</u>**
  - Pros: Precise parametric control over all variables, can run many simulations in less time than it would take to do comparable work in a physical model
  - Cons: requires technical acumen, only as good as the equations and data used to run the model, difficulty simulating complex physical phenomena (e.g., turbulence, flow separation, fine resolution of large-scale time-varying 3-dimensional flow patterns)

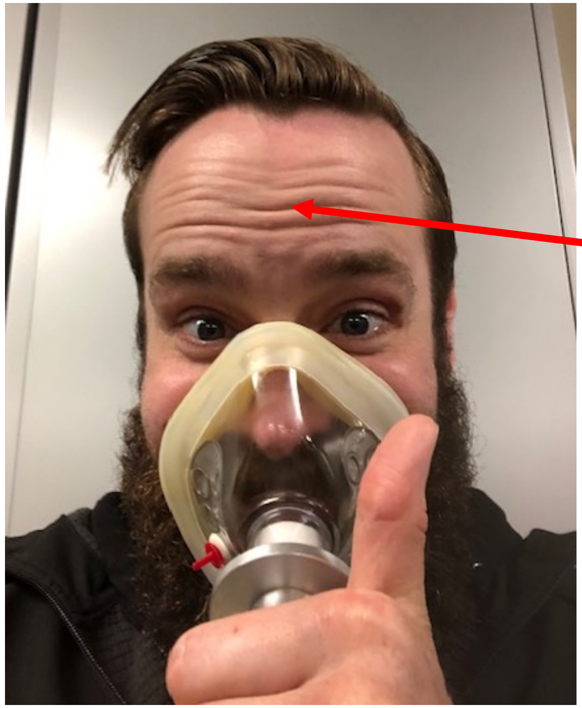
Scherer et al., 2004

Titze & Alipour, 2006



Methods – TYPES OF Laryngeal MODELS

- **<u>Human "model" (*in vivo*; *not a model actually)</u>**
  - Pros: as ecologically valid as it gets
  - Cons: difficult/impossible to precisely control variables, difficult to observe aeroacoustic and kinematic phenomena with high temporal and spatial resolution because the larynx is within the body, can be invasive, can be expensive (e.g., man hours for medical personnel), can be difficult to find subjects, IRB



Human

Abridged Literature Review

***See handout for additional articles (n = 141)**

Cursory Literature review

Computational studies: (16)

Excised larynx studies: (7)

Synthetic self-oscillating studies: (4)

Human studies: (39)

n.b.: All changes were generally observed *during* SOVT exercises for model studies and *after* SOVT exercises for human studies unless otherwise stated.

Abridged Literature Review - Aerodynamics

Computational VF Models

- Decrease in mean and peak glottal airflow *during* SOTVE (Titze, 2006b)
- Increase in mean supraglottal and intraglottal pressures *during* SOTVE (Titze, 2006b)
- Increases in oral pressure *during* tube phonation (Titze & Laukkanen, 2007)

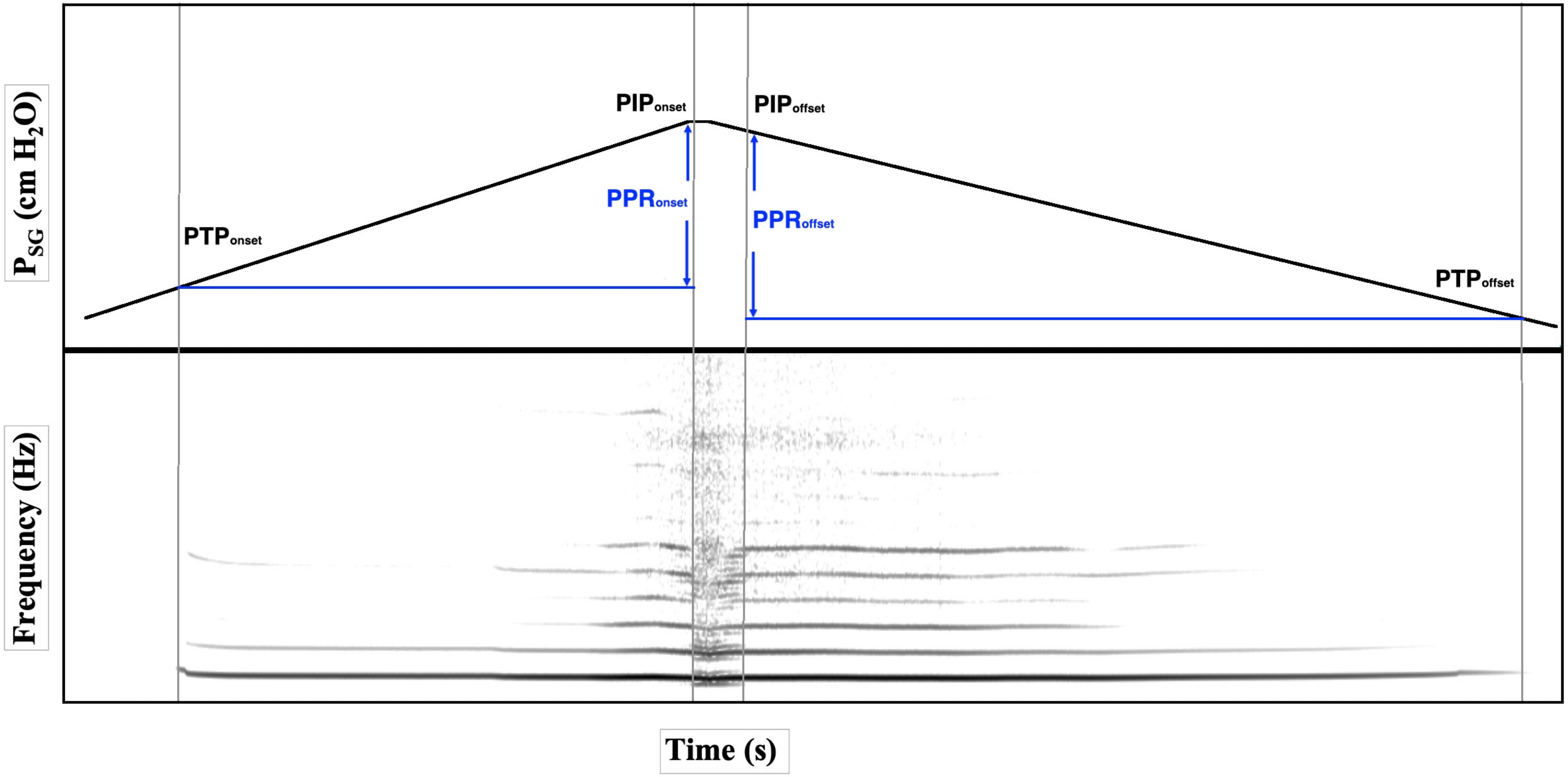
Synthetic (self-oscillating) VF Models

- Increase in subglottal and oral pressures with increased airflow resistance of tubes (Horacek et al 2014b)
- Transglottal pressure amplitude increased with resistance, correlating with increased vocal fold vibration amplitude (Horacek et al 2014b)
- Decrease in PTP for tube-in-water comparted to no tube (Horáček, Radolf, & Laukkanen, 2019)
- Decrease in PTF for tubes/straws compared to vowel (Horacek et al 2014b)
- Water bubbling induced low frequency oscillations in pressures and vocal fold vibration (Horacek et al 2014b)

Excised (animal and human) VF Models

- Decrease in PTP at onset (Conroy et al., 2014; Kang et al., 2019a; 2019b; Tangney et al., 2019)
  - PTP was decreased in the narrower diameter tubes (3, 9, and 15 mm) and longer tubes (5 and 25 cm) vs. control (Tangney et al., 2019)
- Decrease in PTF at onset (Conroy et al., 2014; Kang et al., 2019; Tangney et al., 2019)
  - PTF was only decreased for the narrowest (3mm) diameter tube condition (Tangney et al., 2019)
  - *Significant PTP reduction with the 5-25 cm lengths and 9-15 mm restrictions indicates these may be ideal dimensions for clinical use of straw phonation (Tangney et al., 2019)*
- Increase in PIP, PIF, PPR, and PFR (Kang et al., 2019) *See next slide

Abridged Literature Review - Aerodynamics



Abridged Literature Review - Aerodynamics

Human Studies

Airflow:

- **Increases in average glottal airflow** *after* SOVTEs (Croake, Andreatta, & Stemple, 2017 – n.s.; Dargin & Searl, 2015; Kang et al., 2020, 2019a – only lasted 20 min. after 10 min. straw phonation; Mills et al., 2018)
- **Decreases in average glottal airflow** *after* SOVTEs (Guzman et al 2020)
- **Decreases in peak airflow** (Croake, Andreatta, & Stemple, 2017 – n.s.)

Abridged Literature Review - <u>Aerodynamics</u>

Human Studies

<u>Pressure:</u>

- **Decreases in PTP** (Guzman et al 2020; Kang et al., 2019b; Kang et al., 2020; Kang et al., 2019a – after 10 min straw phonation, reduction only lasted 5 min.)
  - PTP was lowest for tube-in-air (Radolf, 2014)
- Increases in subglottal pressure (Guzmán et al., 2016; single subject: Laukkanen et al., 2008; Laukkanen et al., 2007)
- Decreases in subglottal pressure (Guzman et al 2020)
- Increases in oral pressure <u>*during*</u> SOVTEs (Granqvist et al., 2015; Guzmán et al., 2016; Maxfield et al., 2015)
  - Oral pressure varied across different SOVTEs (nasals produced lowest pressures and straw-in-water produced highest pressures – Maxfield et al., 2015)
  - Tube length had a smaller effect on oral back pressure than diameter (Andrade et al, 2016)
  - Smaller diameter straws increased oral pressure and lung pressure needed for phonation (Titze et al, 2002)
  - Oral pressure increased linearly with tube water depth (Granqvist et al., 2015; Smith & Titze, 2017; Wistbacka et al, 2017) and with tube narrowing (Smith & Titze, 2017)
- High-resolution pharyngeal manometry (HRM) showed pressures increased with greater vocal tract occlusion (Hoffmeister et al 2019)

Abridged Literature Review - <u>Aerodynamics</u>

Human Studies

Resistance/Impedance:

- Decreases in laryngeal airflow resistance (Dargin & Searl, 2015; Mills et al., 2018)
- Various SOVTEs differ in measured impedance (vowels < bilabial fricatives < tubes < bilabial plosives – Story et al., 2000)

Tube-in-water:

- Tube length had a smaller effect on back pressure than diameter (Andrade et al, 2016)
- Oral pressure oscillation occurred at the water bubbling frequency (Laukkanen et al, 2019)
- Laryngeal vibration amplitude was higher at the bubbling frequency than at the phonation frequency (Laukkanen et al, 2019)
- At low flows bubbles were emitted singly, at medium flows in pairs, and at high flows chaotically, with bubble frequency increasing and volume decreasing with flow up to the chaos threshold, while bubble frequency decreased and volume increased with larger back cavity volume (Wistbacka et al, 2017)

Other:

- Greater occlusion related to larger MPT improvements (Bane et al, 2018)
- High intra-subject variability for SOVTEs (Keltz and McHenry, 2022; airflow – Laukkanen et al., 2008)
- No major differences seen between participant vocal condition groups (healthy trained, healthy untrained, MTD, or u/l VF paralysis) for any outcomes measures.

Abridged Literature Review - <u>Acoustics</u>

Computational VF Models

<u>Sound Pressure:</u>

- Increased radiated SPL after tube phonation (Vampola et al., 2011)
- Increase in intraoral acoustic pressure (with resonance tube: Titze & Laukkanen, 2007) → may facilitate resonance sensations

<u>Resonance:</u>

- Formant frequency changes (Story, Laukkanen, & Titze, 2000; Titze & Laukkanen, 2007; Titze, 2020)
  - Decreased F1 with narrowing of tube diameter or increasing of tube length
- Amplitude changes in reactance curves / increase in frequency ranges of inertive reactance / decrease in frequency ranges of negative reactance regions (Story, Laukkanen, & Titze, 2000; Titze & Laukkanen, 2007; Titze, 2020; Vampola et al., 2011)
  - Resonance tube lowered F1 and increased inertive reactance below F1 (*<u>during</u>* SOVTE – Titze & Laukkanen, 2007)
  - Optimal inertance was achieved with narrow tube, narrowed epilarynx, and /i/ or /u/ vowel (Titze, 2020)
- VT resonance decreased given tube-in-water to ~8-10 Hz, which overlapped measured water bubbling frequency of 11-11.5 Hz (Horáček et al., 2017)

n.b.: Matching the VT resonance with the water bubbling frequency may intensify massage-like benefits but could also cause discomfort in some clients

Abridged Literature Review - <u>Acoustics</u>

Human Studies

F0, F0 Range, SPL, SPL range:

- Decreases in F0 (Laukkanen et al., 2007; Paes et al., 2013; Savareh et al., 2021; Vampola et al., 2011)
- Increases in F0 (tongue trill – Schwartz & Cielo, 2009; lip trills - Brockmann-Bauser, M., Balandat, and Bohlender, 2020)
- Increases in F0 *range* (primarily for oscillatory SOVTE conditions: Andrade et al., 2014)
- Singing frequency range, maximum SPL, and dynamic range increased (Brockmann-Bauser, M., Balandat, and Bohlender, 2020)
- Increases in overall SPL and/or singer's/speaker's formant SPL after SOVTEs (Dargin & Searl, 2015; after water-resistance therapy – Echternach et al, 2020; Guzman et al., 2013c; Laukkanen et al., 2012; Schwartz & Cielo, 2009)

Abridged Literature Review - <u>Acoustics</u>

Human Studies

Resonance:

- Formant frequency changes (decreased F1, F2, F4, and F5 but increased F3: Laukkanen et al., 2012; decreases in F1 - Savareh et al., 2021)
- Increased spectral prominence in the singer's/speaker's formant region (Guzman et al., 2013c)
- Clustering of F3 and F4 after tube phonation (Guzman et al., 2013; Vampola, Laukkanen, Horacek, & Svec 2011)
- Decreases in F1-F0 difference (Savareh et al., 2021)
- F1-F0 difference for "fluctuating" exercises > "steady" exercises (Andrade et al., 2014)
- Both tube methods (in air and water) lowered the first formant frequency closer to the fundamental frequency or water bubbling frequency (Horáček, Radolf & Laukkanen, 2019).
- Nonsingers showed no significant formant changes (Kaneko et al 2020)

Abridged Literature Review - <u>Acoustics</u>

Human Studies

Spectral Slope, Noise:

- Vowels after tubes had less steep spectral slope and higher signal-to-noise ratio versus before (Laukkanen, 1992)
- Decreased instability, subharmonics, and noise above 4 kHz (Paes et al., 2013)
- Decreases in glottal-to-noise excitation ratio (De Almeida Ramos & Gama, 2017)
- Increases in glottal-to-noise excitation ratio (noise decreased) after lip trill technique (de Oliveira et al, 2022)

Perturbation:

- Jitter and shimmer improved in both groups (Kaneko et al 2020)
- Jitter, shimmer and singing power ratio improved significantly in the mask group but not the control (Fantini et al, 2017)
- No significant changes in jitter, MPT, or DSI (Brockmann-Bauser, M., Balandat, and Bohlender, 2020)

Abridged Literature Review - <u>Acoustics</u>

Human Studies

Cepstral:

- SOVE (ventilation mask) group showed increased cepstral peak prominence in dysphonic subjects (Frisancho et al, 2020)
- Cepstral peak prominence and cepstral spectral index of dysphonia in sustained vowels improved significantly (Gartner-Schmidt, 2022)

Other:

- No significant changes occurred in acoustics or auditory-perception for either SOVTE (ventilation mask) or water resistance therapy (Kissel et al, 2023)

Abridged Literature Review – <u>VF Contact (EGG CQ)</u>

Human Studies

- Increases in CQ/Decreases in OQ *<u>after</u>* SOVTEs (Calvache et al., 2020; Gaskill & Quinney, 2012; Guzmán et al., 2016, 2017, 2018; increases with tube length – Laukkanen et al., 2007; Tyrmi & Laukkanen, 2017)
- Decreases in CQ/Increases in OQ *<u>after</u>* SOVTEs (Andrade et al., 2014; Croake, Andreatta, & Stemple, 2017; Dajer et al., 2014; Echternach et al., 2020; Gaskill & Erickson, 2008; Granqvist et al., 2015; Guzman et al., 2013c, 2013d, 2015, 2017, 2018; Kang et al., 2020; Mills et al., 2018 – n.s.; Dajer et al., 2014; Saccente-Kennedy et al., 2020)
    - CQ in “fluctuating” > “steady” (Andrade et al., 2014)
    - Combining “steady” and “fluctuating” exercise (e.g. tongue trill + hand-over-mouth) showed benefits of both types of exercises (Andrade et al., 2014)
    - OQ increased with increased tube water depth (Granqvist et al., 2015)
    - CQ decreased more for tube phonation with vibrato vs. without Guzman et al., 2013d)
- Increases in CQ/Decreases in OQ *<u>during</u>* SOVTEs (Dargin & Searl, 2015)
    - Closed quotient increased with the tube in water (Laukkanen et al, 2019)
    - A straw submerged 10cm in water increased CQ the most in both groups (Guzman et al, 2015)
- Variable changes in CQ across subjects (Cordeiro et al., 2012; Dargin & Searl, 2015; Echternach et al., 2020; Gaskill & Erickson, 2010, Gaskill & Quinney 2012; Guzman et al., 2013d, 2016, 2017; Horacek et al., 2017; Kang et al., 2019, 2020; Laukkanen et al., 2007; Mills et al., 2018; Portillo et al., 2018 Radhakrishnan, 2021; Saccente-Kennedy et al., 2020)
- No change in CQ (Echternach et al, 2020; Guzman et al., 2017, 2020)
- Steady SOVTEs had higher contact quotient than fluctuating SOVTEs (Chatterjee Dhruw and Chatterjee 2020)
- SOVTE (ventilation mask) group showed increased contact quotient in dysphonic subjects (Frisancho et al, 2020)

Abridged Literature Review – VF Imaging (Kinematics)

Human Studies

Vibration:

- Improvements in glottal stroboscopic variables (vibrational amplitude, mucosal wave, phase closure, glottal closure) (Dargin, DeLaunay, & Searl, 2016)
- Maximum glottal amplitude and glottal closing velocity decreased (Laukkanen et al, 2019)

Closure:

- Increases in vocal fold closure/reduced glottal gap (Maia et al., 2012; Menezes et al., 2005; for dysphonic subjects – Nam et al., 2019)
- Variable effects on glottal closure and mucosal wave (after tongue trill – Menezes et al., 2005)
- No change in vocal fold closure (Costa et al., 2011; Meerschman et al., 2021; Schwarz & Cielo, 2009)

Tube-in-water:

- "Fluctuating" exercises increased variability of vocal fold vibration (Andrade et al., 2014)
- Water bubbles (tube-in-water) cause modulation of VF vibration amplitude and frequency (Granqvist et al., 2015)
- Increase of the glottal area waveform related OQ and CQ *during* WRT, followed by a drop of both values immediately after WRT, and then a subsequent rise of both values 30 min. after the intervention (Echternach et al., 2020)

Abridged Literature Review – Supraglottic Morphology (imaging)

Human Studies

Larynx vertical position

- Decreased laryngeal height adjustment (Dargin, DeLaunay, & Searl, 2016)
- Decreased laryngeal vertical position (Guzman et al., 2013a; Guzman et al., 2013c; Guzman et al., 2017)
- Increases in laryngeal vertical height (Laukkanen et al., 1996)

Anteroposterior compression in the epilarynx tube region

- Increased A-P compression *during* SOVTE (Dargin, DeLaunay, & Searl, 2016; Guzman et al., 2013a; tube in air and water –Meerschman et al., 2021)
- Decreased anteroposterior compression *during* SOVTE (humming and um-hum tasks – Ogawa et al., 2013)

Medio-lateral compression in the epilarynx tube region

- Decreased M-L compression (i.e., widening) *during or after* SOVTE (Dargin, DeLaunay, & Searl, 2016; Guzman et al., 2013a; Guzman et al., 2013c; Guzman et al., 2017; Maia et al., 2012; tube in air and water – Meerschman et al., 2021; Ogawa et al., 2013)
- Decreased pharyngeal inlet to epilarynx tube outlet area ratio (Guzman et al., 2013c; Guzman et al., 2017; Laukkanen et al., 2012)

Abridged Literature Review – Supraglottic Morphology (imaging)

Human Studies

Pharyngeal constriction/VT volume

- Decreased (Dargin, DeLaunay, & Searl, 2016)
- Increase in vocal tract volume (men only – de Oliveira et al, 2022; increase in 38.5% after tube phonation – Vampola et al., 2011; midsagittal area – Laukkanen et al., 2012; oropharyngeal cross sectional area - Vampola et al., 2011)
- Increases in VT vertical length (Guzman et al., 2017)

Velar closure

- Increased VP closure (Guzman et al., 2013c; Guzman et al., 2017; Laukkanen et al., 2012; Vampola et al., 2011)

Tongue height

- Lowered tongue height (Guzman et al., 2017; ~0.5cm during SOVTEs - Lulich and Patel, 2021)

n.b.: Changes were dependent on SOVTE characteristics and instructions given (Guzman et al., 2017)
Carryover effects were observed after tube removal (Vampola et al., 2011)

Abridged Literature Review – Supraglottic Morphology (imaging)

Human Studies

- Differences were noted in vocal tract morphometric measures between dysphonic (VF nodules) individuals and healthy controls *before* SOVTE treatment (i.e., laryngeal vestibule area and arytenoid length were smaller in the vocal nodules group); however, differences decreased (but did not disappear) *after* tube-in-water exercise such that the dysphonic group was more similar to the healthy group (i.e., changes in the angle between the posterior pharyngeal wall and the vocal folds, in vocal fold length, and in the distance between the epiglottis and the pharyngeal posterior wall were observed) (Yamasaki et al., 2017)

- Variation within and across subjects (Dargin et al., 2016)
- No changes in supraglottal morphology (Costa et al., 2011; de Oliveira et al, 2022; Godoy et al., 2019; Menezes et al., 2005; Schwarz & Cielo, 2009)

Abridged Literature Review – Collision (Impact) Forces

Computational VF Models

- Reduction in collision stress (Titze, 2006b)

Synthetic (self-oscillating) VF Models

- Impact stress increased with higher airflow in all conditions (Horáček, Radolf, & Laukkanen, 2019)
- At airflows matching human phonation, impact stress was lower for tube in water than for no tube (Horáček, Radolf, & Laukkanen, 2019)

Abridged Literature Review – <u>Laryngeal Muscle Activity (EMG)</u>

Human Studies

- Increases in TA activity relative to CT and LCA activity (single subject, hooked wire EMG; <u>*during*</u> tube phonation and [β:] compared to vowels, effect was more pronounced with greater occlusion – Laukkanen et al., 2008)

- Decreases in extrinsic laryngeal muscle activity <u>*during*</u> /β:/ (sEMG) (Laukkanen et al., 1996) and after SOVTEs (lip trill, humming, straw phonation –Savareh et al., 2021)

n.b.: [β] is a voiced bilabial fricative (like a /v/ but made with both lips)
https://en.wikipedia.org/wiki/Voiced_bilabial_fricative

Abridged Literature Review – Perception

Human Studies

Self-Ratings: Generally positive

- Improvements in self-perceptions voice quality after SOVTE (Costa et al., 2011 – for 19/23 disordered and 11/25 healthy subjects; Portillo et al., 2018; Schwarz & Cielo, 2009)
- Decreased perceived vocal effort and laryngeal discomfort after 10 min. straw phonation (Kang et al., 2020)
- Increased subject self-perceptions of: phonatory comfort (68%), improvements in vocal quality (52%), no change in vocal quality (36%) (Paes et al., 2013)
- Self-assessments showed increased phonatory comfort and voice quality perception with the mask (Fantini et al, 2017)
- Patient-reported outcomes improved in both groups for vocal comfort, effort, and quality for SOVTE (ventilation mask) and water resistance therapy (Kissel et al, 2023)
- All SOVTEs increased self-perceived voice quality and muscle relaxation, which remained stable after 1 week (Guzman et al 2018)
- All SOVTEs decreased throat discomfort symptoms after 1 week of practice (Guzman et al 2018)
- Subjects reported generally positive sensations after SOVTE (Schwartz & Cielo, 2009)
- Increased discomfort with increased SOVTE task duration but not with increased tube length (Mills et al., 2018)
- Self-reported improvements in comfort, sonorousness, clarity, power after warm-up (Di Natale et al, 2022)
- Tongue trill yielded vocal quality improvements that declined after 5 minutes and differed by sex; unpleasant sensations increased progressively with longer performance (Menezes et al., 2005)
- “Fluctuating” exercises introduced a secondary vibration source into the vocal tract, which appeared to have a “massage effect” (Andrade et al., 2014)
- Increased sensory awareness as the main benefit (Gartner-Schmidt, 2022)
- Improvements in self-assessed voice handicap, voice symptoms, throat discomfort, and resonant voice quality (Guzman et al 2020)
- Self-assessments improved in both groups(Kaneko et al 2020)
- VHI scores improved significantly more for both treatment groups than control (Kapsner-Smith et al, 2015)
- VHI-10 decreased significantly post-therapy (Gartner-Schmidt, 2022)
- Flow-resistant tube therapy was noninferior to VFE for reducing VHI scores (Kapsner-Smith et al, 2015)
- Flow-resistant tube significantly reduced CAPE-V Roughness ratings versus control (Kapsner-Smith et al, 2015)
- Tube phonation was difficult at high pitches but easier at middle pitches versus vowels (Laukkanen, 1992)

Abridged Literature Review – Perception

Human Studies

External Auditory-Perceptual Ratings: Generally positive

- Decreased external rater perception of vocal roughness, breathiness, and dysphonia grade (De Almeida Ramos & Gama, 2017; decreased roughness only in 18/23 subjects – Ogawa, 2013)
- Increased external rater perception of improved vocal quality (Guzman et al., 2013c; Paes et al., 2013 – 60%)
- No significant difference in perceptual ratings or acoustic measures pre/post warm-up or pre/post performance (Di Natale et al, 2022)
- Improved perceived voice quality after exercise (Enflo et al, 2013)
- No significant changes occurred in auditory-perception for either SOVTE (ventilation mask) or water-resistance therapy (Kissel et al, 2023)

What does all of this mean??

