Measurements of phonatory power flows and efficiencies in a human airway phantom

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Introduction

We present empirical characterization of phonation power flows and efficiencies for three distinct regions of a human airway phantom: the larynx, the vocal tract, and the combination of larynx and vocal tract. A control volume power flow formulation [1], which identified inputs, outputs and losses in terms of joint statistics between volume flow and pressure, guided the measurements. New results include refinements to the efficiency measures, showing an explicit relation to laryngeal resistance, and showing how previously presented measures of efficiency [] are incorporated into the current formulation. The measurements presented here are used to estimate the terms in the energy equation for the larynx, the vocal tract and the system composed of their combination. From these estimates the efficiencies are also estimated.

Methods

Refinements of a previous mechanical energy equation analysis [1] are presented. These refinements consist of cycle-averaging and incorporating features such as mean laryngeal flow resistance. In addition the importance of volume flow-pressure covariances is highlighted. The terms of the resulting averaged equations represent power flows to or form the region in question, the direction of the power flow being given by its sign. The terms in this formulation were estimated from measurements. In addition, the ratio of average output to average input power flow was taken as the definition of efficiency for each region.

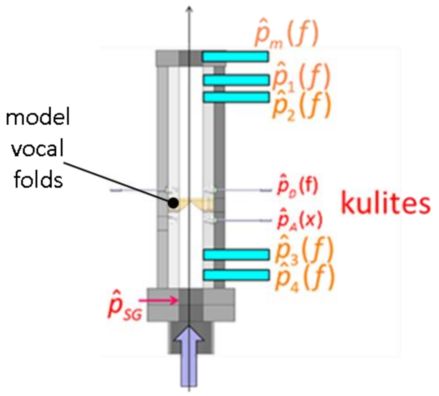

Figure 1: Schematic of Penn State Upper Airway model. Locations of pressure measurements shown – 5 microphones to measure sound pressure and 2 kulite XCS-093 pressure transducers to measure transglottal pressure difference. A high-speed camera (not shown) is used to capture vocal fold motion.

Measurements were performed in the Penn State Upper Airway phantom [1-3], shown in Figure 1. Air was supplied from a compressed air source through a 7.62cm diameter tygon tube. Upstream of this tube a thermal flow meter was installed to measure average air mass flow. The tygon tube connected to the airway phantom, which has a 2.54cm square cross section, with a trachea section of length 10cm, a vocal tract section of length 17.3, and a larynx section containing multilayer rubber molded vocal folds with a swept-ellipse section. Pressure measurements were performed in the airway phantom: microphones at the mouth opening, a pair of microphones near the mouth opening, and another microphone pair near the trachea entrance. In addition, two Kulite pressure transducers were installed, one just upstream and the other just downstream of the model vocal folds, to measure the transglottal pressure difference. The microphone pairs were used to estimate the right- and left-running wave pressures and velocities associated with the acoustic field. These were then used to estimate the relevant variances and covariances that appear in the power flows and efficiencies from the auto- and cross-spectra estimated from the microphone pair measurements.

Results

Measurements were conducted for two vocal fold models that exhibit different vibration patterns. The first of these is a pair of identical three-layer rubber vocal folds, and exhibits a periodic and the second is composed of model vocal fold of this same type and one composed of a single layer. This setup results in two folds with different vertical stiffness, resulting in a quasiperiodic vibration pattern with reduced sound production.

The pressure measurements are used to estimate power flows and efficiencies as described above. A particular result concerns the importance of pressure-volume flow covariances at the laryngeal inlet and outlet.

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References

[1] Krane et al, Proc. of 11th ICVPB, E. Lansing, MI, 2018.

[2] Schutte, H. The efficiency of voice production. PhD diss. 1980.

[3] Isshiki, N. Vocal fold physiology, 193-203, 1981.

[4] Titze, et al., J. Voice, 30(4) 398-406, 2015.

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[5] Campo, L. MS Thesis, Penn State Univ., 2012.
[6] McPhail, et al *JASA* 146(2) 1230-1238, 2019.

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