An Experimentally Validated Model of Phonation-Induced Aerosolization

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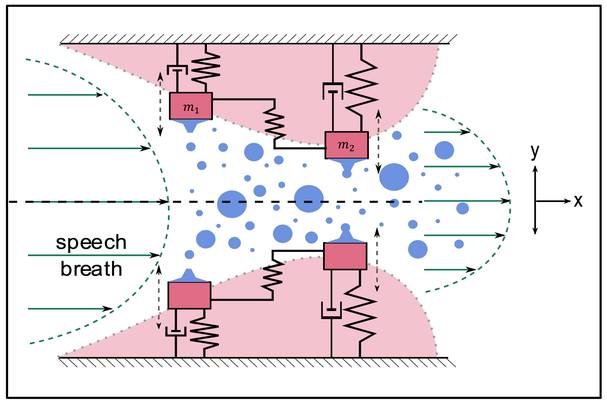
Vibration-Induced Atomization Model



Two-mass Vocal Fold Oscillation Model [2]

$$\begin{cases} m_1\ddot{x}_1 + \beta_1\dot{x}_1 + k_1x_1 + \hat{k}_{ij}(x_1 - x_2) = f_1 \\ m_2\ddot{x}_2 + \beta_2\dot{x}_2 + k_2x_2 + \hat{k}_{ij}(x_2 - x_1) = f_2 \end{cases}$$

Vibration-Induced Droplet Ejection Model [3]

$$m_i = f(m_{i,t}, \overline{m_i})$$

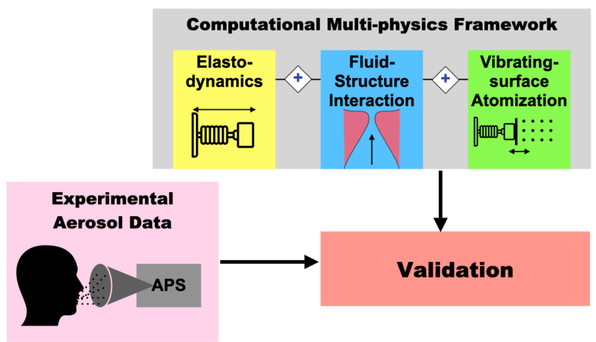
$$\dot{\bar{m}}_i = \begin{cases} 0, & \ddot{x} \le a_c \\ -r(\ddot{x} - a_c), & \ddot{x} > a_c \end{cases}$$

$$m_1 \ge m_2$$

Highlights

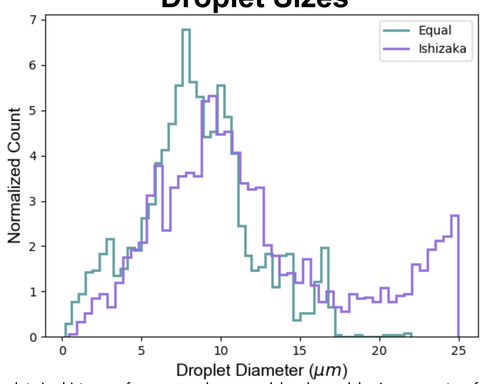
- Exhaled aerosols originate in three locations: the lungs, the larynx, and the mouth.
- Vocal-fold oscillation models eject aerosol particles from 0 – 35 μm diameter.
- **Geometry Matters:** mass, stiffness, and damping of the tissue affect the ejection process.
- ***Validation is important but difficult…***