- **A recent systematic review and meta-analysis (Pozzali et al., 2021) found that <u>the overall quality of evidence on SOVTEs was judged to be "very low"</u> (as assessed by the Cochrane Risk of bias and ROBINS-I tools).**

- **Furthermore, <u>much of the evidence is equivocal (ambiguous or contradictory)</u>**

- **Therefore, can we even make educated judgements regarding for whom these exercises may be appropriate??**

What does all of this mean??

- While we have insufficient evidence to make solid determinations regarding which populations may be helped by these therapeutic tools, some consistent patterns are evident, indicating that they may be useful for some clients with some clinical presentations…

So, based on the current evidence, we can say that SOVTEs probably…

SOVTEs probably…

1. **Reduce transglottal pressure by increasing intraoral pressure;**
2. **Increase inertance of the vocal tract (an optimal condition is an impedance matching between the glottis and the entryway to the vocal tract);**
3. **Facilitate voice onset by lowering PTP and increasing overall PTP range;**
4. **Reinforce vocal fold vibration by feeding energy back into the glottis via proper phasing of acoustic pressures within the vocal tract due to resonance (i.e., velocities between supraglottal pressure and airflow are in-phase);**
5. **Facilitate resonance that may be associated with increasing sensory feedback sensations (which may or may not be pleasant depending on the client and their familiarity with the exercises);**
6. **Presumably reduce the risk of phonotrauma by minimizing vocal fold impact forces during phonation and increasing vocal economy (i.e., higher SPL with lower vocal fold impact stress);**
7. **Promote "optimal" adduction that is neither pressed nor breathy such as that achieved in "resonant voice";**
8. **Change vocal quality in such a way that the resultant sound is perceived to be "clearer", "brighter", and/or "more sonorous" by both vocalist and/or the listener; and, in some cases,**
9. **Widen the pharynx as related to the epilarynx yielding a clustering of F3-F5 known as the "singer's formant" or "speaker's formant", and**
10. **Facilitate respiratory/breath "support" during vocal warm-up**

(Guzman et al., 2013; Laukkanen et al., 1996, 2012; Story et al., 2000; Titze, 1988, 1996, 2001, 2006; Vampola, et al., 2011; Verdolini et al., 1998).

What does all of this mean??

- So we don’t yet know which clients SOVTEs might be most appropriate for (we aren’t even definitively sure what changes or by how much…some of this may be due to individual variation both within and across healthy and disordered populations)
- Of course, **more and better SOVTE research is needed.**
  - For example, research examining the effects of SOVTEs on various outcome measures in various *dysphonic populations* (vs. neurotypical/healthy populations and trained singers).
- We still need more information to determine precisely what is appropriate and for whom.
- That being said, SOVTEs are much more likely to help than to harm.

Break/Rest! (15 min.)

Now a bit of my research…

Aerodynamic Measures in a Synthetic Silicone Vocal Fold Model Coupled with a 3D-Printed Vocal Tract: A Pilot Study

Nicholas May, Ph.D., CCC-SLP[1]
David Meyer, D.M.[2]
Ronald Scherer, Ph.D.[3]

Presented at the Voice Foundation's Annual Symposium, Summer 2023

[1]The University of Maine, [2]Shenandoah University, & [3]Bowling Green State University

Introduction

Research Questions

How does PTP and PTF (at onset and offset) in a dynamic silicone vocal fold model change across the following experimental conditions:

1) No VT
2) Uniform cylindrical VT
3) MRI-based 3D printed /a/ vowel
4) MRI-based 3D printed /u/ vowel
5) MRI-based 3D printed /a/ vowel + drinking straw (SOVT)
6) MRI-based 3D printed /a/ vowel + coffee stirrer straw (SOVT)

Definitions

Phonation threshold pressure (PTP):

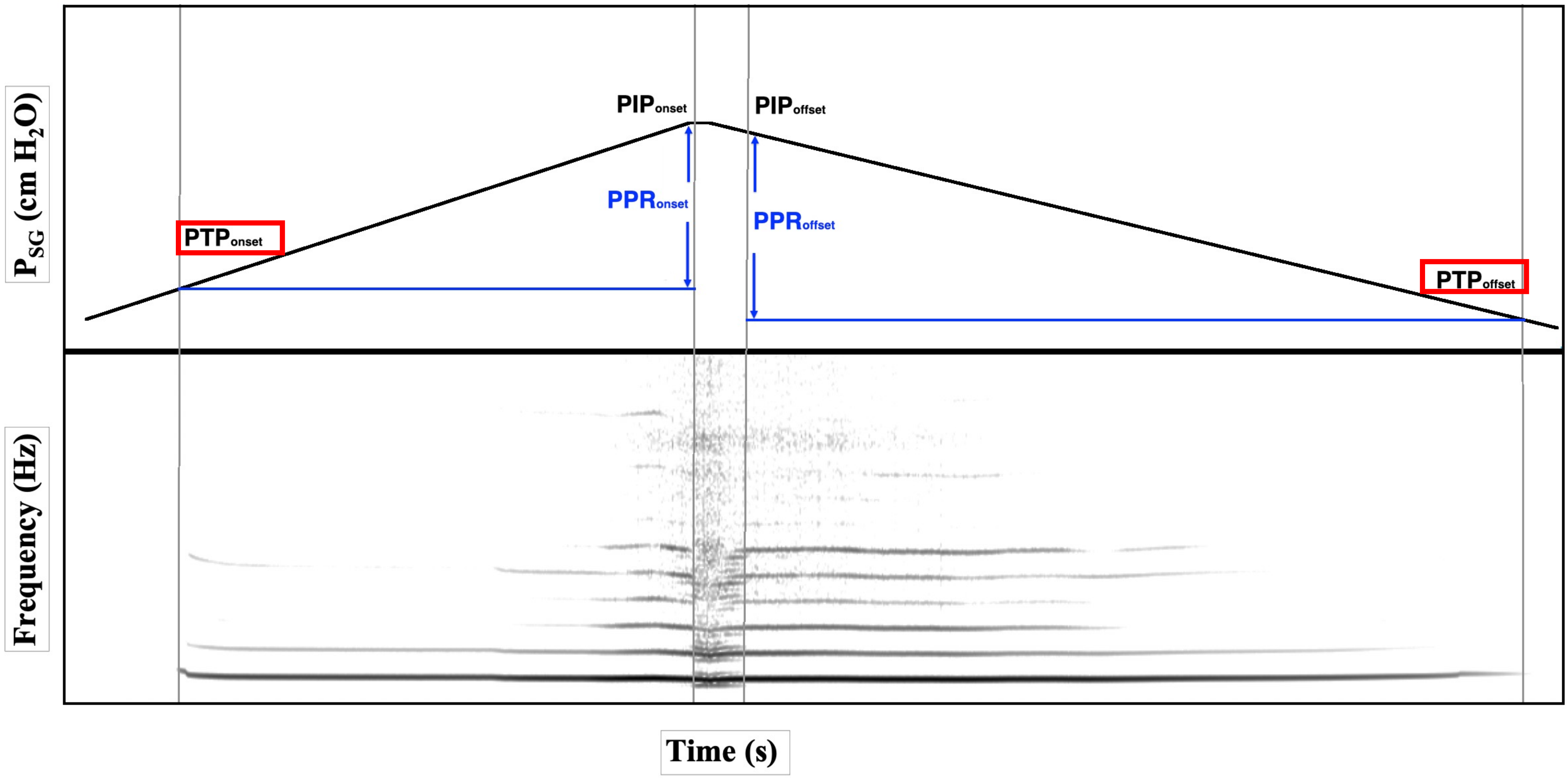
“The minimum lung pressure required to initiate [and sustain] phonation” (Titze, 1991, p. 2344).

Phonation threshold flow (PTF):

“The minimum airflow that can initiate [and sustain] stable vocal fold vibration” (Jiang & Tao, 2007, p. 2874).

Experimental Airflow Sweep Protocol

<u>Airflow was slowly and consistently increased</u> via manually opening airflow valves <u>until irregular/chaotic phonation began</u> and was <u>then slowly and consistently decreased</u> until phonation ceased (similar to Smith et al., 2013)



P_{SG} (cm H_2O)
PIP$_{onset}$
PIP$_{offset}$
PPR$_{onset}$
PPR$_{offset}$
PTP$_{onset}$
PTP$_{offset}$
Frequency (Hz)
Time (s)

Methods

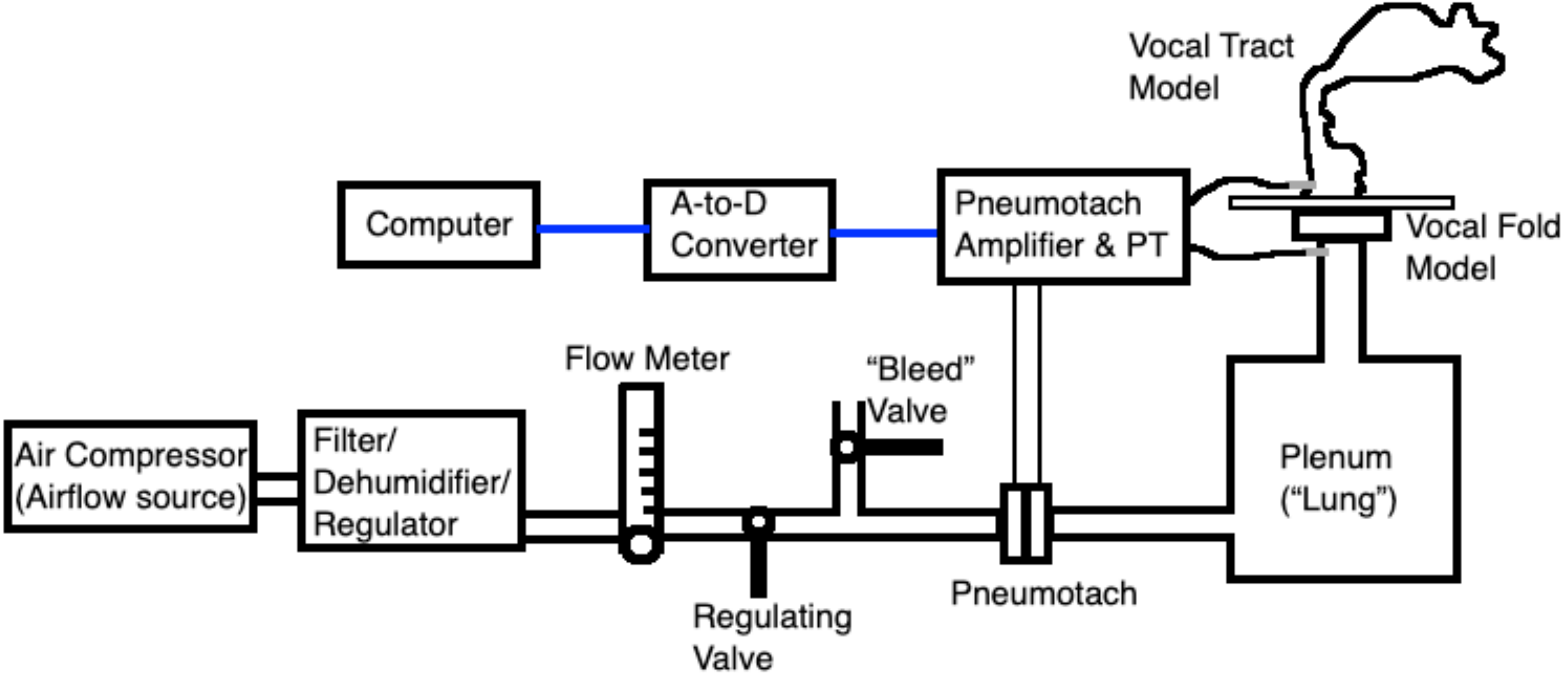
Vocal Fold Model

- Human vocal folds will be modelled by multi-layered silicone vocal folds after Murray & Thomson (2011 & 2012), which uses a modification of the M5 (Scherer et al., 2001) vocal fold geometry
- The model has been demonstrated to produce kinematic, acoustic, and aerodynamic properties similar to human vocal fold vibration (May, 2022; Murray & Thomson, 2011, 2012)

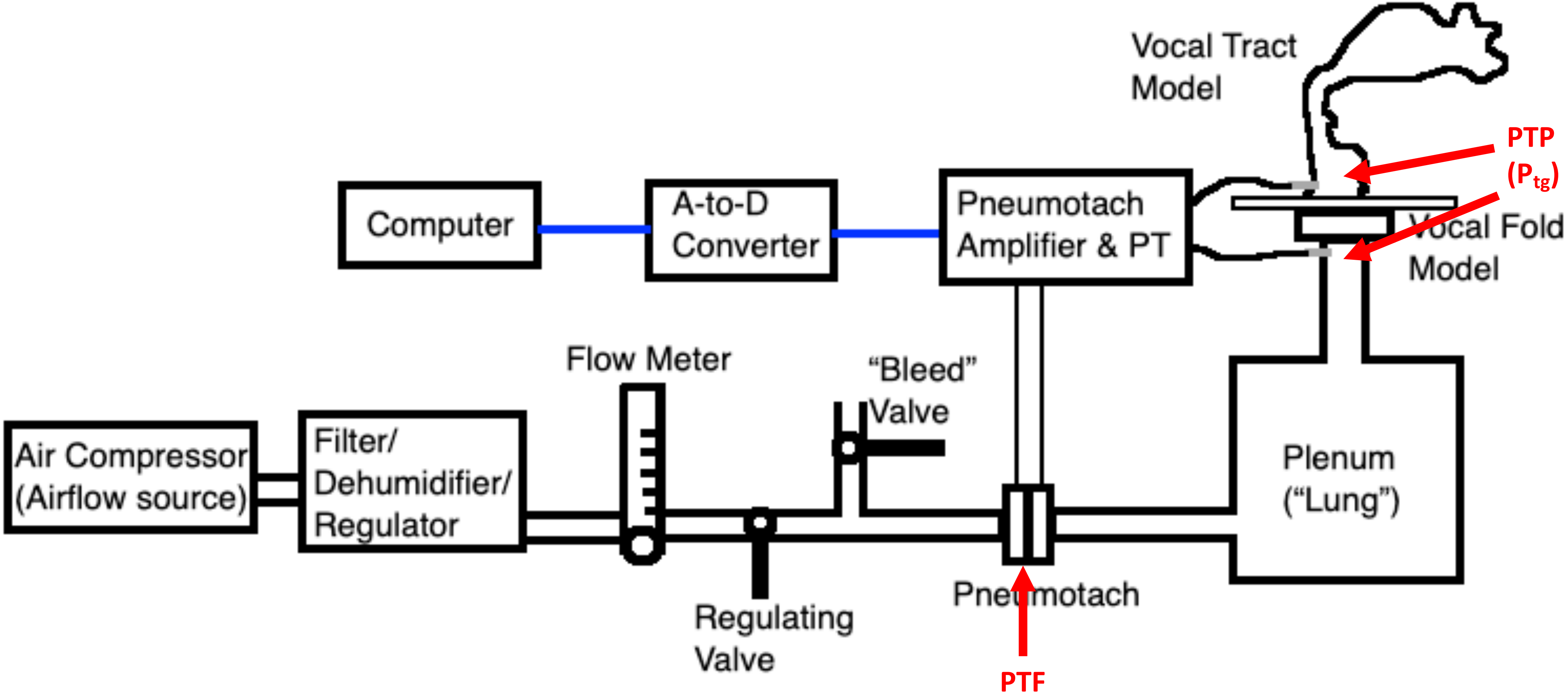
Vocal Tract Model

- MRI-derived 3D printed models of an adult male subject producing an /a/ vowel and an /u/ vowel (Meyer et al., 2022)

Schematic: Bench Set-up



Schematic: Bench Set-up



Schematic: Vocal Fold Model

Length = 16.3 mm

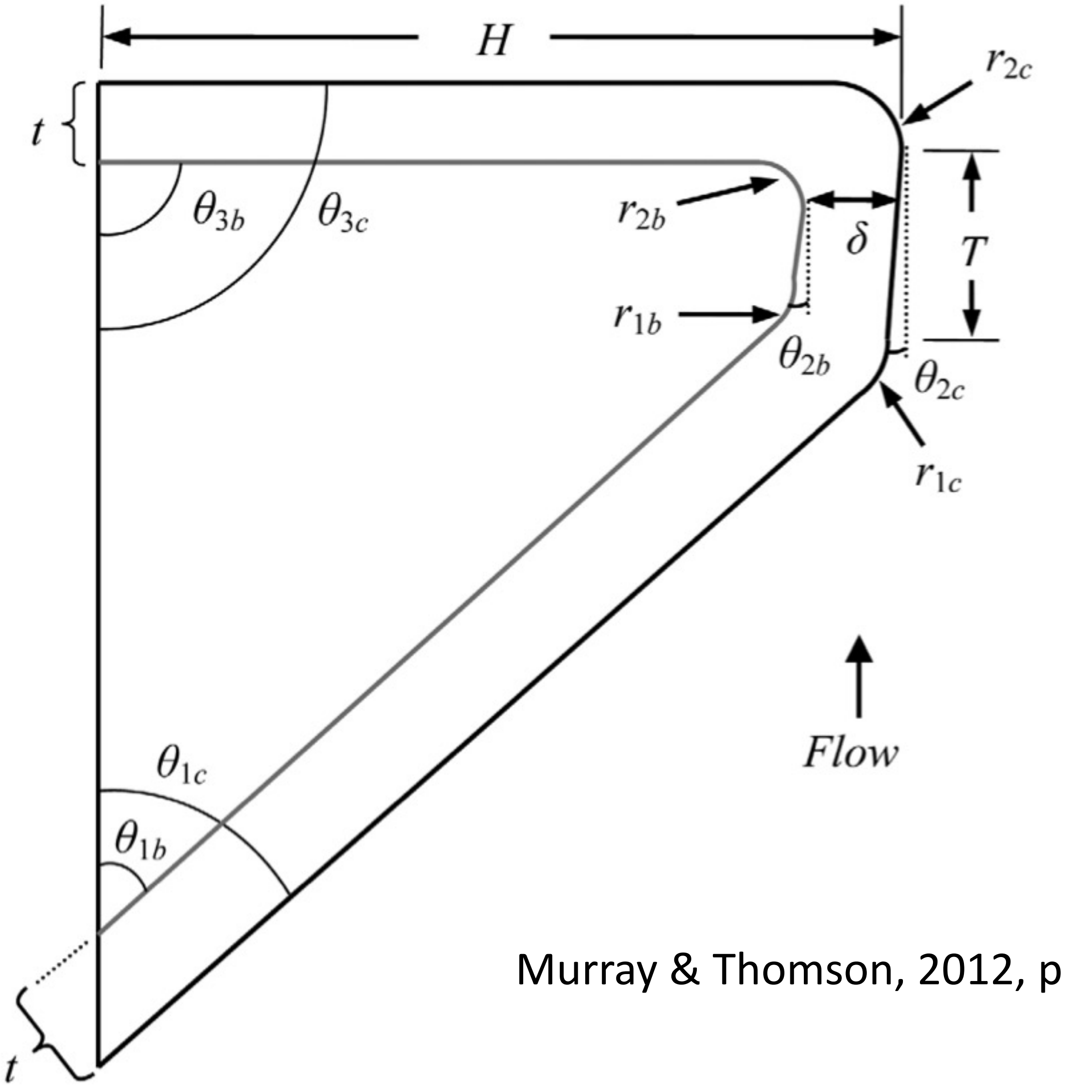


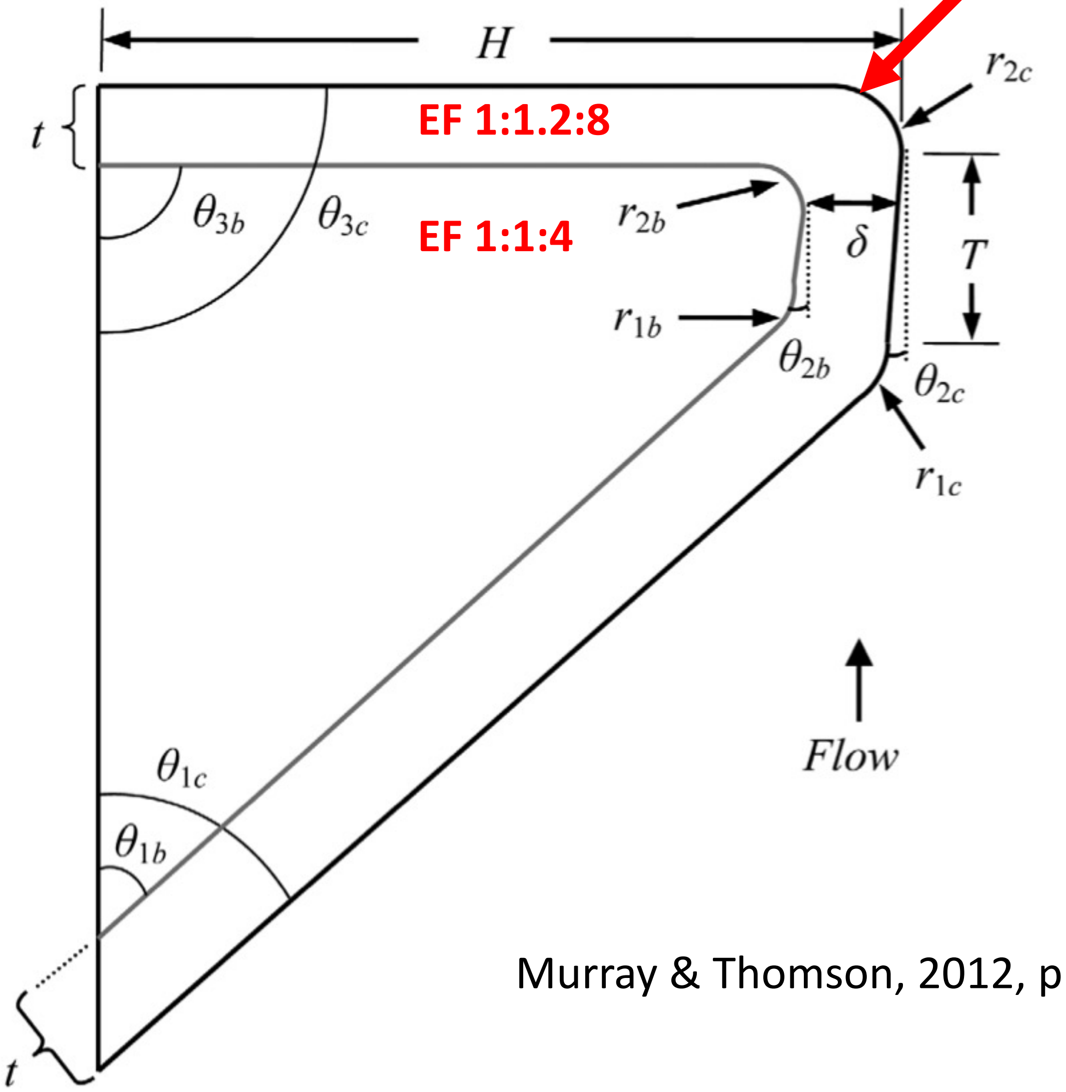
FIG. 2. Geometric parameters for the M5-UNI, M5-CONV, and EPI models.

Murray & Thomson, 2012, p. 3430

Parameter	M5-CONV
$\theta_{1b,c}$	50°
$\theta_{2b,c}$	5°
$\theta_{3b,c}$	90°
r_{1c}	1.5 mm
r_{2c}	0.987 mm
r_{1b}	1.12 mm
r_{2b}	0.513 mm
T	2 mm
t	1.5 mm
δ	1.5 mm
H	8.4 mm

Silicone Type part A:part B:silicone thinner
EF = Ecoflex 00-30
DS = Dragon Skin FAST 10

DS 1:1:1 + 1.5% of part B SLIDE surface tension diffuser (reduces surface tackiness)



Murray & Thomson, 2012, p. 3430

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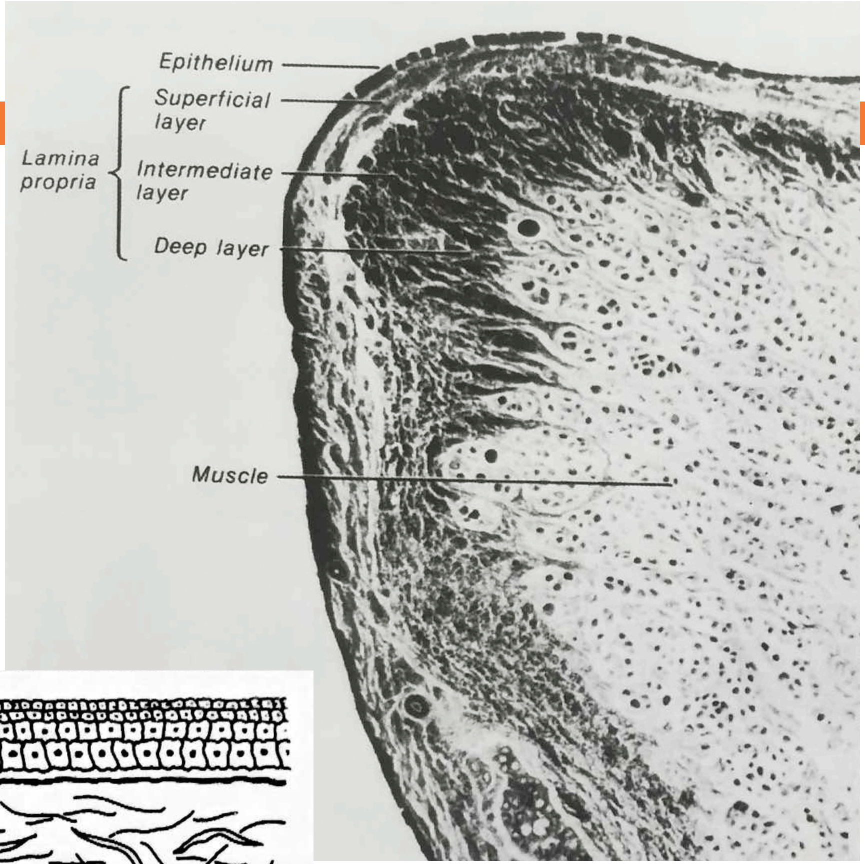
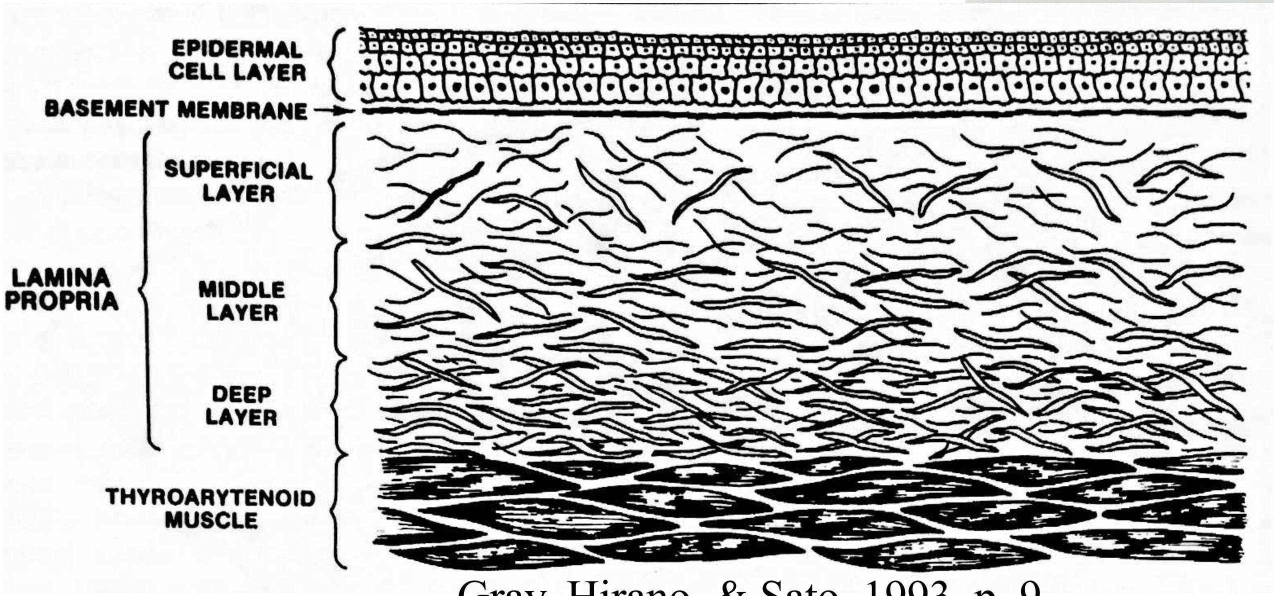
r_{2b}	0.513 mm
T	2 mm
t	1.5 mm
δ	1.5 mm
H	8.4 mm

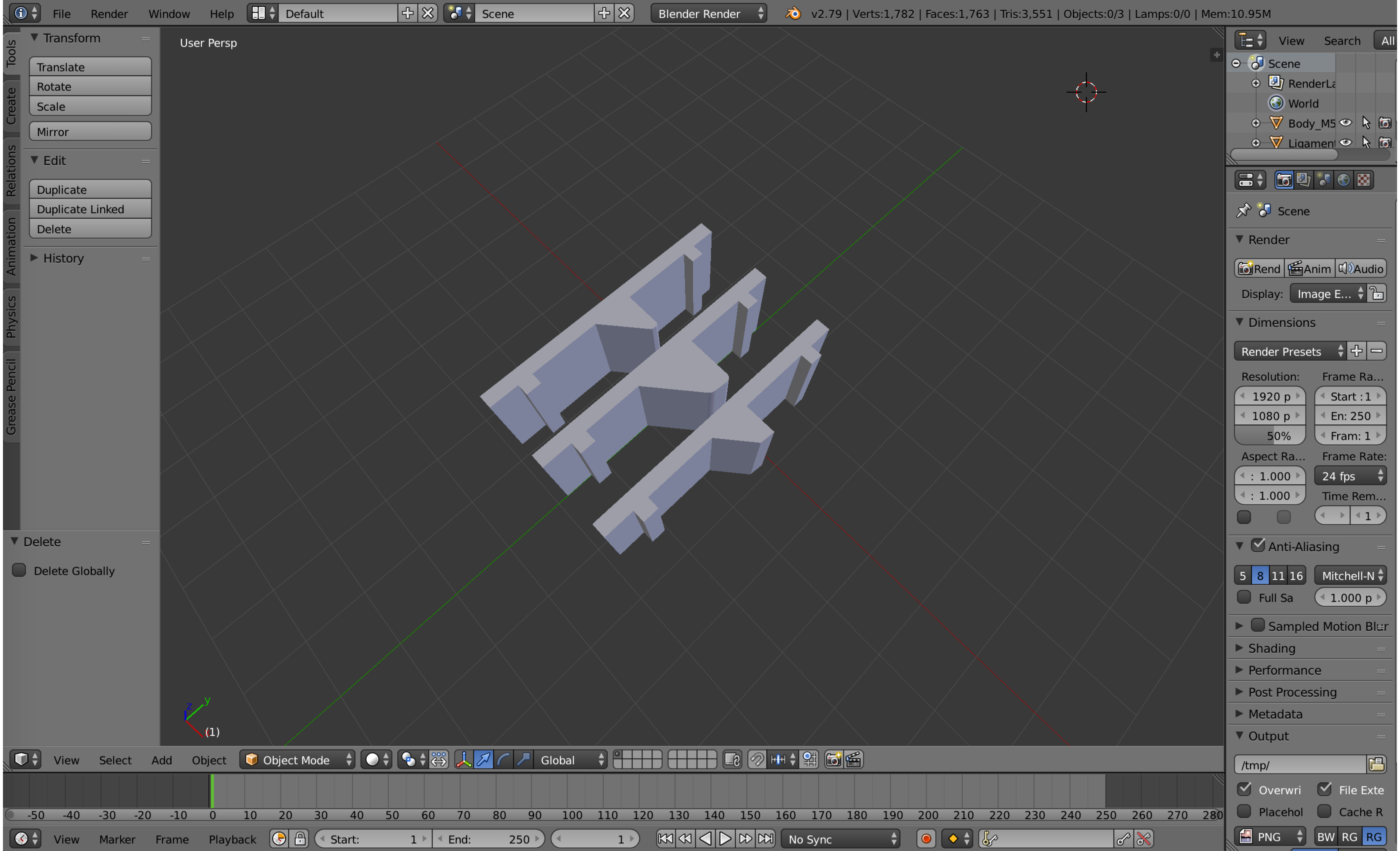
The Five Layered Structure of the Vocal Folds



Hirano, 1981, p.5



Gray, Hirano, & Sato, 1993, p. 9


File
Render
Window
Help
Default
Scene
Blender Render
v2.79 | Verts:1,782 | Faces:1,763 | Tris:3,551 | Objects:0/3 | Lamps:0/0 | Mem:10.95M
Transform
Translate
Rotate
Scale
Mirror
Edit
Duplicate
Duplicate Linked
Delete
History
Delete
Delete Globally
Tools
Create
Relations
Animation
Physics
Grease Pencil
User Persp
(1)
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Search
All
Scene
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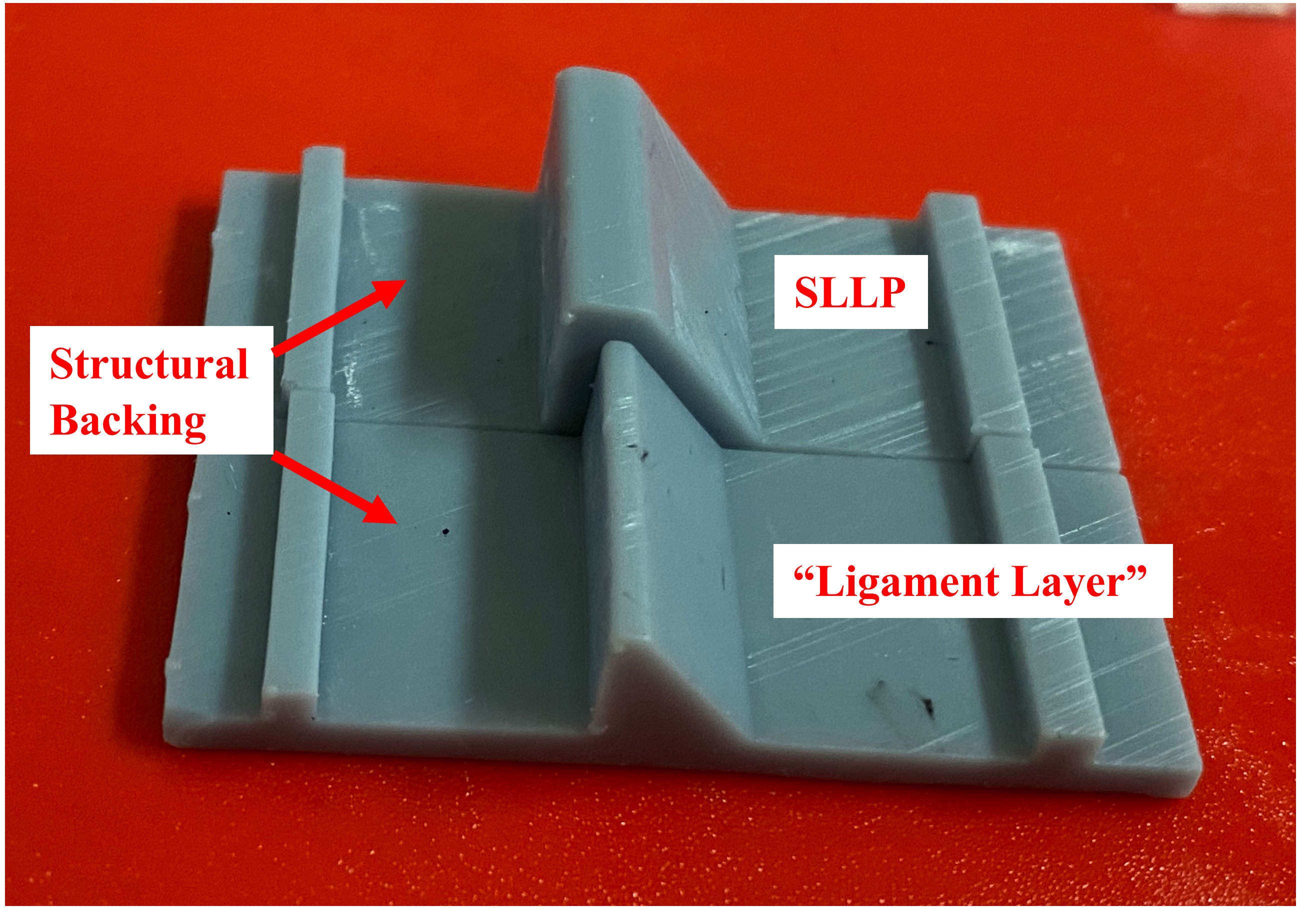
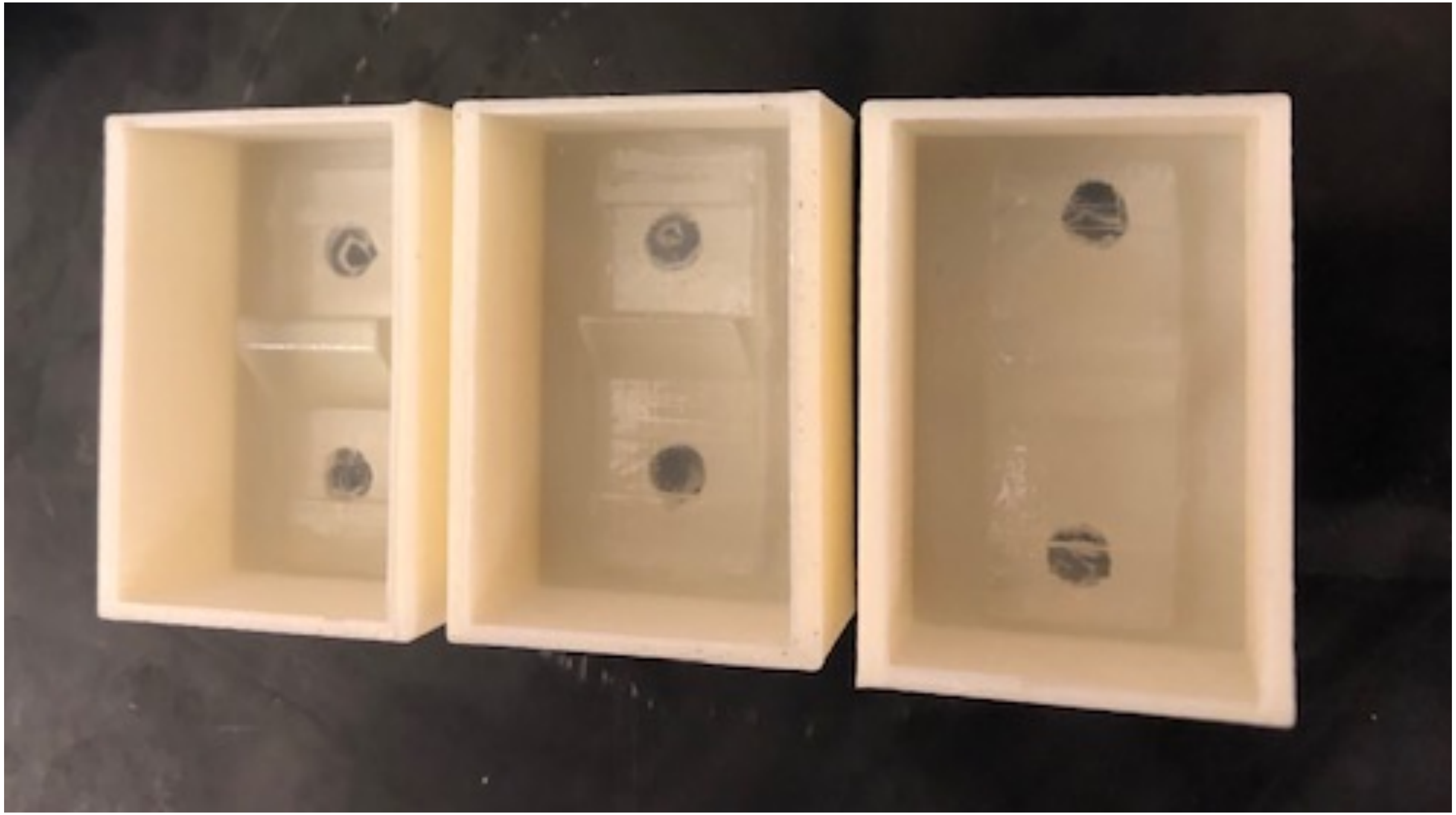
World
Body_M5
Ligament
Scene
Render
Rend
Anim
Audio
Display:
Image E...
Dimensions
Render Presets
Resolution:
Frame Ra...
1920 p
1080 p
50%
Start : 1
En: 250
Fram: 1
Aspect Ra...
Frame Rate:
: 1.000
: 1.000
24 fps
Time Rem...
1
Anti-Aliasing
5 8 11 16
Mitchell-N
Full Sa
1.000 p
Sampled Motion Blur
Shading
Performance
Post Processing
Metadata
Output
/tmp/
Overwri
File Exte
Placehol
Cache R
PNG
BW RG RGB
View
Select
Add
Object
Object Mode
Global
-50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280
View
Marker
Frame
Playback
Start: 1
End: 250
1
No Sync

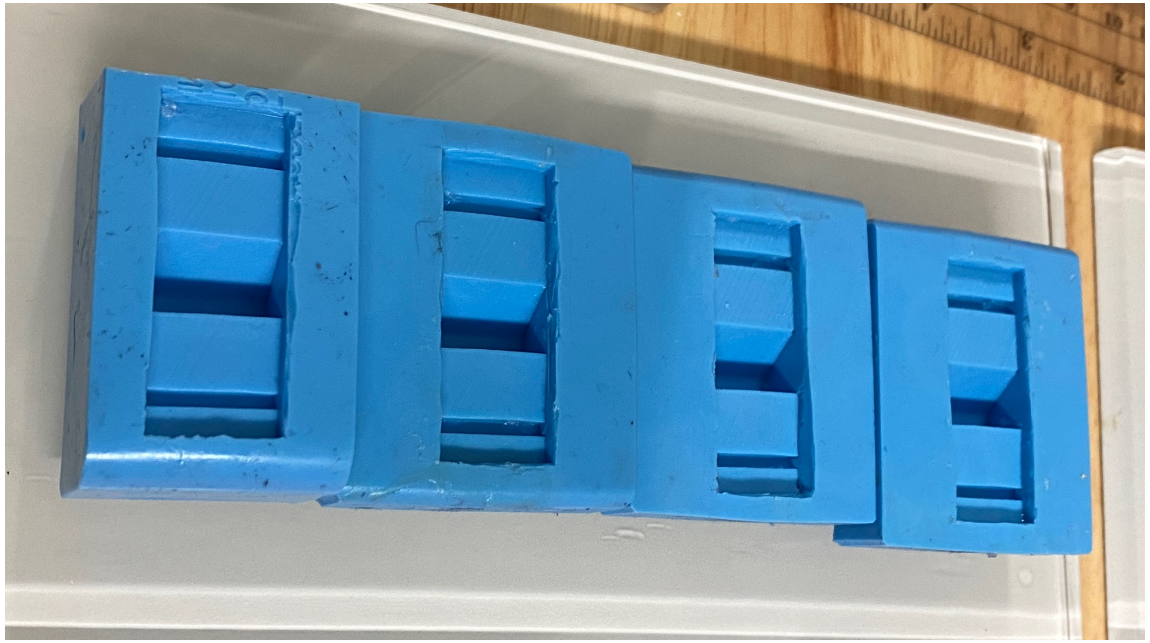
Vocal Fold "Positive" Models

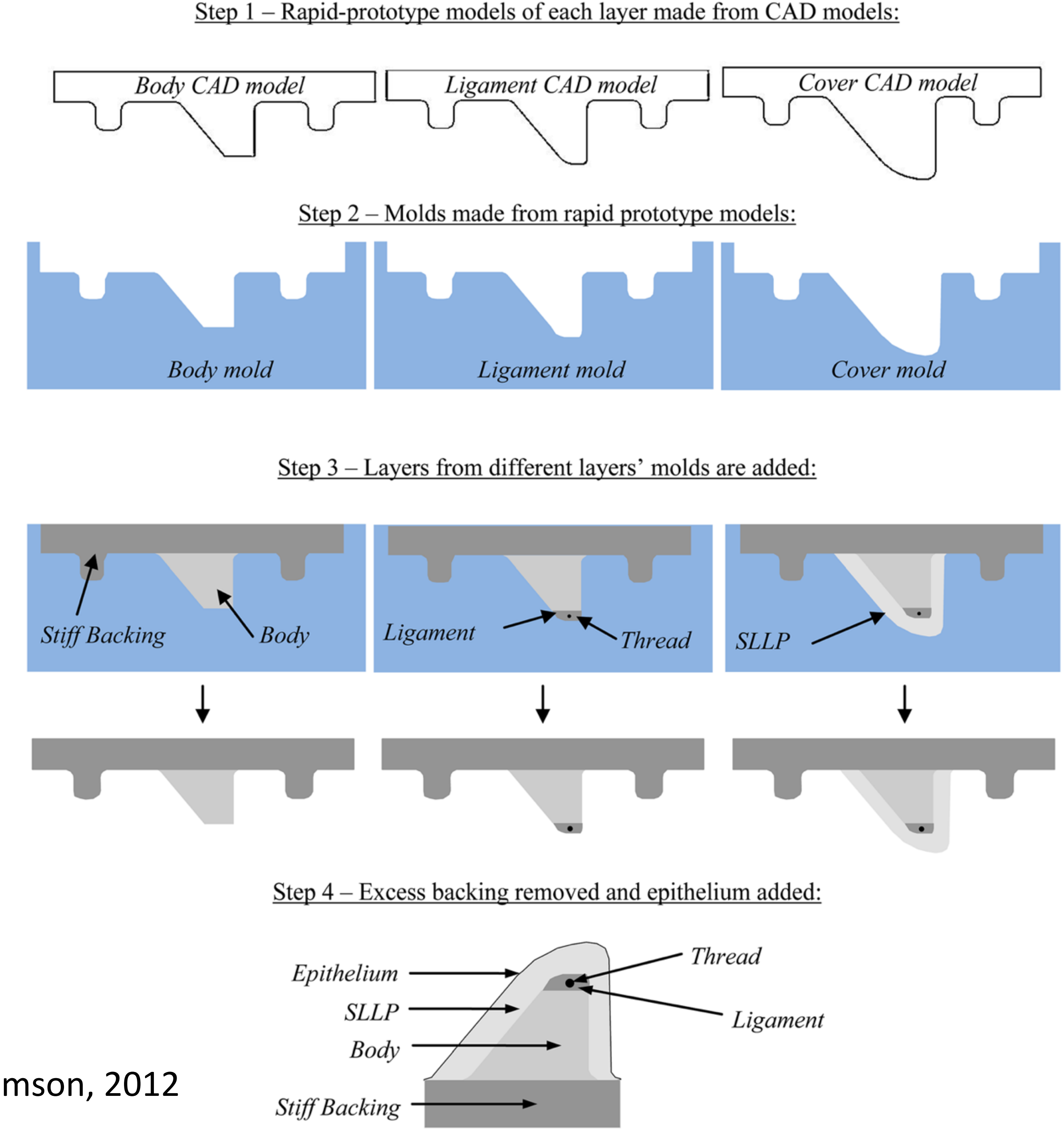


Preparation for "Negative" Vocal Fold Model Molds



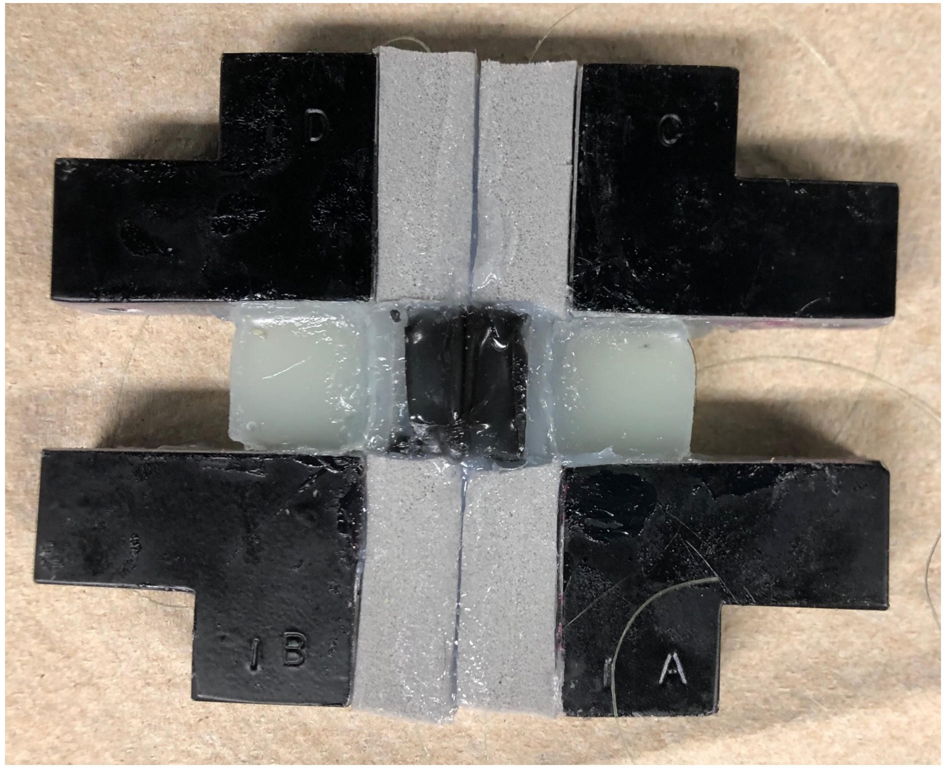
Complete Vocal Fold Models – SLLP + Epithelial Layer