Aerosolization Framework



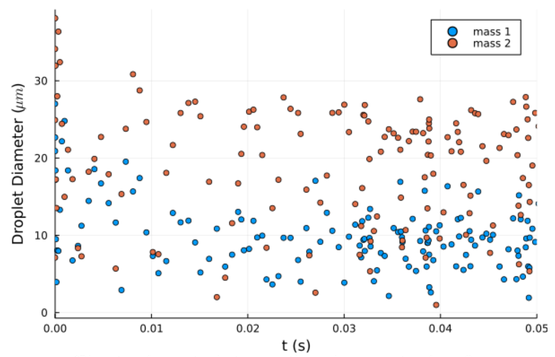
Model Results

Droplet Sizes



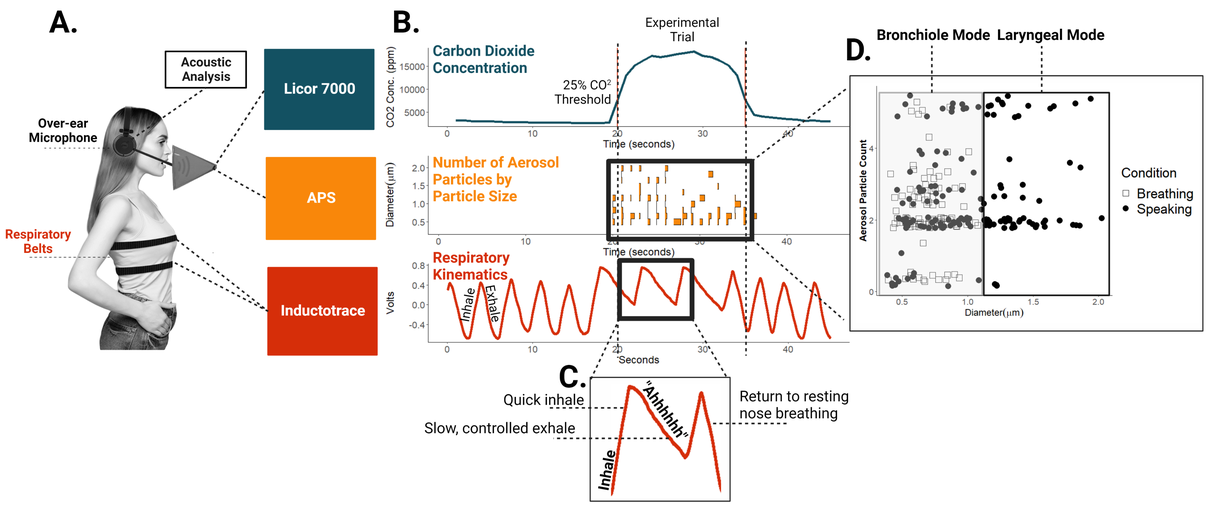
*Droplet size histogram from an equal mass model and a model using parameters from [2].

Droplets Ejected over Time

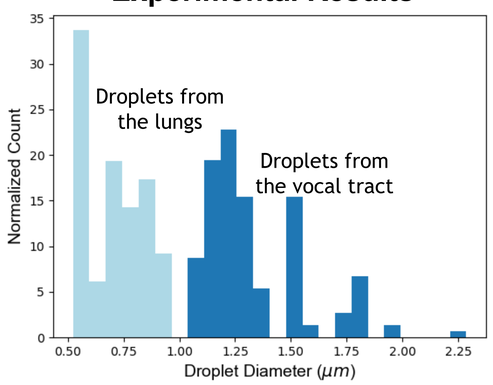


*Diameter of droplets ejected over time using parameters from [2].

Experimental Validation



Experimental Results



While the model yields larger droplets than we see in the experimental results, the model appears to predict the approximate range of droplet sizes we see during experimental phonatory tasks. We expect the larger droplets (>5 μm) projected in the model will deposit out or undergo secondary breakup within the downstream vocal tract, which is omitted from the current model.

Approach

- Evaluate sizes of particles emitted during various phonation tasks (e.g., modal voicing).
- Subtract off respiratory droplets.
- Compare the histograms of the particles emitted during phonation to the model output.
- ***Challenges***:
  - No filtration, deposition, and secondary breakup of particles through the vocal tract.
  - Computational model is not patient-specific.

Conclusions & Next Steps

This computational aerosolization framework is a first step toward understanding the physics of aerosol generation during phonation. The vibration-induced atomization model estimates oscillation accelerations that are sufficient to eject droplets off the surface of the mucosal layer. However, the model's droplet sizes appear to be highly sensitive to geometric parameterization. Parameter tuning and validation remain key challenges in this work. We will extend this computational framework to a multi-mass oscillatory system, adding in unsteady fluids forcing and fluid-structure interaction. We will also validate this approach further by comparing our histogram outputs with experimental aerosol data collected with an aerosol particle sizer during speech trials.

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2. Ishizaka, K. & Flanagan, J. L. Synthesis of Voiced Sounds From a Two-Mass Model of the Vocal Cords. Bell System Technical Journal 51, 1233–1268 (1972).
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