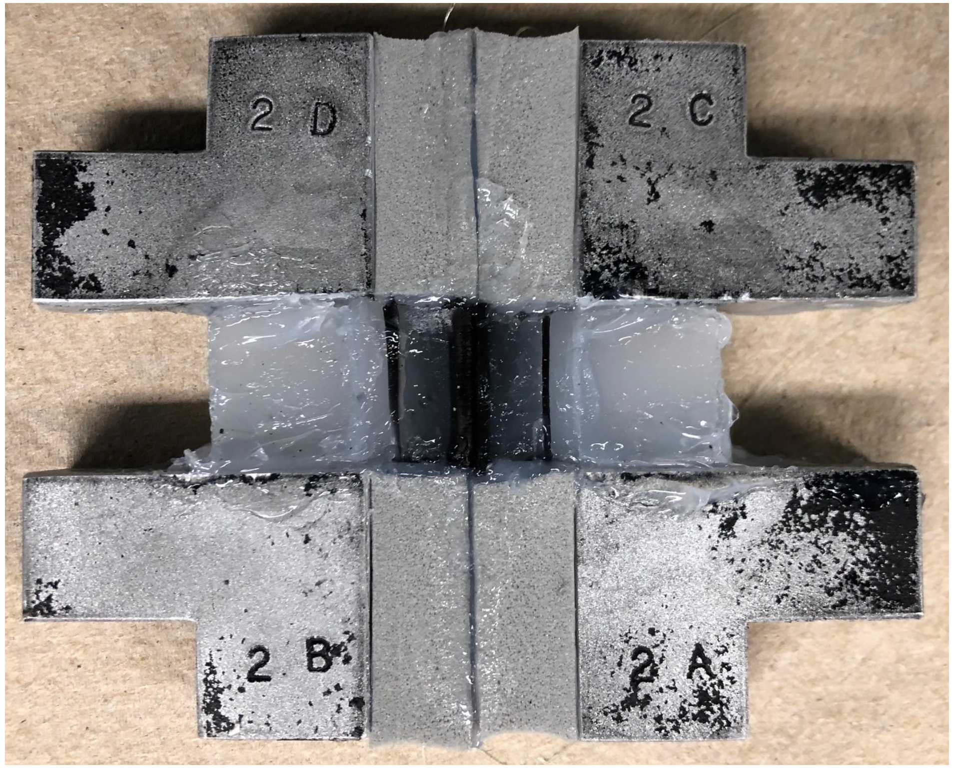




Murray & Thomson, 2012

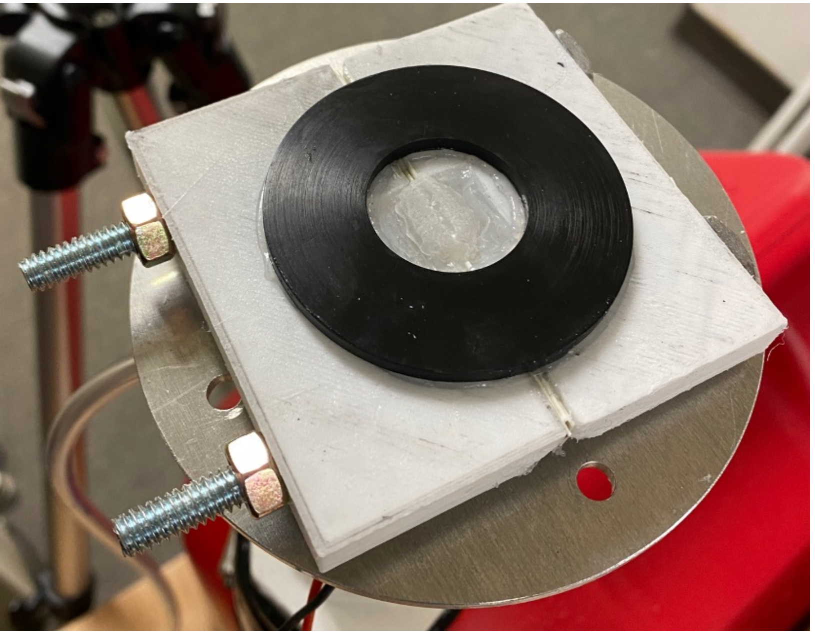
Mounted Vocal Folds



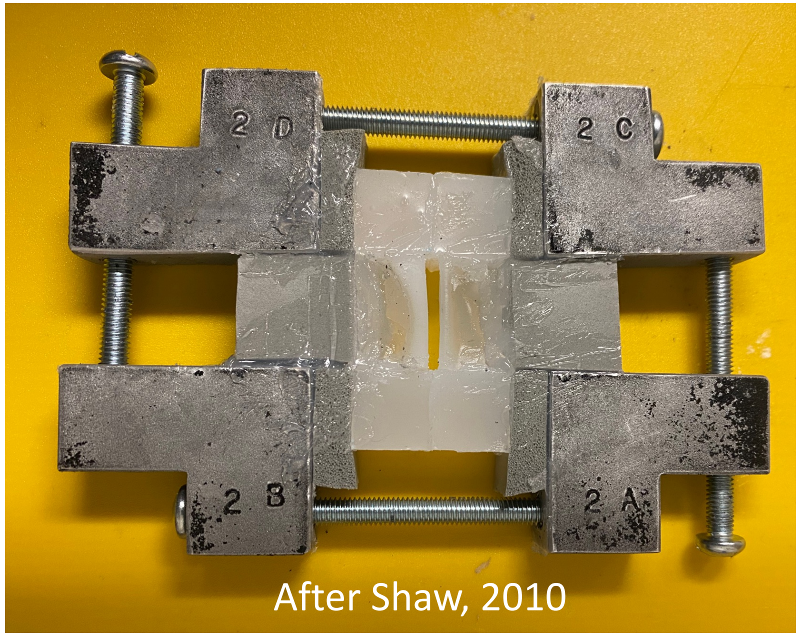


Mounted Vocal Folds

Model 1

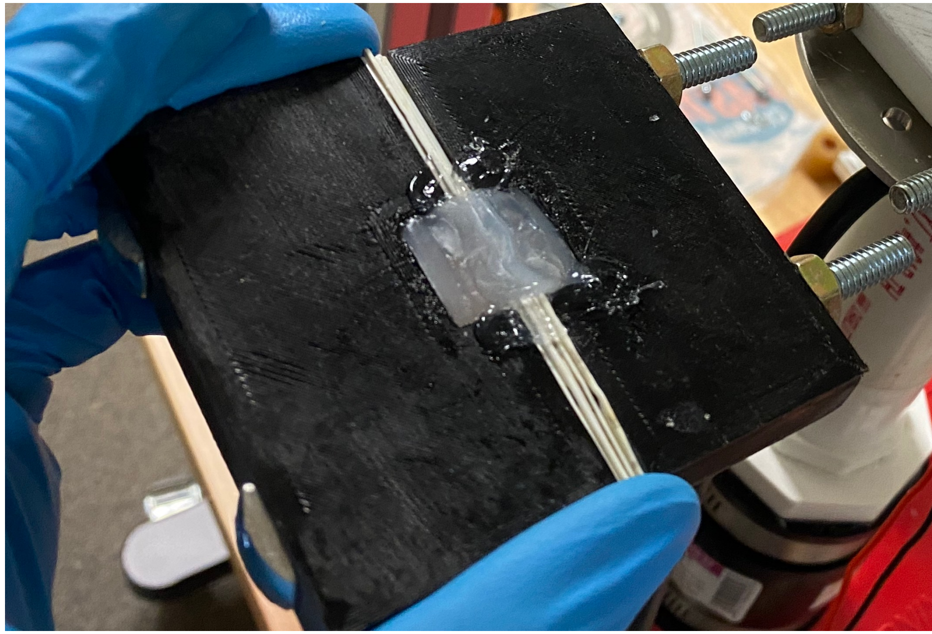


Model 2



After Shaw, 2010

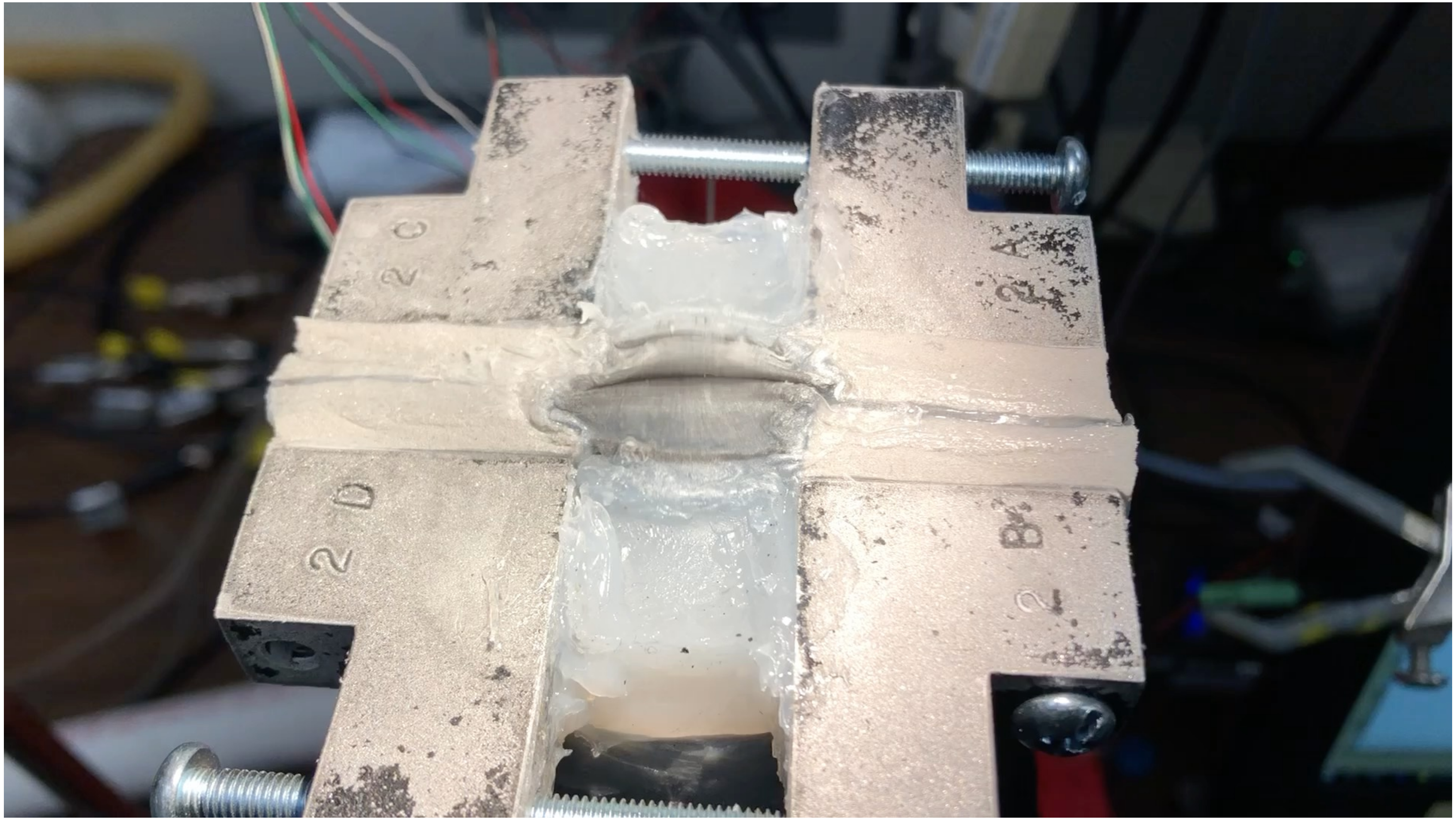
Model 3



Vocal fold length (passive tension) and adduction were held constant across all conditions

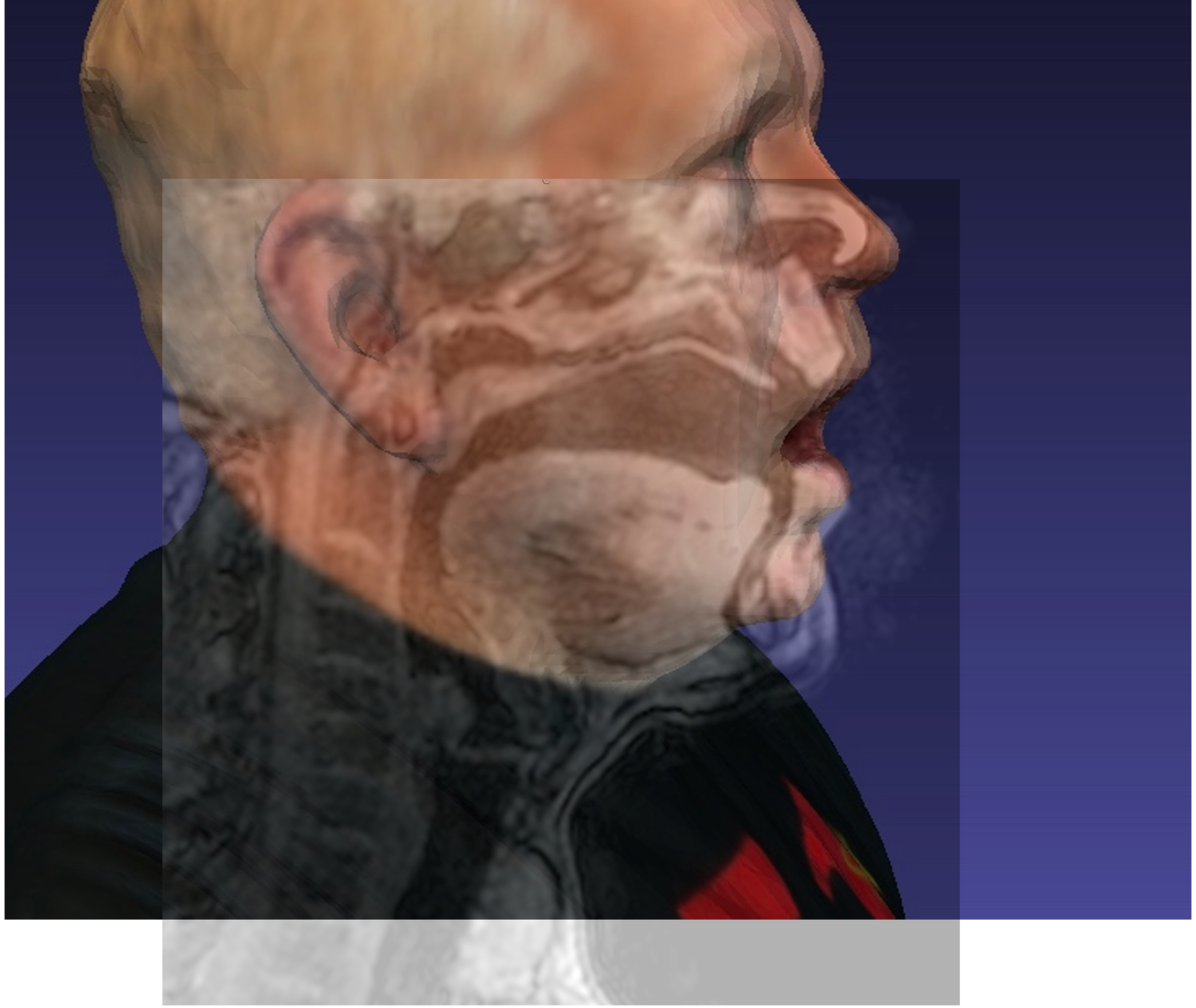

No VT condition

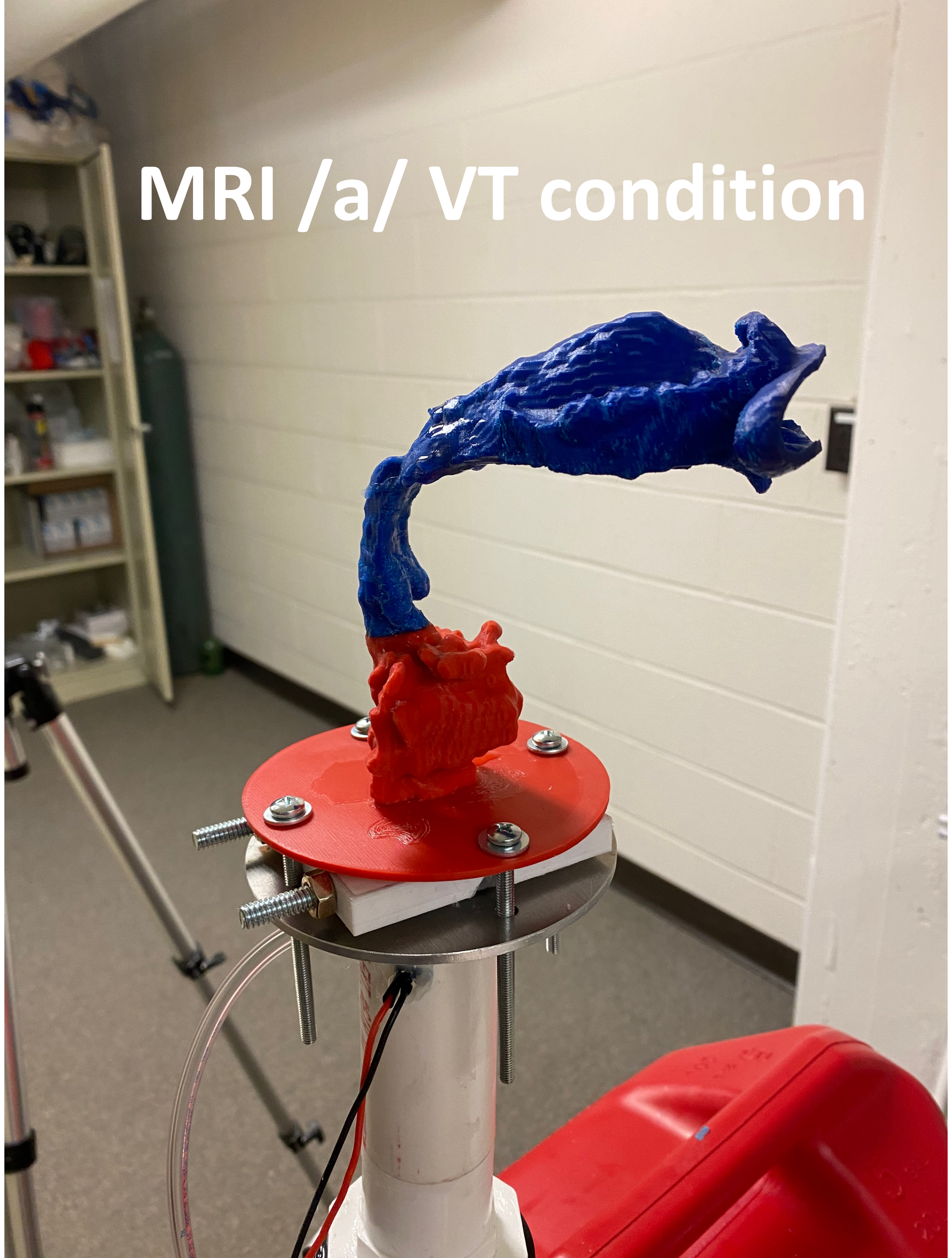
Video Demos



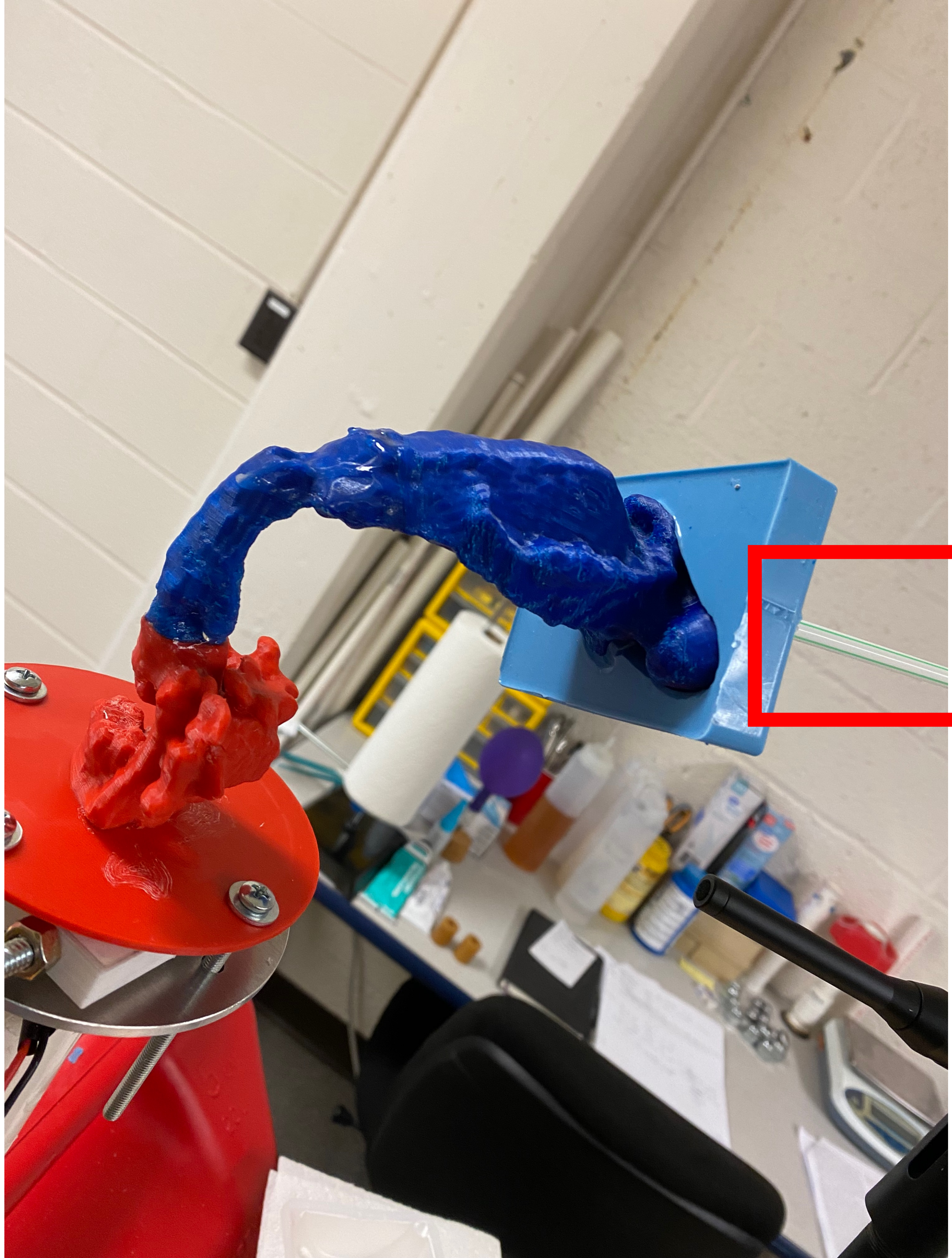
Video Demos

Uniform cylindrical VT condition



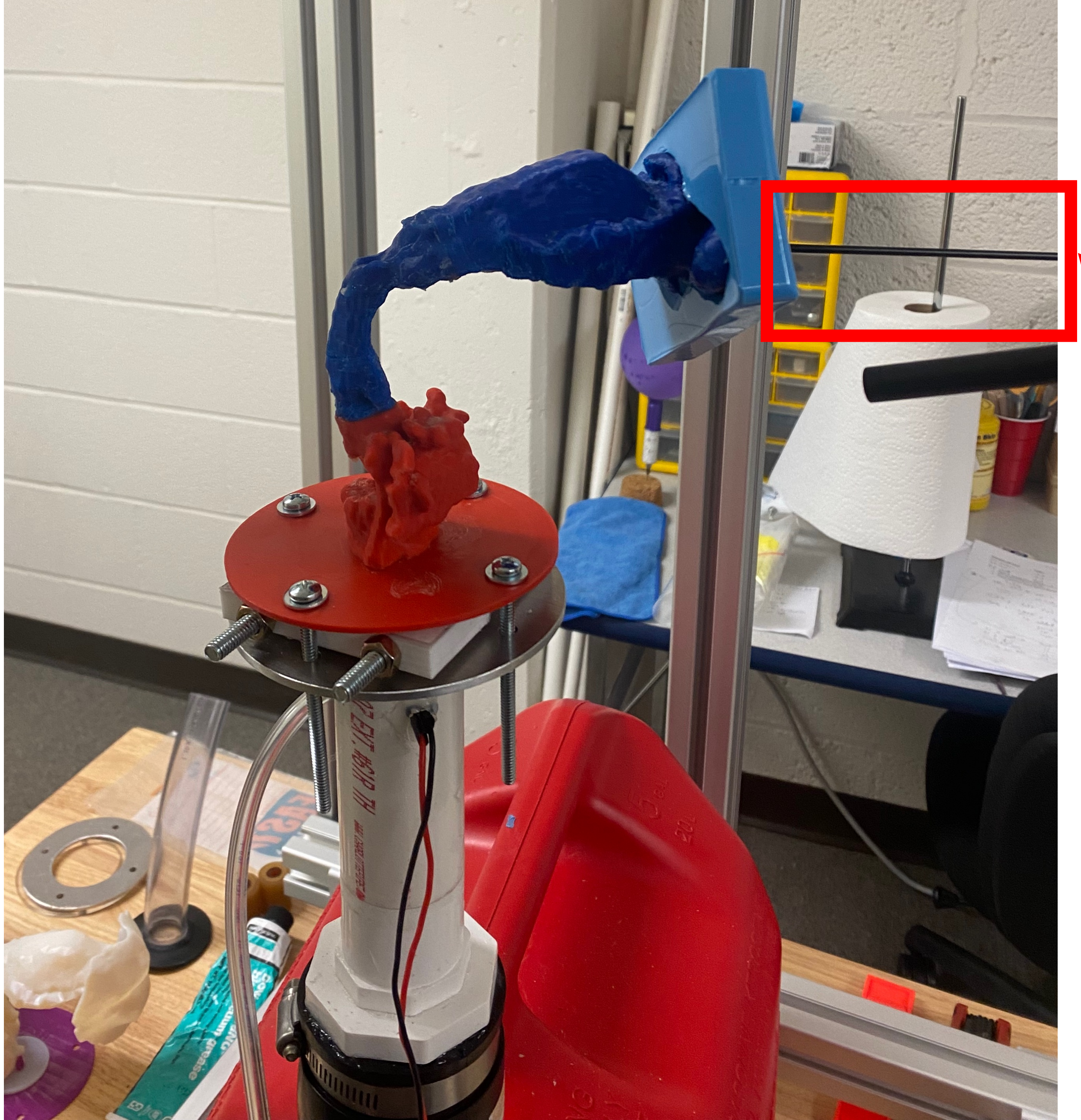

MRI /a/ VT condition

MRI /a/ VT + drinking straw condition



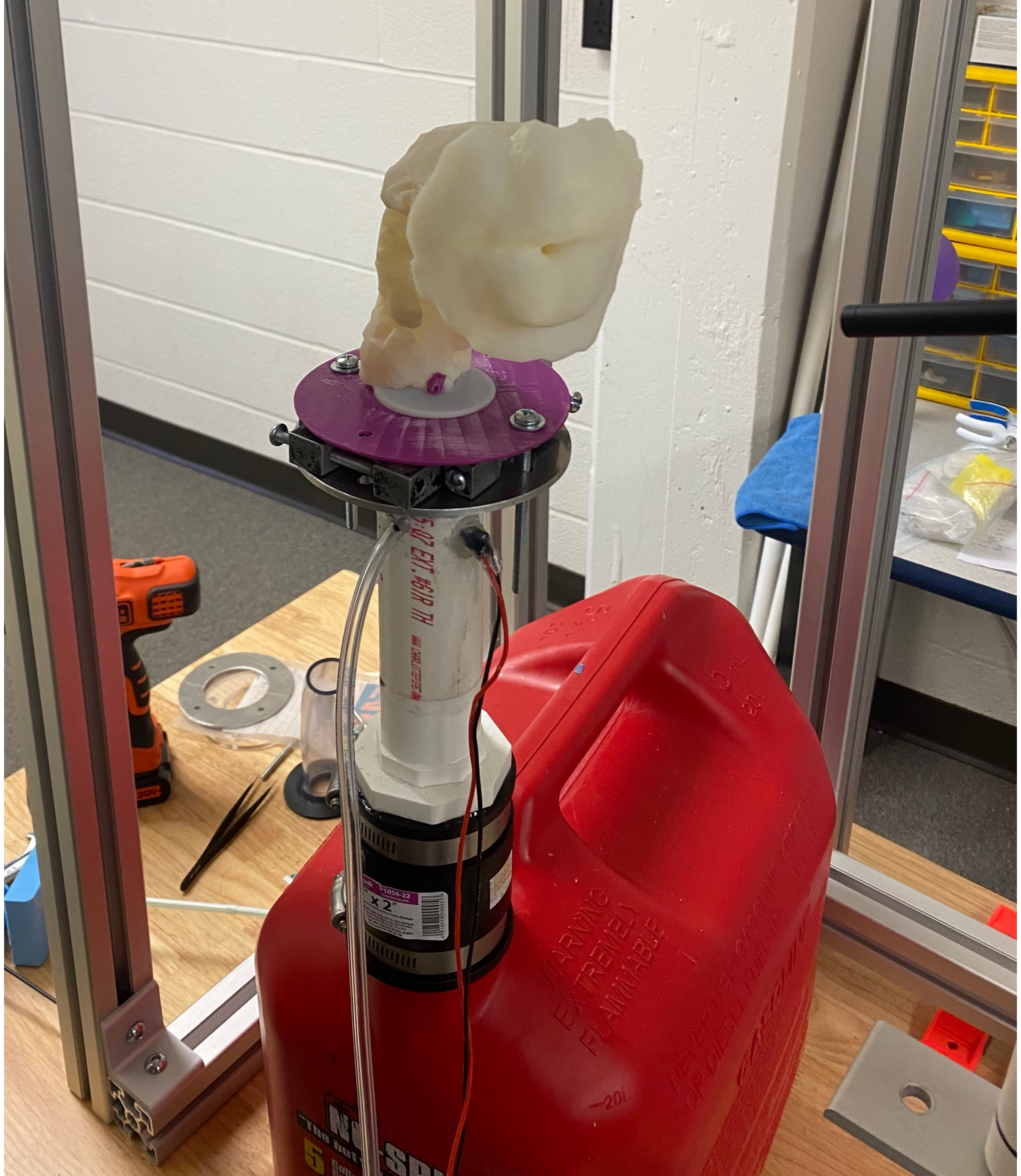
Drinking Straw!

MRI /a/ VT + coffee stirrer straw condition

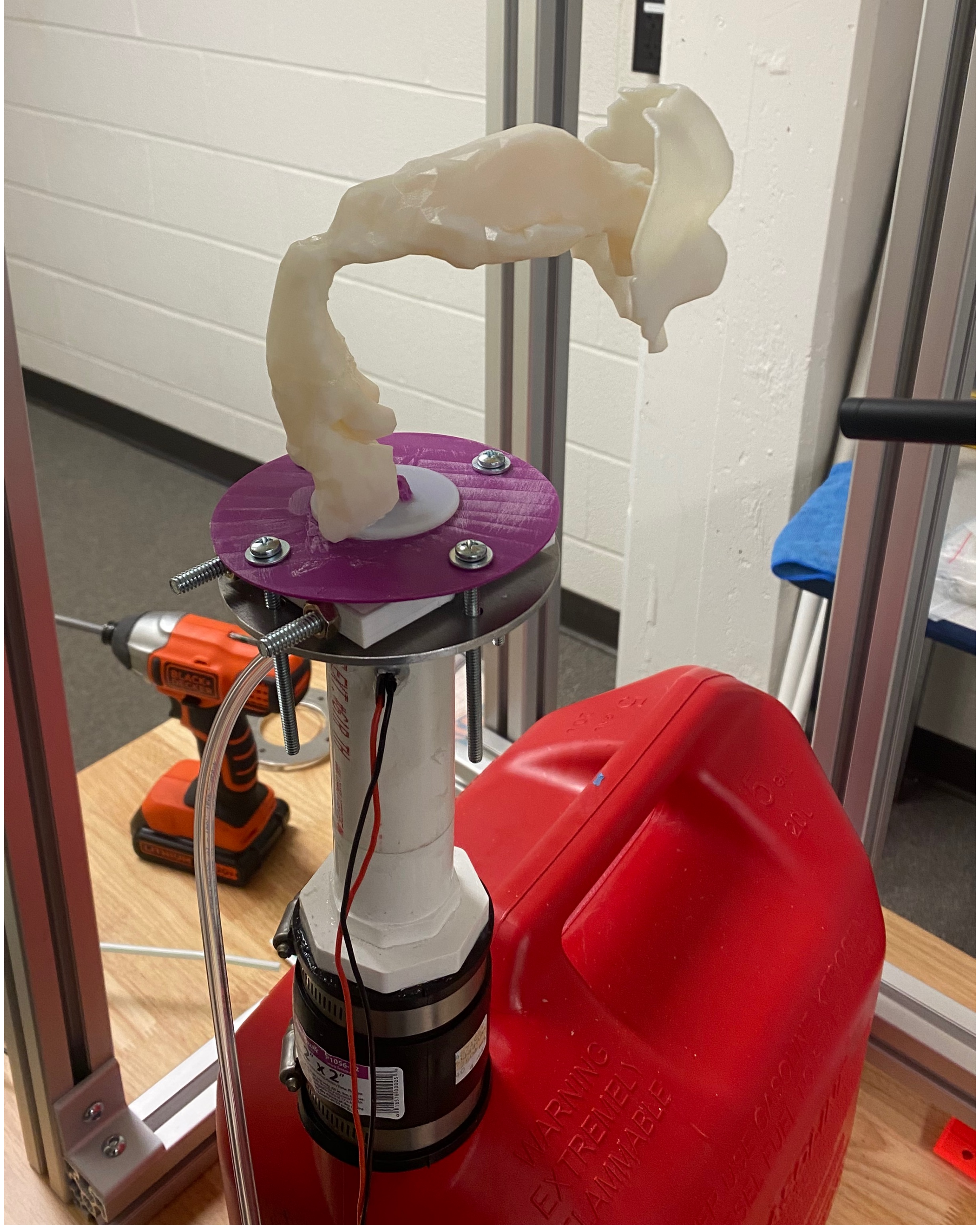


Coffee Stirrer Straw!!

MRI /u/ VT condition

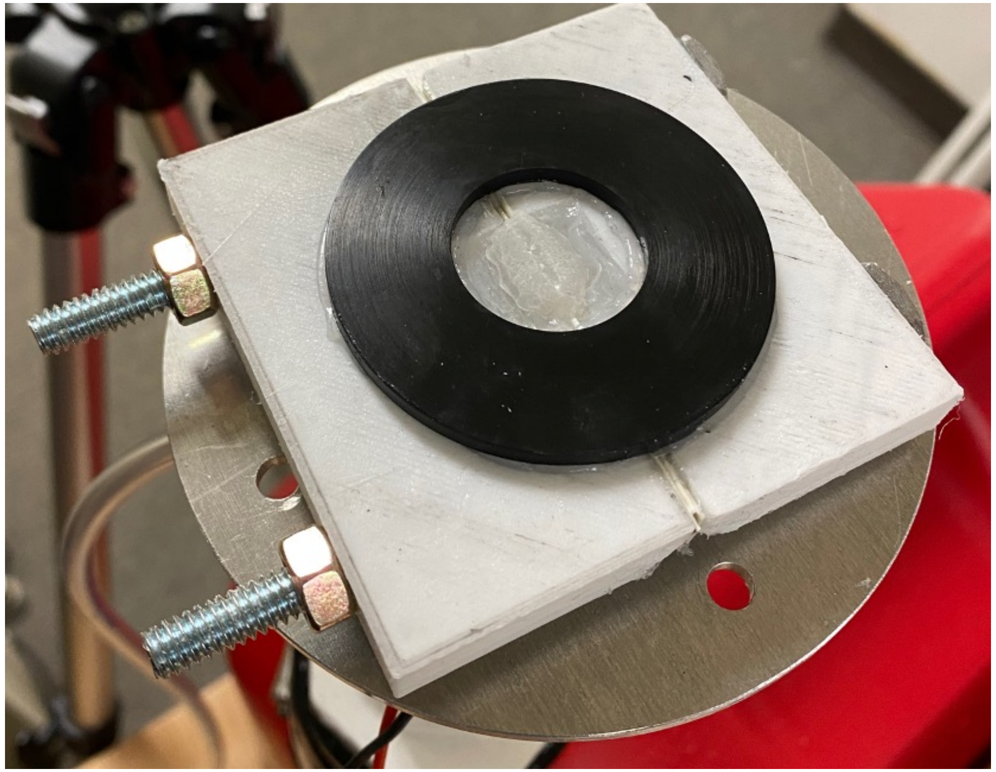


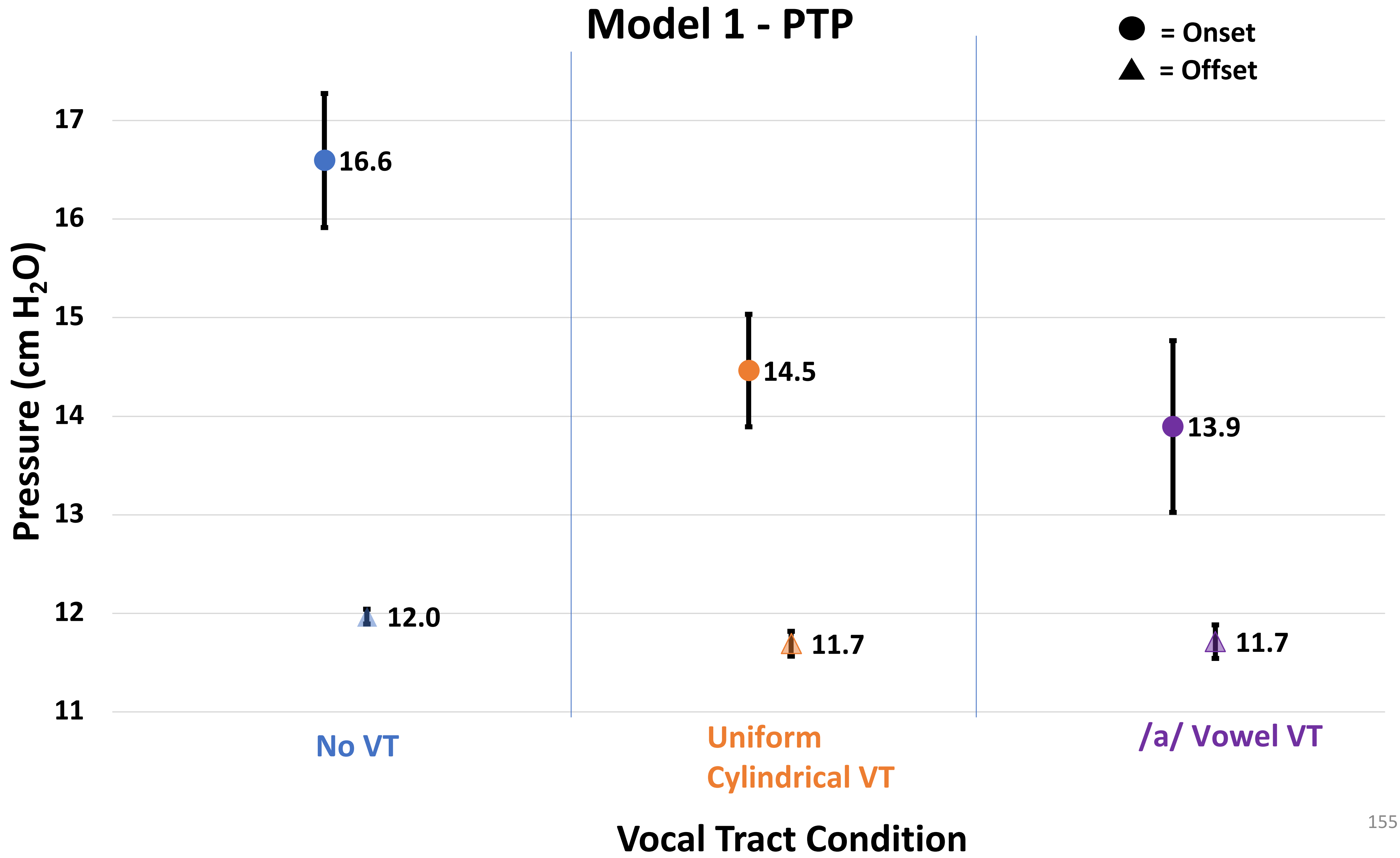
MRI /u/ VT condition



Results

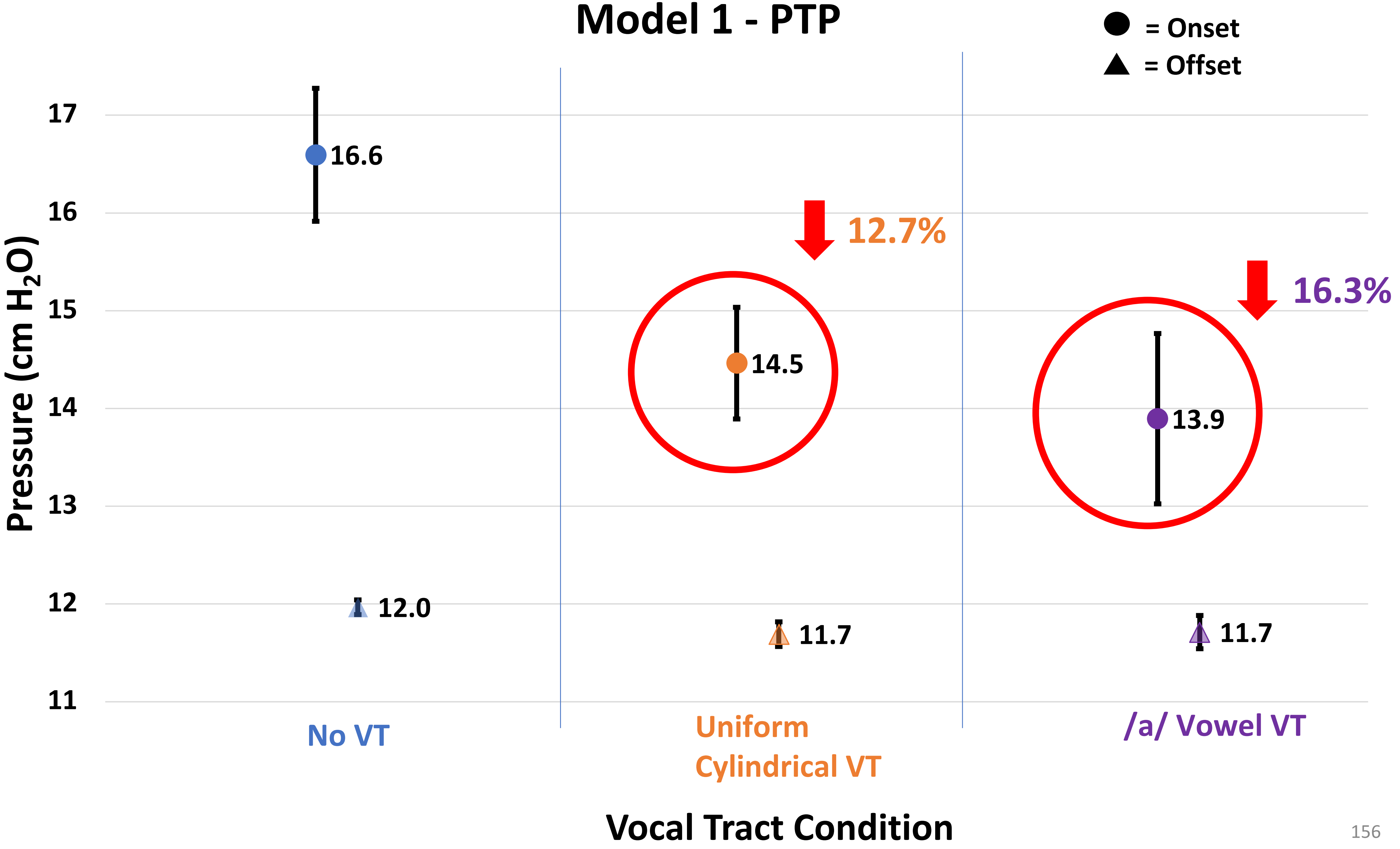
Model 1



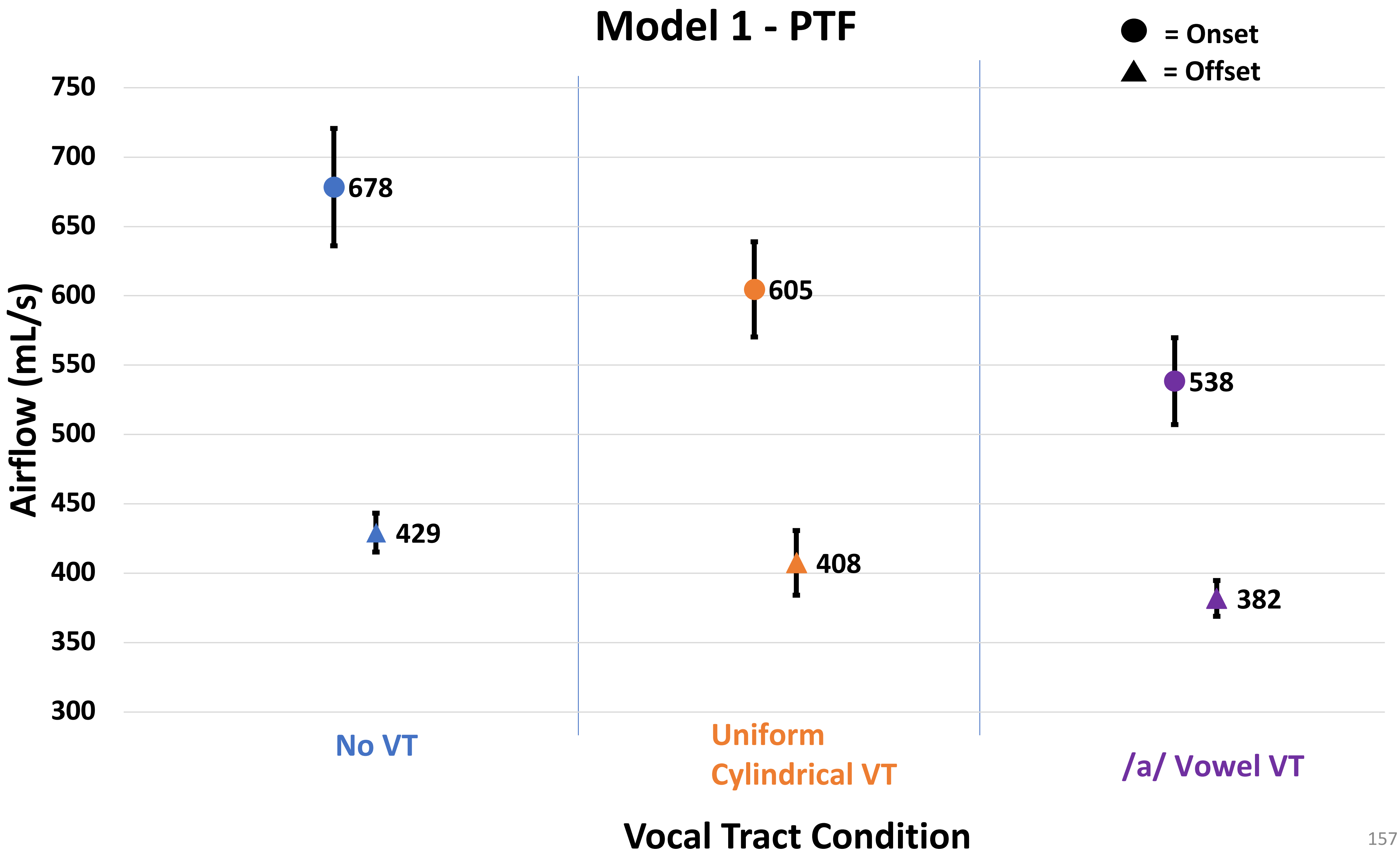


Model 1 - PTP
= Onset
= Offset
Pressure (cm H_2O)
17
16
15
14
13
12
11
16.6
12.0
14.5
11.7
13.9
11.7
No VT
Uniform Cylindrical VT
/a/ Vowel VT
Vocal Tract Condition

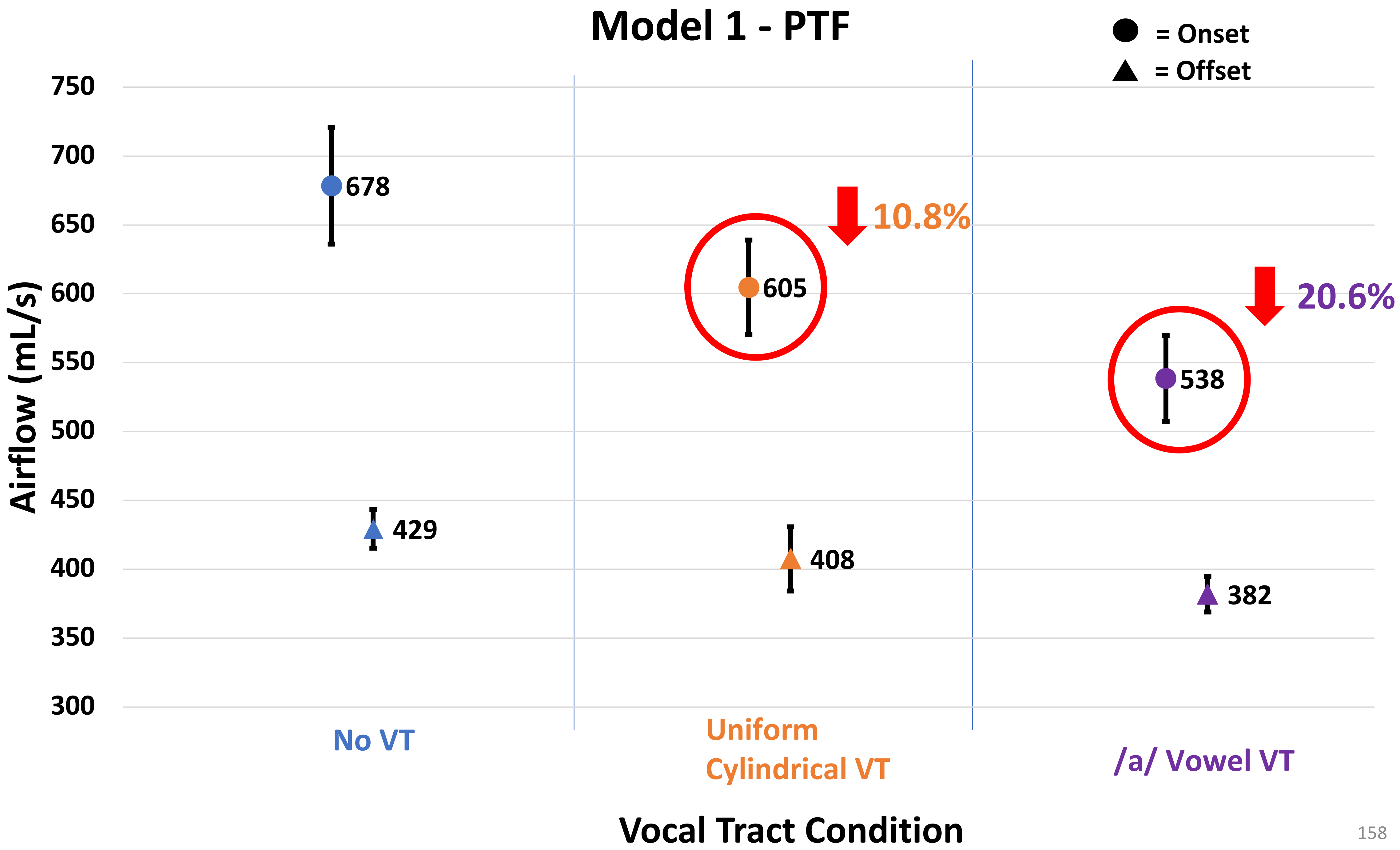
Model 1 - PTP



= Onset
= Offset
17
16
15
14
13
12
11
Pressure (cm H_2O)
16.6
12.0
12.7%
14.5
11.7
16.3%
13.9
11.7
No VT
Uniform
Cylindrical VT
/a/ Vowel VT
Vocal Tract Condition

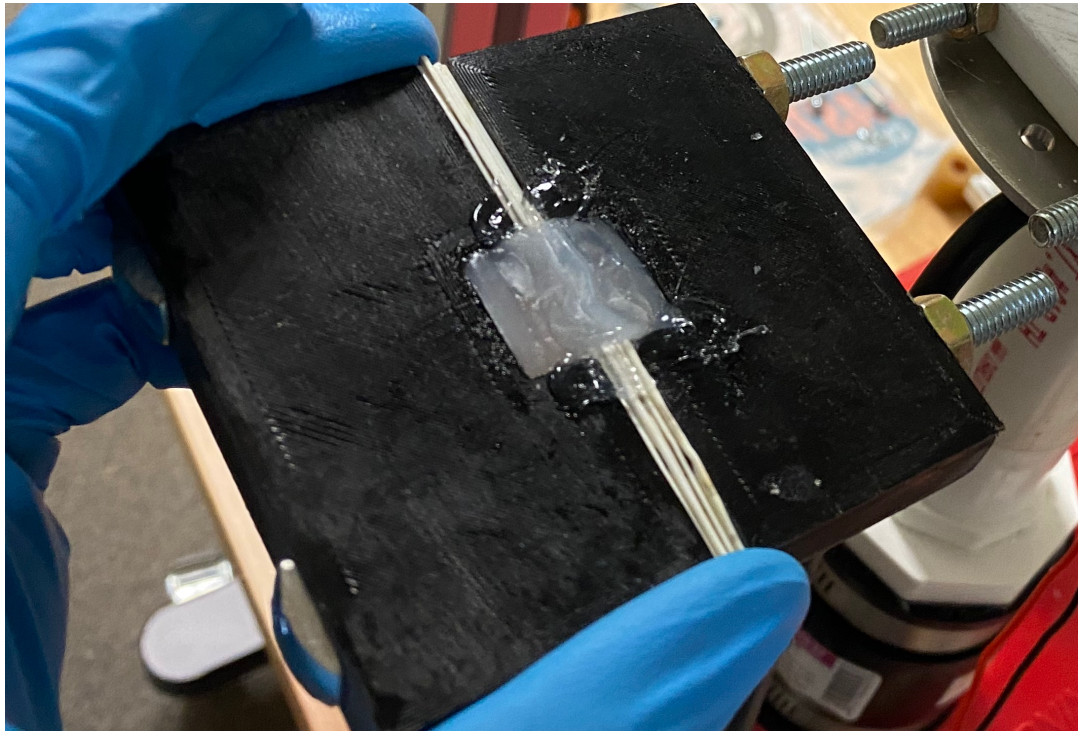


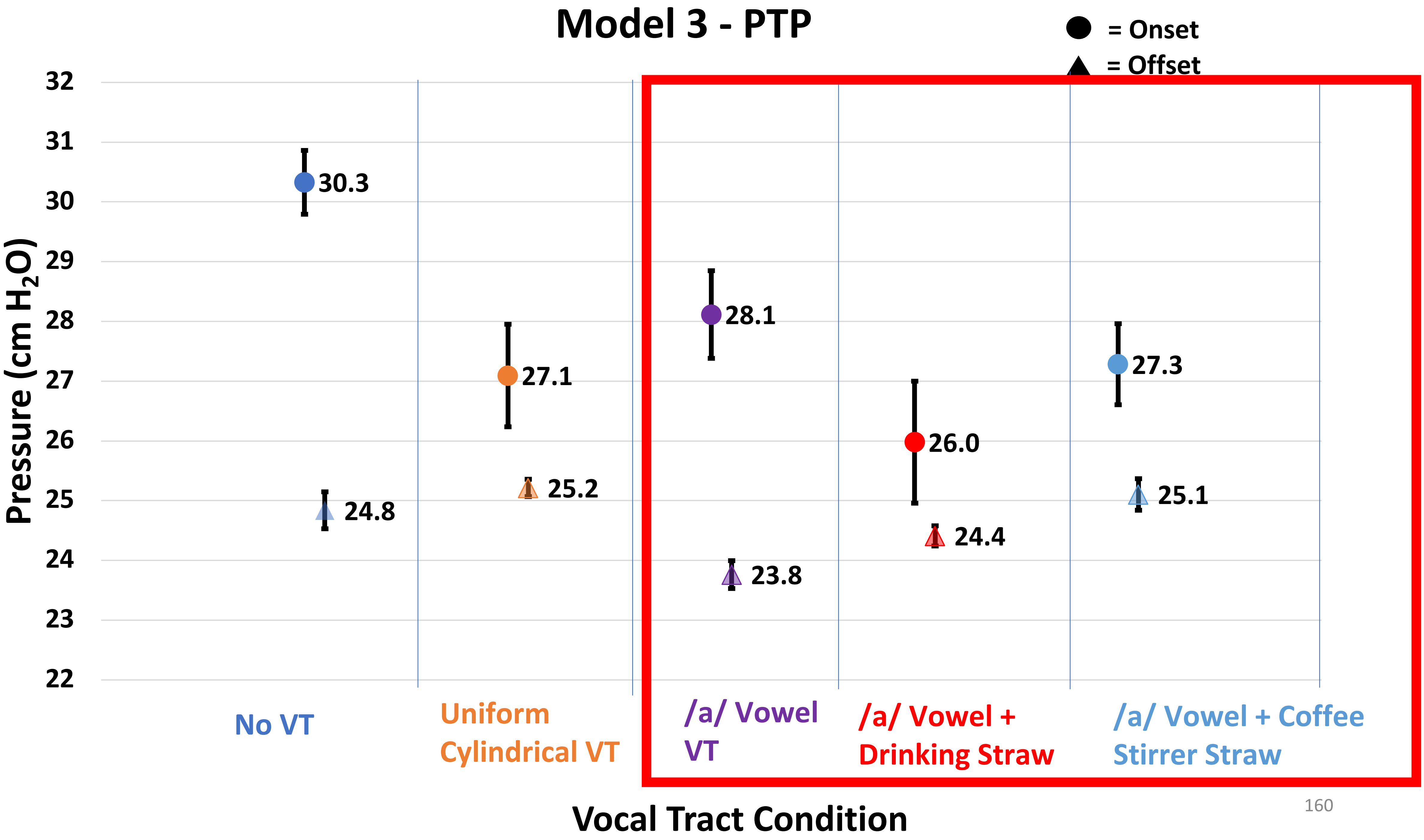
Model 1 - PTF
= Onset
= Offset
750
700
650
600
550
500
450
400
350
300
Airflow (mL/s)
678
429
605
408
538
382
No VT
Uniform
Cylindrical VT
/a/ Vowel VT
Vocal Tract Condition



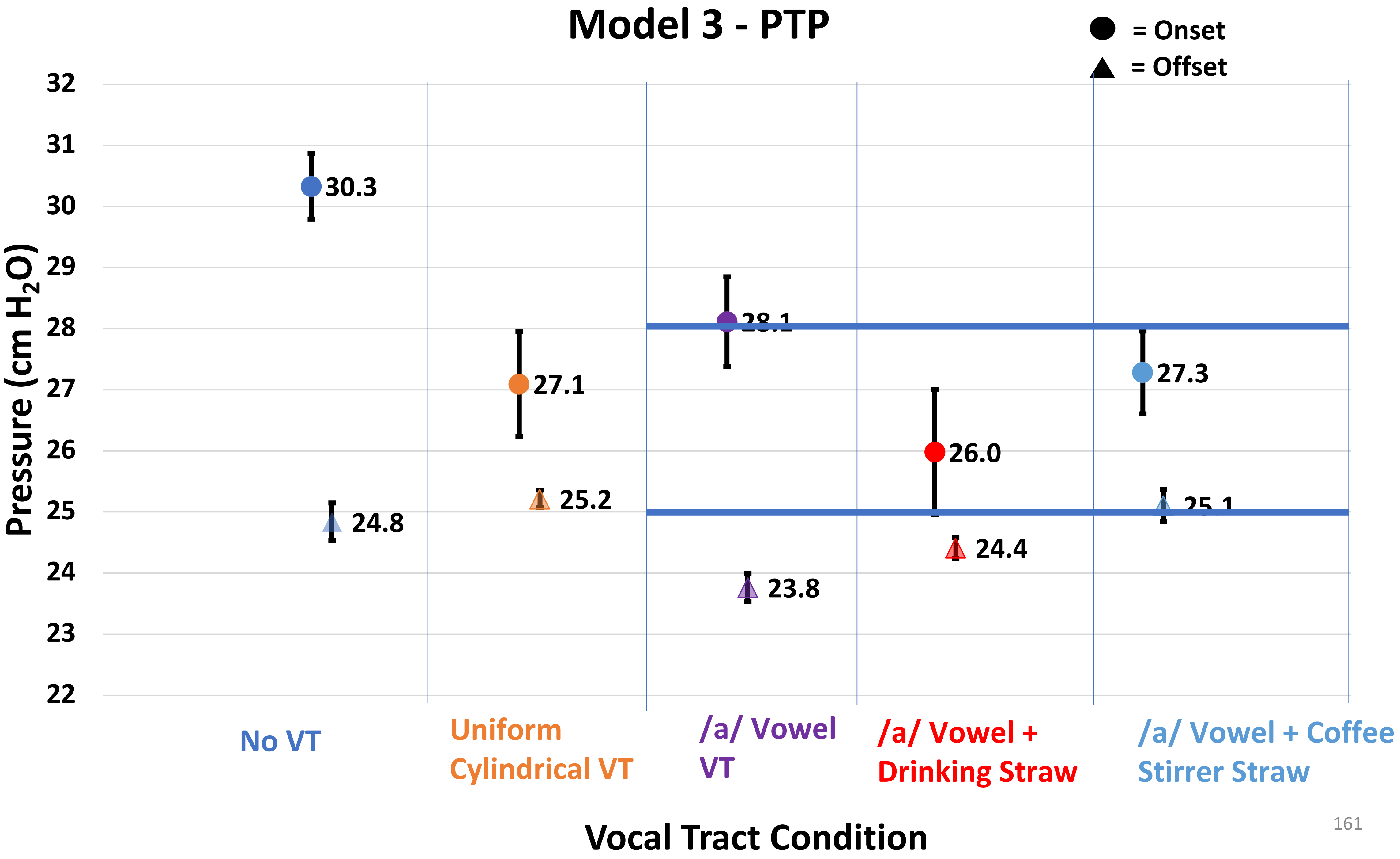
Model 1 - PTF
= Onset
= Offset
750
700
650
600
550
500
450
400
350
300
Airflow (mL/s)
678
429
605
10.8%
408
538
20.6%
382
No VT
Uniform Cylindrical VT
/a/ Vowel VT
Vocal Tract Condition

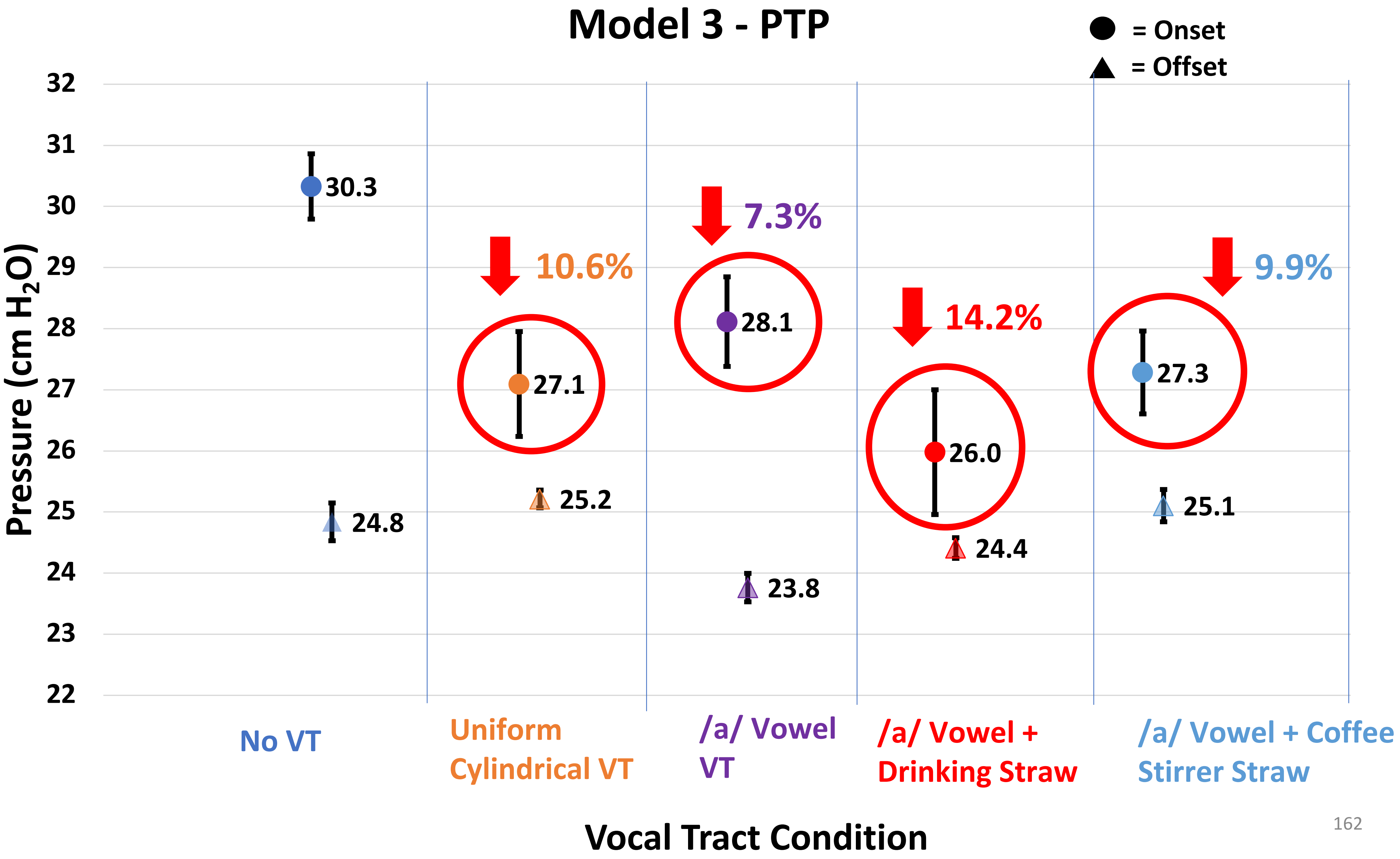
Model 3



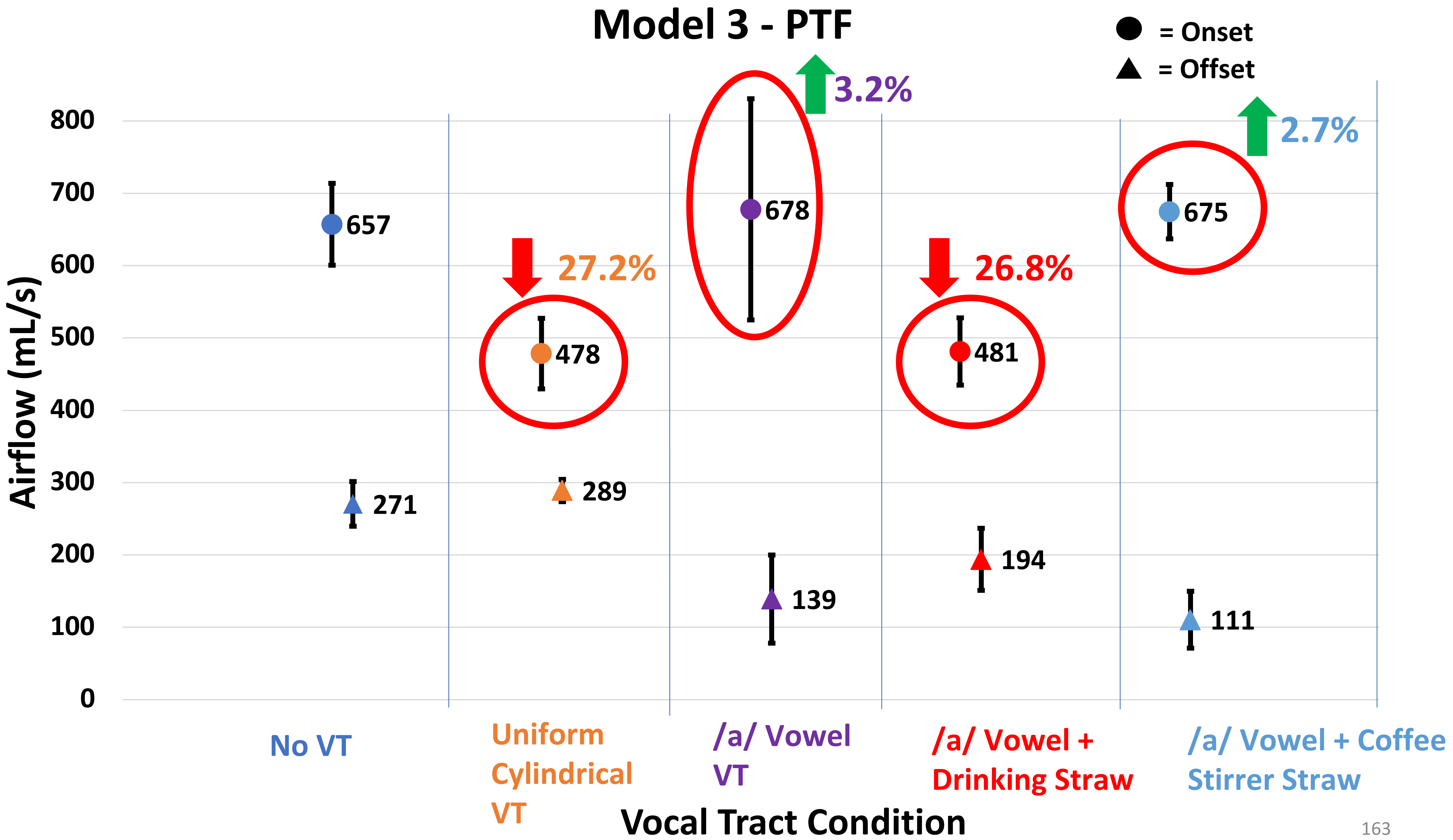


Model 3 - PTP
= Onset
= Offset
Pressure (cm H_2O)
32
31
30
29
28
27
26
25
24
23
22
30.3
24.8
27.1
25.2
28.1
23.8
26.0
24.4
27.3
25.1
No VT
Uniform Cylindrical VT
/a/ Vowel VT
/a/ Vowel + Drinking Straw
/a/ Vowel + Coffee Stirrer Straw
Vocal Tract Condition


Model 3 - PTP
= Onset
= Offset
Pressure (cm H_2O)
32
31
30
29
28
27
26
25
24
23
22
30.3
24.8
27.1
25.2
28.1
23.8
26.0
24.4
27.3
25.1
No VT
Uniform Cylindrical VT
/a/ Vowel VT
/a/ Vowel + Drinking Straw
/a/ Vowel + Coffee Stirrer Straw
Vocal Tract Condition



Model 3 - PTP
= Onset
= Offset
Pressure (cm H_2O)
32
31
30
29
28
27
26
25
24
23
22
30.3
24.8
10.6%
27.1
25.2
7.3%
28.1
23.8
14.2%
26.0
24.4
9.9%
27.3
25.1
No VT
Uniform Cylindrical VT
/a/ Vowel VT
/a/ Vowel + Drinking Straw
/a/ Vowel + Coffee Stirrer Straw
Vocal Tract Condition


Model 3 - PTF
= Onset
= Offset
Airflow (mL/s)
800
700
600
500
400
300
200
100
0
657
271
27.2%
478
289
3.2%
678
139
26.8%
481
194
2.7%
675
111
No VT
Uniform Cylindrical VT
/a/ Vowel VT
/a/ Vowel + Drinking Straw
/a/ Vowel + Coffee Stirrer Straw
Vocal Tract Condition

Discussion/Conclusions

- M1
  - PTP and PTF decrease from no VT to uniform cylindrical VT to MRI-based /a/ vowel VT conditions with onsets decreasing >> offsets
- M3 (added two SOVT conditions)
  - PTPs and PTFs for the SOVT conditions were lower than the un-occluded /a/ vowel conditions

Another study

- May & Scherer, 2023, *JASA* (in review)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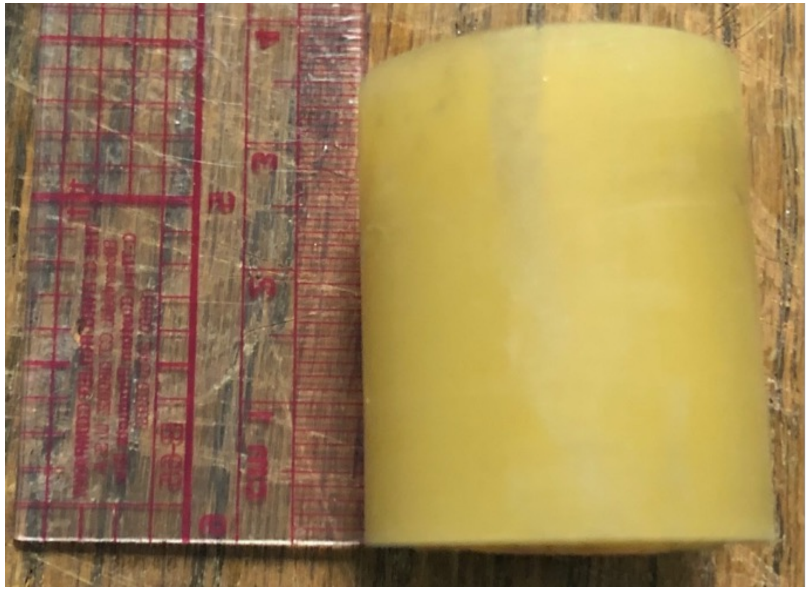
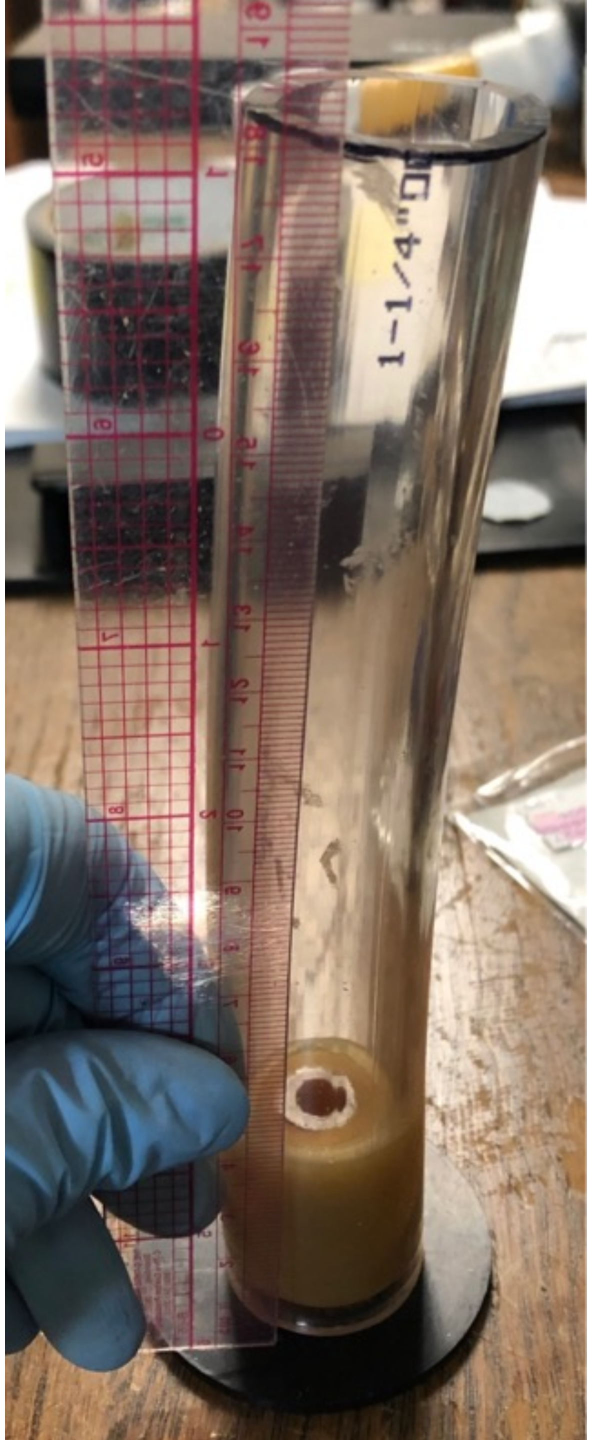
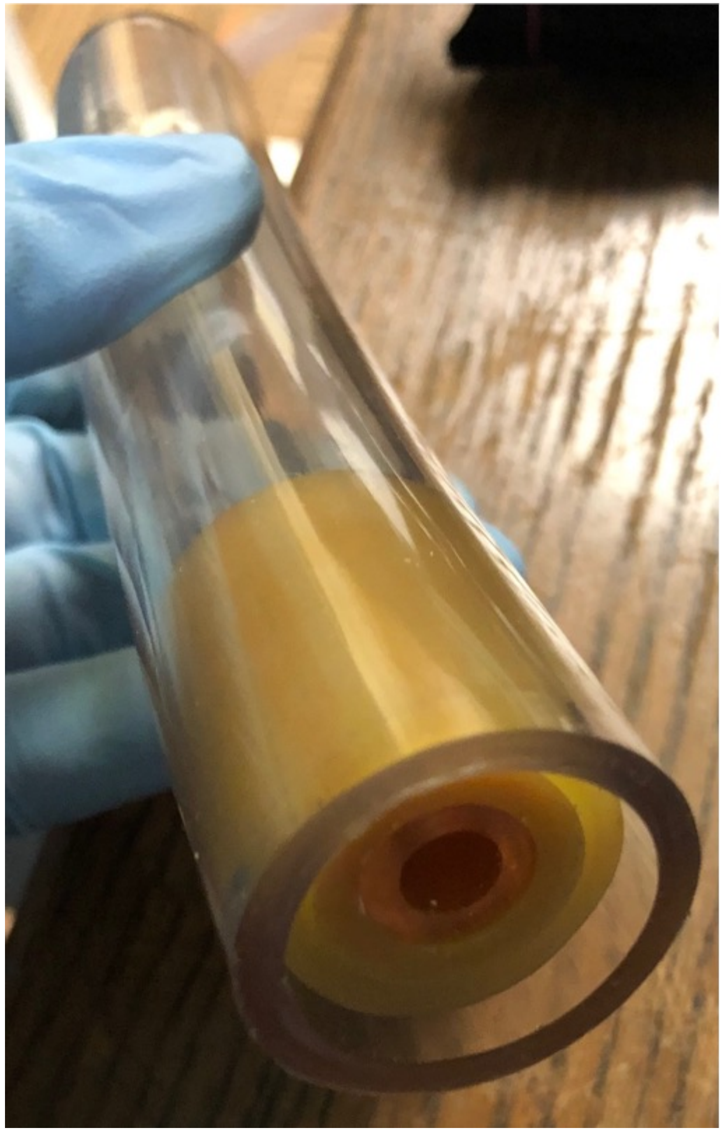



1-1/4"OD



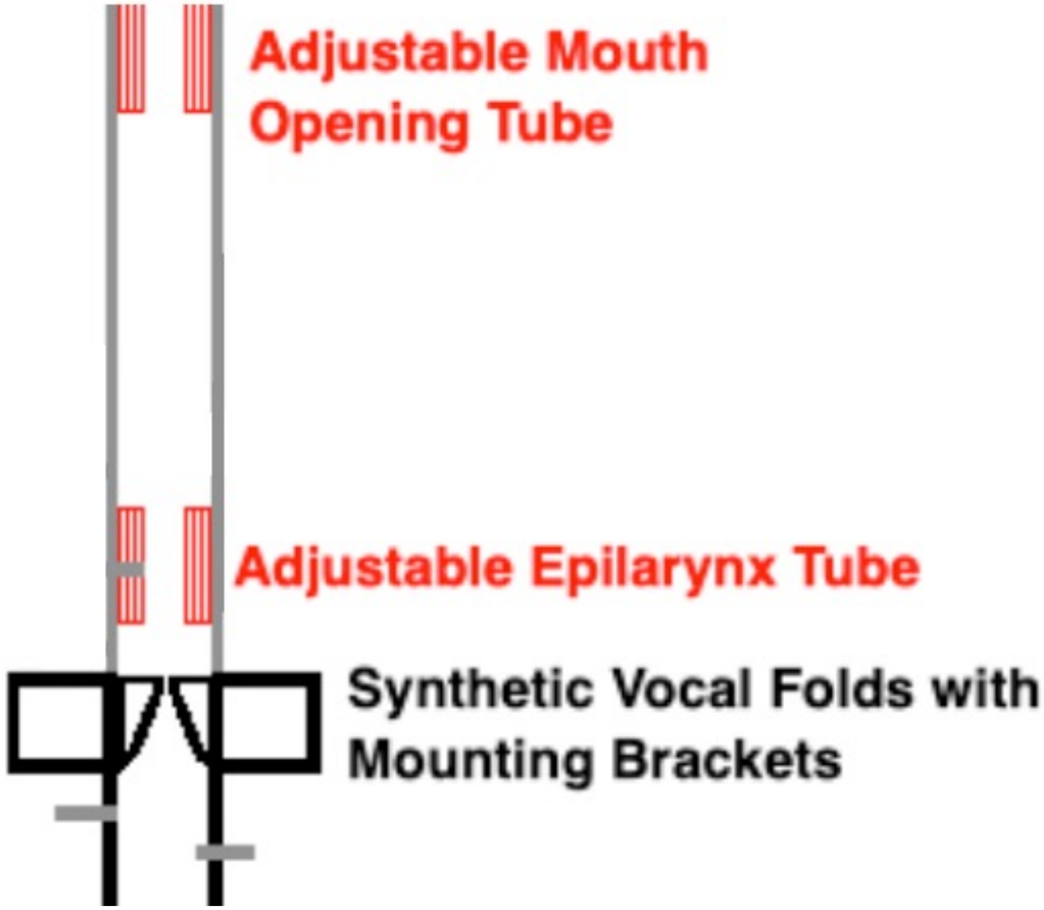
May & Scherer, 2023, *JASA* (in review)

No VT control	**Open, Open**	**Open, Large**	**Open, Medium**
Open, Narrow	**Large, Open**	**Medium, Open**	**Narrow, Open**

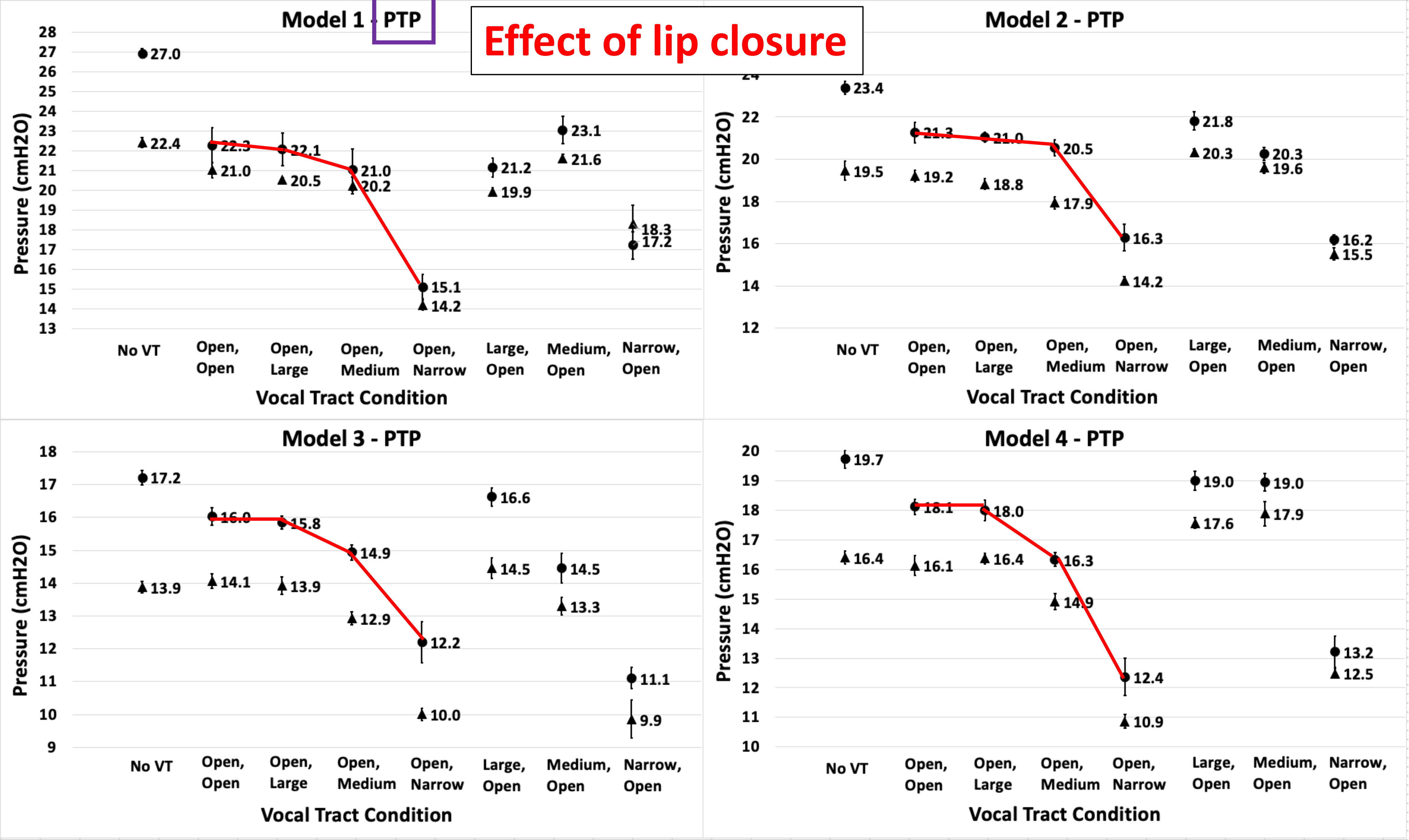
“[proximal tube constriction], [distal tube constriction]”

Experimental tube inner cross sectional areas are as follows: “Open” = c. 5.208 cm^2 *,
“Large” = c. 2.761 cm^2,
“Medium” = c. 1.277 cm^2,
“Narrow” = c. 0.442 cm^2.

*The “Open” condition is without constriction.

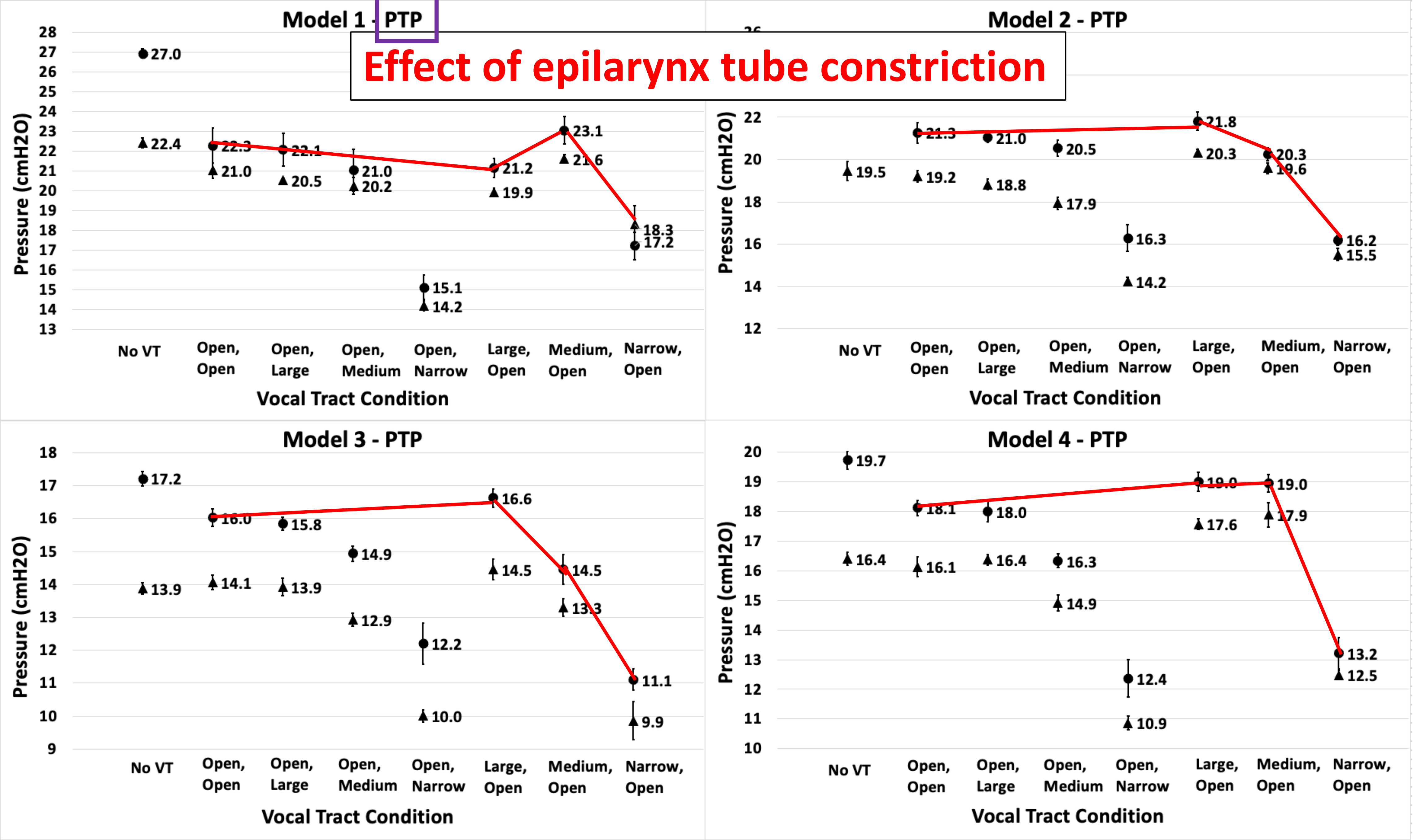


Effect of lip closure



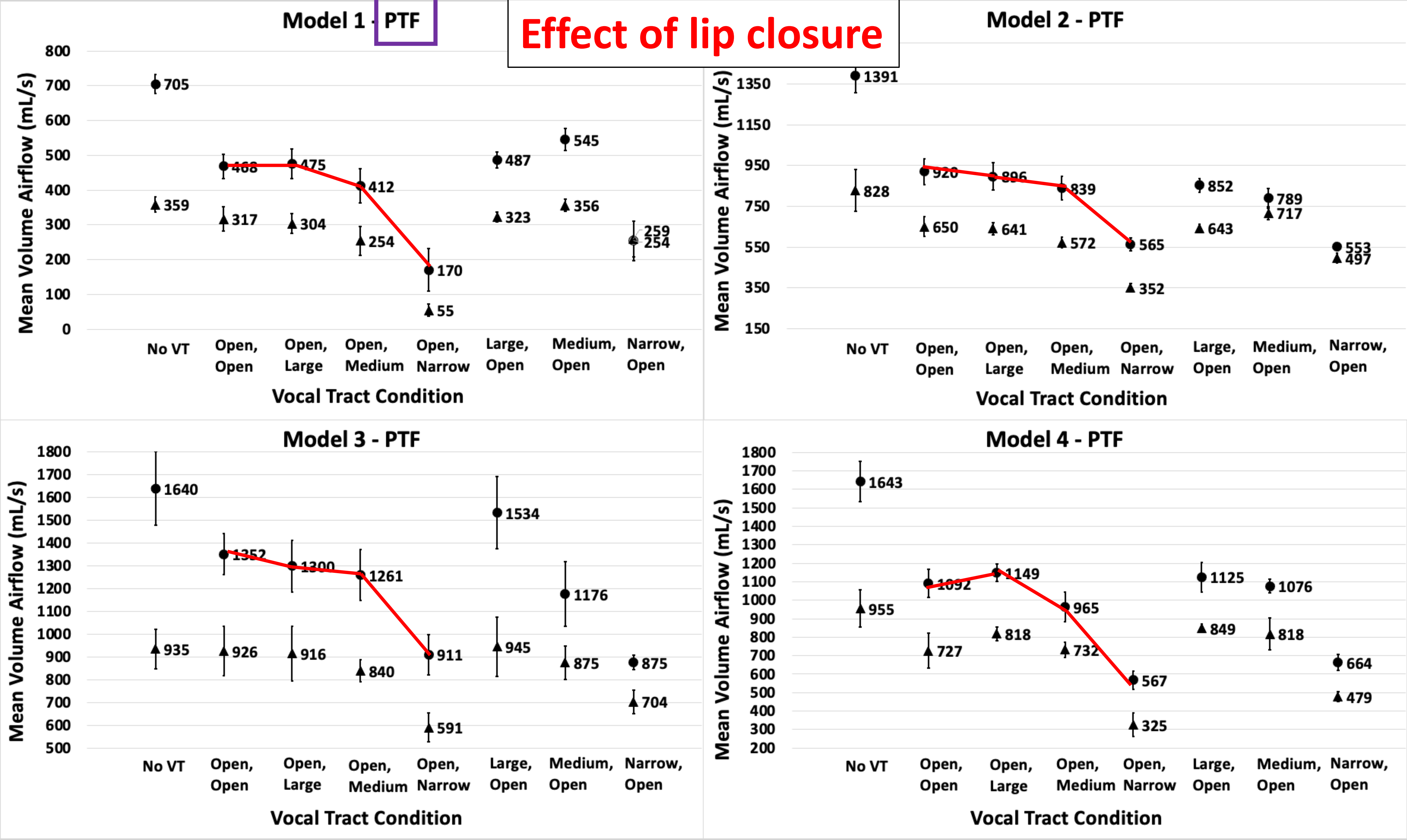
May & Scherer, 2023, JASA (in review)

Effect of epilarynx tube constriction



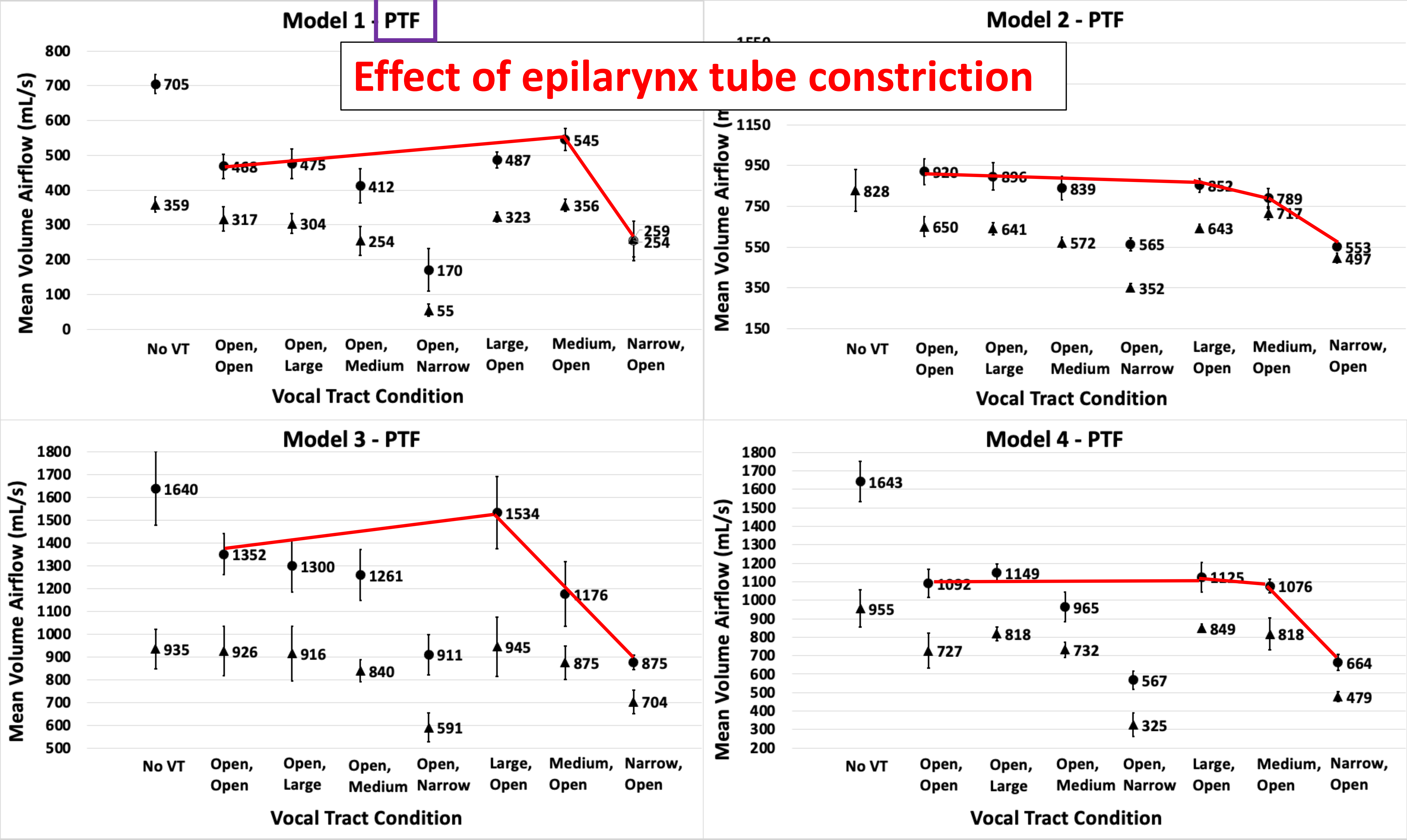
May & Scherer, 2023, JASA (in review)

Effect of lip closure

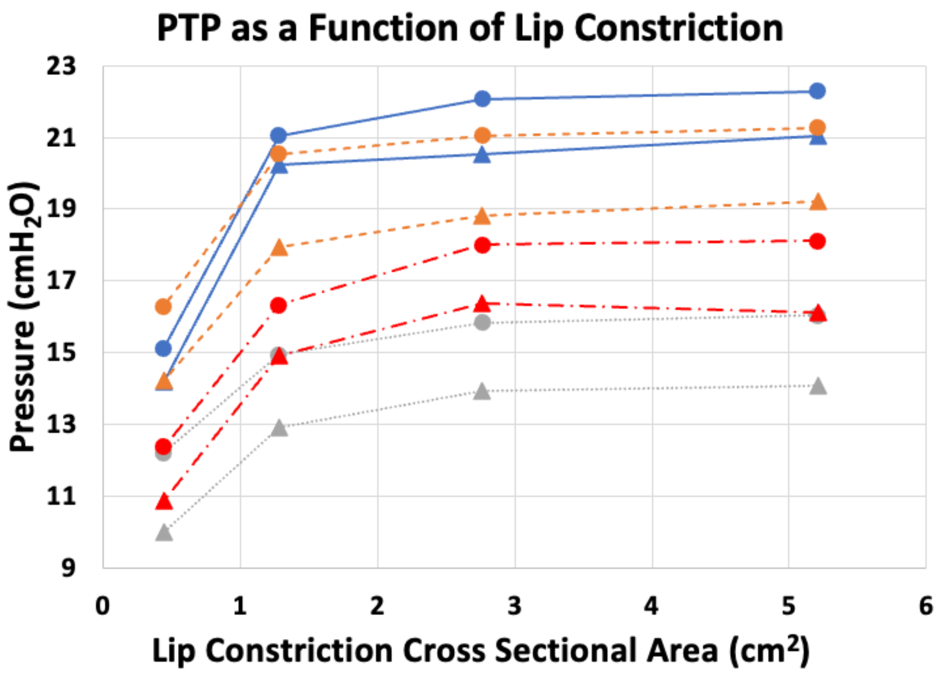


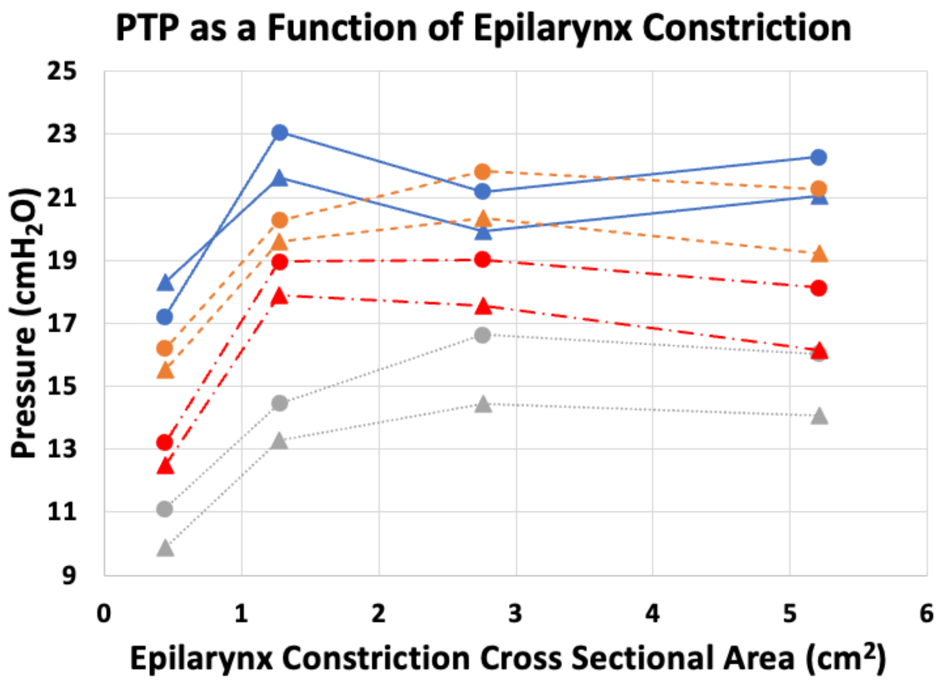
May & Scherer, 2023, JASA (in review)

Effect of epilarynx tube constriction



May & Scherer, 2023, JASA (in review)





M1 curves are in solid blue,
M2 curves are in dashed orange,
M3 curves are in dotted gray, and
M4 curves are in dash dotted red.

Onset PTPs are circles,
Offset PTPs are triangles

So, PTP and PTF were both observed to decrease with lip and epilarynx tube narrowing (although the pattern was more consistent with lip narrowing)

May & Scherer, 2023, JASA (in review)

3. Clinical Applications

(from Titze, 2006; Titze & Verdolini, 2012; Rosenberg, 2014)

Applications of SOVTEs

- Reducing pressed phonation (hyperfunctional adduction) (Stemple, Lee, D'Amico, & Pickup, 1994; Verdolini-Marston, Burke, Lessac, Glaze, & Caldwell, 1995; Verdolini-Marston, Drucker, Palmer & Samawi, 1998).
  - ***Potentially useful for populations with hyperfunctional dysphonia (e.g., MTD)?***
- Facilitate forward resonance sensations (carryover into connected speech?)
- Provides an external focus (kinesthetic FB) to helps facilitate long-term learning of a new motor skill (Wulf, McNevin, Fuchs, Ritter & Toole, 2000; Wulf & Prinz, 2001).
- "Low-impact "resonant hum may inhibit acute vocal fold inflammation and promote wound healing (Verdolini-Abbot et al., 2012).
  - ***Potentially useful during wound healing s/p surgery (part of protocol for returning clients to voice use after period of vocal rest)?***

Rosenberg, 2014

Hierarchy of SOVTEs (Airflow Resistance)

- The oral cavity can then be adjusted for any vowel or consonant. In an ideal therapy or voice training regime, one could rationalize that semi-occlusives be used in the order ''greatest effect, but most artificial'' to ''smallest effect, but closest to natural.''

- <u>This rationale would suggest the following order</u>:

1. Highly resistant (small diameter) stirring straw
2. Less resistant (larger diameter) drinking straw
3. Tubes
4. Cups
5. Standing wave
6. Bilabial or labiodental voiced fricative
7. Lip or tongue trill
8. Nasal consonants
9. Vowels /u/ and /i/
10. Open Vowels

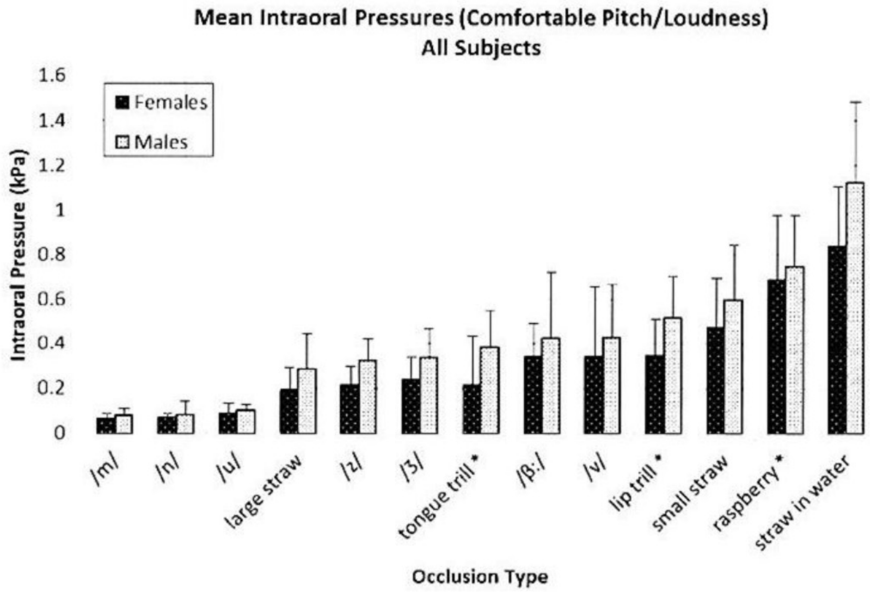
Most resistive (artificial)

Small diameter
Longer tube
Free end in water

Large diameter
Shorter tube
Free end in air

Least resistive (speech-like)

Maxfield et al., 2015, p. 9



Rosenberg, 2016; Rosenberg & Laborgne, 2016; ; Titze, 2006

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8. Nasal consonants
9. Vowels /u/ and /i/
10. Open Vowels

NOW TRY SOME!

What do you feel?...

Can you feel any differences?...

Most resistive (artificial)

Small diameter
Longer tube
Free end in water

Large diameter
Shorter tube
Free end in air

Least resistive (speech-like)

Rosenberg, 2016; Rosenberg & Laborgne, 2016; ; Titze, 2006

Where to Start, How to Progress?

- Voiced fricatives (/ð/, /v/, /z/, and /ʒ/) and nasal consonants (/m/, /n/, and /ŋ/) require little explanation for English speaking clients and thus may be good starting point (along with tube/straw phonation)
- Choose a straw/tube inner diameter and length that facilitates sensations of resonance (i.e., in anterior facial structures/maxilla) and “easy” phonation.
- Use plenty of air, and stay relaxed. It should feel easy.
- While doing these exercises don’t forget about other aspects that impact voice (e.g., posture, breath management, adduction, subglottal pressure)

Titze, 2006

Where to Start, How to Progress?

- Since some clients may be unfamiliar with producing sound with a nearly closed mouth, starting in the middle of the hierarchy (e.g., perhaps with humming or lip trilling, or even /u/ or /i/ vowels) might be preferred to prevent the client from pushing or straining.
- Once the client becomes more familiar and comfortable with the ‘‘feel’’ of the production, try experimenting with more occluded SOVTEs and slowly progressing to less occluded ones.

Titze, 2006

Where to Start, How to Progress?

- Oscillatory SOVTEs (lip trills or buzzes, tongue trills, and raspberries) may be difficult for novice vocalist (i.e., speakers and singers with little to no training).
- Many patients are able to generate either a lip or tongue trill spontaneously while others require some training.
- However, *it is often the case that one exercise is easier for an individual than another* (e.g., raspberries may be easier for the client to produce than lip trills or vice versa).
- If patients are unable to complete a tongue or lip trill, straw phonation, or use of sustained fricatives can serve as an alternative.
- *Trial and error is needed.*
- *May need to give your client "permission" (i.e., encourage them) to make "silly sounds".*
- These sounds are performed for the purpose of producing an easier, healthier production.

Titze, 2006

Where to Start, How to Progress?

- Note that, in order to vibrate the lips or tongue in an oscillatory manner, the following conditions must be met:

1. The vibrating structure needs to be pliable (i.e., not too tense),
2. Sufficient driving pressure (trans-lip or trans-tongue) must be present, and
3. The vibrating structure(s) must be sufficiently approximated together (
    - e.g., both lips in the case of the lip trill, the tongue and the bottom lip in the case of the raspberry) or the vibrating structure must be sufficiently approximated to a another rigid articulator (e.g., the tongue and the hard palate in the case of the tongue trill)

- Trouble shoot by checking that each of these conditions is met.
    - For example, in the case of lip trills/buzzes, placing the index fingers at the corners of the mouth and slightly pushing medially may assist the client in producing the lip oscillation if the lips are not sufficiently relaxed or pliable.

Titze, 2006

Tasks During SOVTEs

- A hierarchical approach is often helpful. Start in a comfortable range and move up and down in pitch if comfortable.
- These exercises can then progress to open vowels and more complex speech tasks.
- Nonspeech exercises:
  - Repeated pitch glides → initial range may be no more than a fifth of an octave but then gradually increasing the frequency range until two octaves or more can be produced easily
  - Singing
    - Variety of vocalizes (ascending, descending, sustained/sostenuto, coloratura/melismatic, messa di voce, etc.)
    - Melody of a simple song (through the semi-occlusion)
  - For carryover into speech: intonation and stress patterns of spoken sentences, reading passages may also be phonated through the semi-occlusion (varying stress patterns/intonation)

Titze, 2006

A few notes on straw/tube phonation

- Compliance for out-of-therapy-room practice may be most easily achievable with straw phonation as produces the least amount of sound. Thus, exercises can be done in a variety of settings (e.g., car, walking on the street, hotel rooms) without drawing much attention since these sounds are not interpreted as speech sounds by listeners.
- Compliance yields results (i.e., training effects may be accomplished in the least amount of time).
- Also straw/tube phonation requires little training (motor control) to perform correctly and straws are readily available.

Rosenberg, 2016;

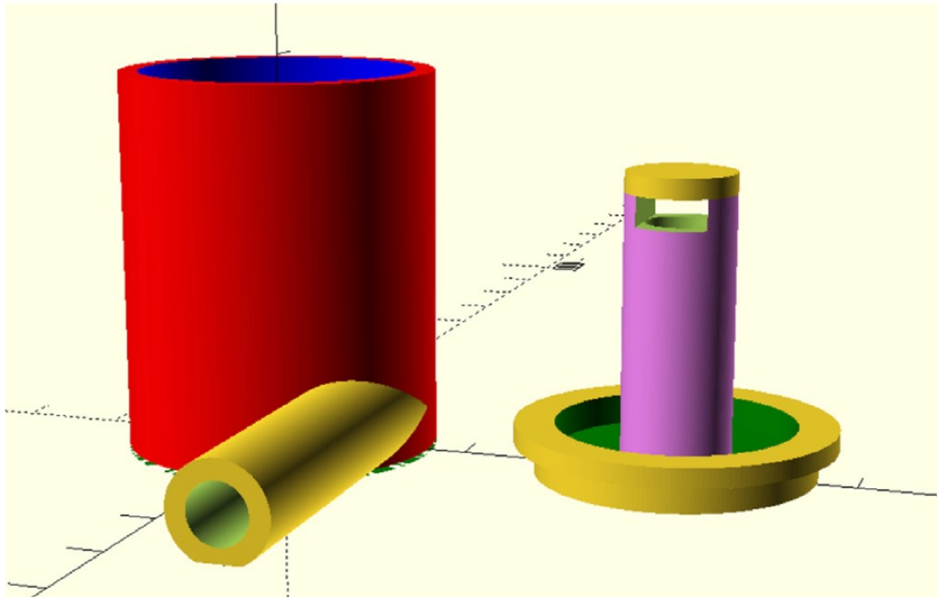
A few notes on straw/tube phonation

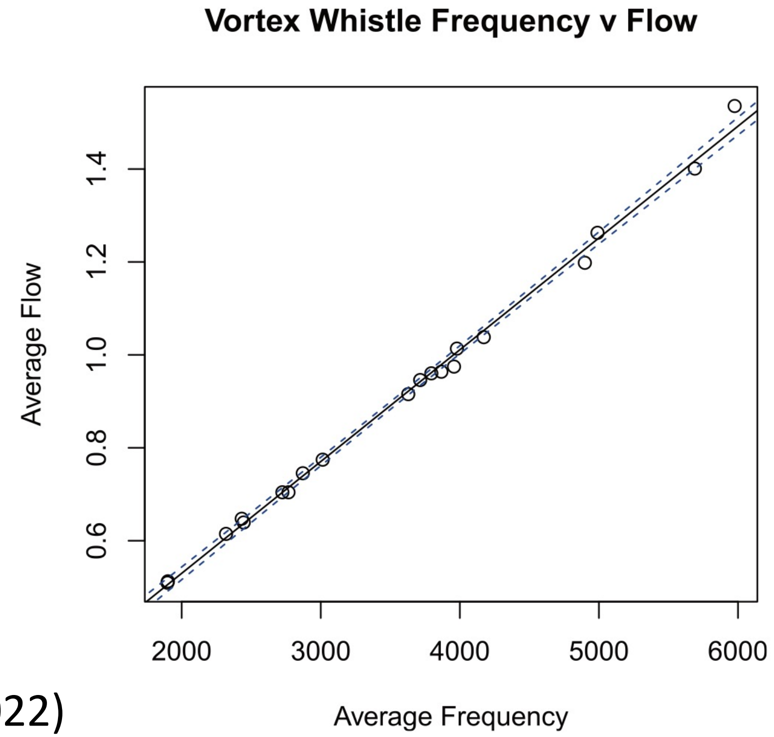
- Straw/tube is placed in the client’s mouth with no air leaking around the lips
- Client is encouraged to sustain gentle, easy phonation (e.g., glides and sirens)
- Client should generate sound as if the straw were not present (adequate airflow and loudness)
- May take several minutes of practice before phonation through the straw becomes easy/natural
- Client should get the “feel” of the exercise before complexity is added
- Providing an external focus (e.g., feeling vibration on the fingertips or directing client to send the sound through the straw across the room) may be useful
- Once comfortable, client can experiment with expanding the pitch range and trying more or less occlusive straws/tubes or placing the free end in various depths of water

Rosenberg, 2016;

Other SOVTEs

- Vortex Whistle (Awan & Awan, 2022)
  - Airflow strongly directly correlated with whistle frequency





(Awan & Awan, 2022)

Other SOVTEs

- Flow-ball (PowerBreathe®)
    - Airflow directly correlated with ball height (like a flow meter)

https://voicefoundation.org/product/flow-ball/

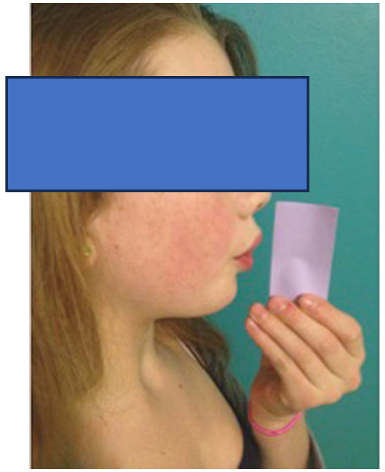
Other SOVTEs

- Lessac Y-Buzz (Arthur Lessac, 1997; Rosenberg, 2016)
  - /y/ combined with /i/, comfortable pitch (lower third of vocal range), inverted megaphone VT shape, sense the buzzing of the anterior hard palate and front of the face (maxilla)

Other SOVTEs

- Card Kazoo (lip/tongue trill alternative) (Rosenberg, 2016)
  - Small card or post-it note is lined up perpendicularly to the lips (vertically), lips are pursed, client is prompted to pitch glide comfortably up and down staying within a comfortable pitch range.
  - Client is prompted to focus on vibration of the lips.
  - Inverted megaphone VT may be facilitated by prompting client to maintain and open space in the back of the throat while maintaining the pursed lips.

A regular kazoo may also be used for SOVTEs…



(Rosenberg, 2016)

Other SOVTEs

- Cup phonation (Rosenberg, 2016; Rosenberg & LeBorgne, 2014)
  - Allows for vowel variation and producing running speech with some downstream airflow resistance
  - A hole (approximately the diameter of a pencil or slightly bigger) is punched through the bottom of a standard 10 oz. styrofoam coffee,
  - The open top of the cup is completely sealed around the client’s mouth,
  - The patient is instructed to generate a neutral vowel
  - Sound and airflow only travels through the hole on the bottom of the cup
  - Airflow resistance can be modified by altering the size of the hole
  - Complexity may be added as desired
  - May be useful for singers (facilitation of mixed vocal register)

(Rosenberg, 2016)

Other SOVTEs

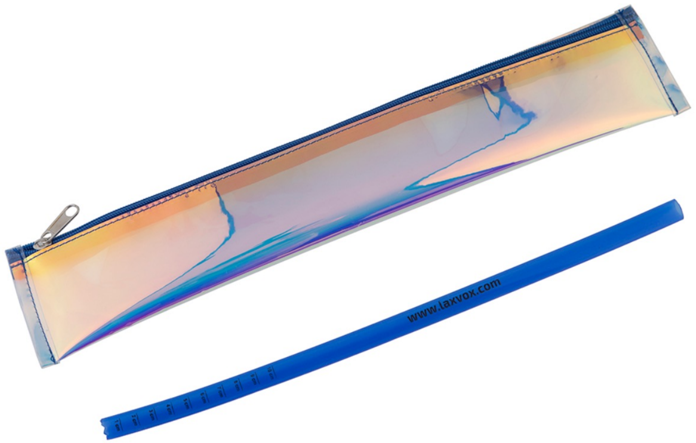
- "Wave in a cave" and "Standing wave" (Behlau & Oliveira in Behrman & Haskell, 2013; Rosenberg, 2016)
  - Standing wave: hand over mouth exercise (good for singers – high range)
  - Wave in a cave: make a "cave" by cupping both hands together, produce a neutral vowel into the "cave", adjust "cave" shape (airflow resistance) as needed
  - Clients are cued to seek maximum vibration ("bounce-back") of the sound back into the oropharyngeal space.
  - Glides are often at first. Once client is comfortable with this task, complexity can be added (from rote to running speech)

(Rosenberg, 2016)

Other SOVTEs

- Lax-Vox tube, doctorVOX, maskVOX
  - Large diameter silicone tube with markers for submersion depth in water
  - Other products (masks, etc.) are also available from DoctorVox

(https://www.doctorvox.com/product/lax-vox-tube/)



I have no commercial relationship/interest in this or any products/companies discussed

Other SOVTEs

- **Resonant Voice Therapy (RVT)** (Verdolini- Marston et al., 1998; Verdolini-Marston et al., 1995)
  - **"Resonant voice" (RV)** is voice production that is simultaneously easy to produce and vibrant in the facial tissues (Verdolini-Marston et al., 1995)
  - **RV** is characterized by low VF collision forces despite large-amplitude VF vibration, moderate adduction, and acoustic efficiency
    - When the glottal energy conversion process is efficient vibrations are distributed across the head (eyes, nose, mouth), neck, and thorax → where resonance FB sensations are thought to originate
    - Poor energy conversion is thought to result in more localized vibrations
    - Note that the vibrations themselves are not resonance, rather they are the byproduct of source-vocal tract interaction

Titze & Verdolini Abbott, 2012

Other SOVTEs

- **Resonant Voice Therapy (RVT)** (Verdolini- Marston et al., 1998; Verdolini-Marston et al., 1995)
  - Designed to increase efficiency of VF vibration by using nasals (forward hum) to shape speech; client sustains nasal phoneme /m/, noting sensations of vibration in the front of the face with little effort in the throat.
  - **<u>Hierarchical approach progressing from sustained nasals to connected speech:</u>**
    - **Stretches** (e.g. shoulders, neck, jaw, floor of mouth, lips, tongue, pharynx) and **breathing maneuvers** (e.g. abdominal release, breathe-release…, sustained fricatives)
    - **Basic gesture: Hmm sigh** with **extreme forward focus**, **breath awareness**, and **relaxation**
    - **Step 1 (all voiced):** add nonlinguistic speech contexts (e.g. /mɑmɑmɑmɑ/) experimenting with rate, ease, intensity, and pitch; eventually chant speech on carrier phrases is added (e.g. "Mary made me mad")
    - **Step 2 (voiced-voiceless):** add voiceless consonants (e.g. /mɑmɑpɑpɑ/) varying same variables as in step 1. Adding voiceless consonants requires rapid laryngeal articulation, which is more similar to running speech. Eventually chant speech with voiceless consonants is added (e.g. "Mom may put Paul on the moon")
    - **Step 3 (any phrase):** introduce novel phrases maintaining forward focus.
    - **Step 4 (paragraph reading):** combine strings of phrases maintaining forward focus.
    - **Step 5 (controlled conversation):** begin carryover into conversation maintaining forward focus
    - **Step 6 (environmental manipulation):** conversation in novel environments (or simulated novel environments) consistent with patient's needs. These environments should include some adverse characteristics (e.g. background noise).
    - **Step 7 (emotional manipulation):** add topics that elicit laughter, loud talking, anger, etc.
    - **Home exercises:**15-20 min twice/day (includes stretches, basic RVT gesture, and selected steps)

Other SOVTEs

- **Vocal Function Exercises** (Gorman, Weinrich, Lee, & Stemple, 2008; Sabol, Lee, & Stemple, 1995; Stemple et al., 1994).
  - The Vocal Function Exercise voice therapy program was first described by Briess in the 1950's, and was modified by Stemple (Stemple, 2000, Verdolini et al., 1998).
  - The program is intended to improve vocal efficiency by "rebalancing" and "strengthening" the three subsystems of voice production (i.e., respiration, phonation, and resonance) (Stemple, 2000).
  - Multiple studies have demonstrated its efficacy with both the normal and voice disordered population (Roy, Gray, Simon, Dove, Corbin-Lewis, & Stemple, 2001; Sabol, Lee, and Stemple, 1995; Stemple, Lee, D'Amico, and Pickup, 1994)

(Ishikawa, 2006, p. 6-7)

Other SOVTEs

- **Vocal Function Exercises** (Gorman, Weinrich, Lee, & Stemple, 2008; Sabol, Lee, & Stemple, 1995; Stemple et al., 1994).
    - Series of four exercises designed to improve glottal efficiency and function:
        1. MPT warm-up task on /i/ (comfortable pitch, extremely soft, with extreme forward focus – almost nasal),
        2. Stretching exercise: smooth ascending glide on extremely closed /o/ (word “knoll”) from lowest to highest pitch,
        3. Contracting exercise: smooth descending glide on extremely closed /o/ (word “knoll”) from highest to lowest pitch
        4. Low impact power exercise: MPT tasks on extremely closed /o/ (word “knoll”)

Practice Makes Permanent…

- Clinicians should gauge recommendations regarding number of sets and reps based on the patient’s need (e.g., diagnosis, vocal endurance, time post-surgery if applicable).
- Do your best to ensure correct execution of SOVTEs during therapy to avoid the client ingraining errors at home.
- To reduce the risk of incorrect practice, have clients provide frequent self-feedback regarding what they are feeling, hearing, and experiencing during and after SOVTEs during each session.

Rosenberg, 2016

Practice Makes Permanent…

- Varied-practice schedule (i.e., alternating after several trials from one SOVT variation to another) may help promote better long-term learning of the motor patterns associated with these voice tasks (Schmidt & Lee, 2010).
- Can have the client review how they are practicing at home to allow the clinician to assess and modify exercises as needed.
- Having client make audio or video recordings of their practice and reviewing these with the clinician during session may also help ensure correct practice.

Rosenberg, 2016

Treatment variables to consider

- **Duration** of sessions (i.e., micro: # min/session, macro: how long on caseload)
- **Frequency** (i.e, how many times/week?)
- **Load/dose** (i.e., how many reps and sets)
- **Intensity** (i.e., how much effort per rep)
- **Tx Sequence** (task order)
- **Tx Progression** (how fast to progress through different targets, levels of speech and language)
- **Generalization** (how practice on one target affects similar, but untrained, targets)
- **Carryover/Retention** (Performance levels after practice is completed or after course of Tx is over)
- **Motivation, adherence, and compliance**
  - Stemple & Hapner → methods for enhancing pt engagement and success
- **Booster Tx (in the future)?**

Maas, 2008, "Principles of motor learning in treatment of motor speech disorders", p. 282

Condition	Options	Description	Notes	Evidence in speech
Practice amount	Small vs. **large**	Small: low number of practice trials or sessions Large: high number of practice trials or sessions	Potential interaction with practice variability (high number of constant practice trials may be detrimental to learning)	No systematic evidence
Practice distribution	Massed vs. **distributed**	Massed: practice a given number of trials or sessions in small period of time Distributed: practice a given number of trials or sessions over longer period of time		No systematic evidence
Practice variability	Constant vs. **variable**	Constant: practice on the same target, in the same context (e.g., syllable-initial /f/) Variable: practice on different targets, in different contexts (e.g., syllable-initial and final /f/, /z/, /b/)	Potential interactions with practice schedule, amount, complexity, and feedback variables Opposite effects on GMP vs. parameter learning	Limited evidence for benefit of variable practice in unimpaired speech motor learning; no evidence from MSD
Practice schedule	Blocked vs. **random**	Blocked: different targets practiced in separate, successive blocks or treatment phases (e.g., treatment on /f/ before initiating treatment on /z/) Random: different targets practiced intermixed (e.g., practice on /f/ and /z/ in each session)	Potential interactions with practice amount and complexity Opposite effects on GMP vs. parameter learning	Limited evidence for benefit of random practice, in unimpaired speech motor learning and treatment for AOS
Attentional focus	Internal vs. **external**	Internal: focus on bodily movements (e.g., articulatory placement) External: focus on effects of movements (e.g., acoustic signal)	Focus must be task-related Difficult to define external for speech	No systematic evidence
Target complexity	Simple vs. **complex**	Simple: easy, earlier acquired sounds and sound sequences (e.g., plosives, CV-syllables) Complex: difficult, later acquired sounds and sound sequences (e.g., affricates, CCV syllables)	Potential interactions with practice schedule, feedback variables, and learner's skill level	Limited evidence for benefit of targeting complex items in treatment for AOS

Note. Options that may be expected to enhance learning are indicated in bold. GMP = generalized motor program; MSD = motor speech disorder; AOS = apraxia of speech.

Maas, 2008, “Principles of motor learning in treatment of motor speech disorders”, p. 282

Condition	Options	Description	Notes	Evidence in speech
Feedback type	KP vs. **KR**	KP: knowledge of performance, how a sound was produced (e.g., biofeedback) KR: knowledge of results, whether a sound was correct or incorrect	Potential interactions with learner's error detection abilities	No systematic evidence
Feedback frequency	High vs. **low/summary-KR**	High: feedback after every attempt at production (regardless of accuracy) Low: feedback only after some attempts at production (regardless of accuracy)	Potential interactions with practice variability, attentional focus, complexity, and learner's skill level and error detection abilities Opposite effects on GMP and parameter learning	Some evidence for benefit of reduced feedback frequency in treatment for AOS and speech motor learning in hypokinetic dysarthria
Feedback timing	Immediate vs. **delayed**	Immediate: feedback immediately following attempt at production Delayed: feedback provided with a delay (e.g., 5 s)	Potential interactions with attentional focus	Some evidence for delayed feedback in treatment for AOS and hypokinetic dysarthria

Note. Options that may be expected to enhance learning are indicated in bold.

Evidence Based Medicine

- EBM is "The conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence-based medicine means integrating individual clinical experience with the best available external clinical evidence from systematic research." Sackett et al. BMJ. 1996;312:71-72.

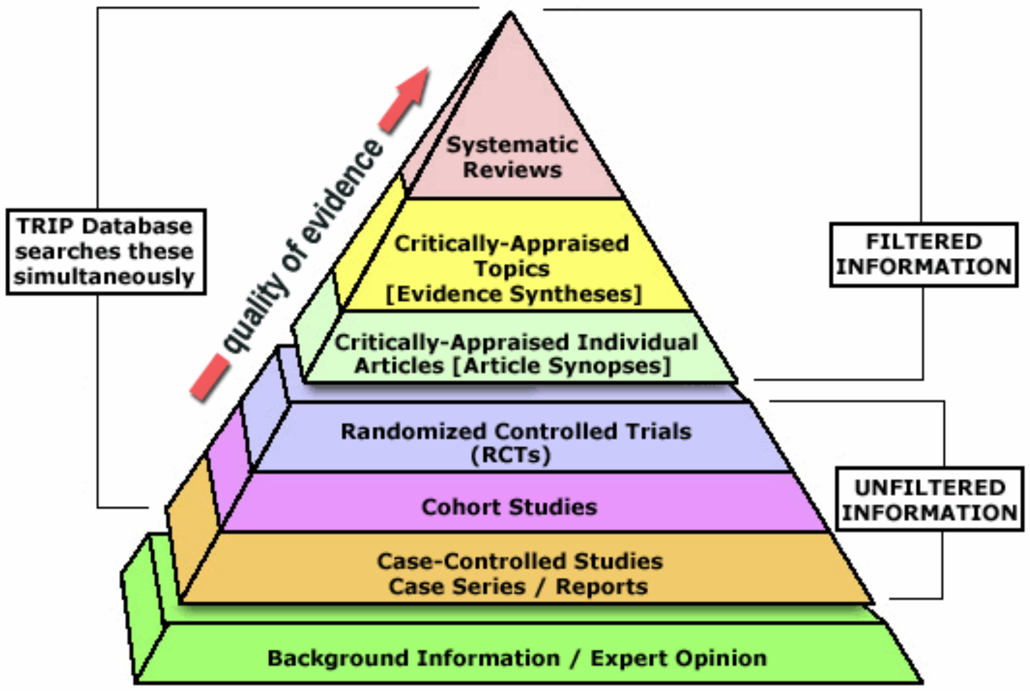
On EBP in Voice Tx

(from discussions & presentations by Scherer, Sataloff, Verdolini)

- Evidence for much of voice Tx does not yet meet rigorous requirements for evidenced-based Tx; however, as clinical measures of vocal function and pt-reported outcomes are validated & applied to programs of Tx it is expected that the effectiveness and efficiency of appropriate voice Tx will be demonstrated
- The 3 “principles” of (1) research, (2) practitioner expertise, and (3) client preference and values (ASHA Leader, October, 2014, page 28) are important. But one must understand what “research” means in the context of voice therapy.
- “Research” certainly should mean that the specific therapy approaches you wish to consider have been studied, or that the problem you face with your client gives rise to numerous therapy approaches that have been studied.

On EBP in Voice Tx

- However, in voice therapy, more important is that the research has explained the relationships among phonation production variables.
- That is, when you are confronted with a problem in voice production, what do basic studies of phonation tell you about that issue and about how to change your client's phonatory behavior to improve voice production?



On EBP in Voice Tx

- It’s not the therapy package itself, it’s what’s inside the package that addresses the physiological reality which should be addressed.
- “In the near future, we will want to make sure clinicians are well trained in the basic principles of packaged therapies – not only in the ‘step-by-step instructions -- and thus equipped to be flexible with them. Packaged therapies should be delivered with an understanding of underlying principles.” (-K. Verdolini, Voice Tx Conference, c. 2015)

Summary

Evidence suggests that utilizing SOVTEs should:

1. Reduce transglottal pressure by increasing intraoral pressure;
2. Increase inertance of the vocal tract (an optimal condition is an impedance matching between the glottis and the entryway to the vocal tract);
3. Facilitate voice onset by lowering PTP and increasing overall PTP range;
4. Reinforce vocal fold vibration by feeding energy back into the glottis via proper phasing of acoustic pressures within the vocal tract due to resonance (i.e., velocities between supraglottal pressure and airflow are in-phase);
5. Facilitate resonance that may be associated with increasing sensory feedback sensations;
6. Presumably reduce the risk of phonotrauma by minimizing vocal fold impact forces during phonation and increasing vocal economy (i.e., higher SPL with lower vocal fold impact stress);
7. Promote "optimal" adduction that is neither pressed nor breathy such as that achieved in "resonant voice";
8. Change vocal quality in such a way that the resultant sound is perceived to be "clearer", "brighter", and/or "more sonorous" by both vocalist and/or the listener; and, in some cases,
9. Widen the pharynx as related to the epilarynx yielding a clustering of F3-F5 known as the "singer's formant" or "speaker's formant", and
10. Facilitate respiratory/breath "support" during vocal warm-up

(Guzman et al., 2013; Laukkanen et al., 1996, 2012; Story et al., 2000; Titze, 1988, 1996, 2001, 2006; Vampola, et al., 2011; Verdolini et al., 1998).

Summary

- **SOVTEs are certainly not a panacea. Much is still unknown about fluid-structure-acoustic interaction.**
  - While doing these exercises don't forget about other aspects that impact voice (e.g., posture, breath management, adduction, subglottal pressure, respiratory-phonatory coordination)
- They are simply another tool in your arsenal to be used judiciously when appropriate
  - Evidence indicates that appropriate situations might include the following…
- Clinicians should have knowledge of basic vocal function and how an intervention alters aspects of vocal production in order to optimize client care.

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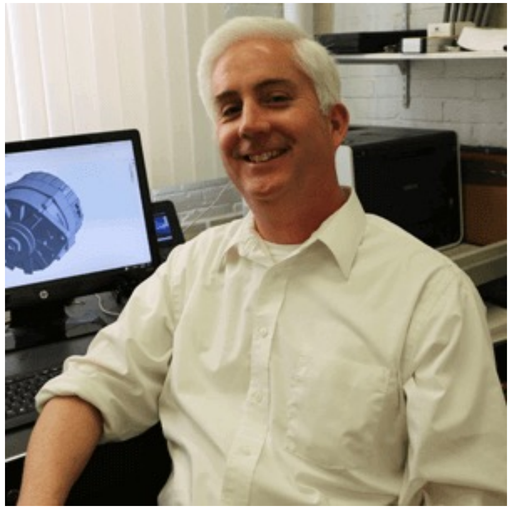
Acknowledgements

- UMaine Voice Lab Group:
  - Calder Levine, UMaine CSD grad student
  - Aurora Hodgdon, UMaine CSD undergrad student
  - Audrey Young, UMaine CSD undergrad student

- Stephen Abbadessa, Crosby Laboratory Manager, Mechanical Engineering Dept., Umaine



No financial interests to disclose

Thank you!

Questions &/or comments?