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FLOW-INDUCED OSCILLATIONS OF A VOCAL-FOLD REPLICA WITH TAILORED ANTERIOR-POSTERIOR AND MEDIAL-LATERAL ARTICULATIONS

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Abstract:

Objectives / Introduction:

In the past two decades, *in vitro* studies of human phonation have shifted from static or controlled oscillations to self-oscillating bio/phono-mimetic replicas, yielding promising results (1–5). Artificial vocal folds have high availability, affordability, and they can be reused during an extended period of time. Moreover, control and access to the vibration and airflow parameters is made easier. Finally, they are essential to better evaluate and link together the results that come from theoretical and numerical models (2). However, they are generally still far from representing the physiological reality of human vocal folds. Besides, few studies have focused on varying either the mechanical properties of the chosen material or the pre-phonatory strain applied to the replica to better understand their influence on its vibratory properties. In particular, only four studies have investigated the impact of changing the vocal-fold anterior-posterior strain condition (ϵ_{ap}) on fundamental frequency of oscillation (f_0), and on subglottal pressure-airflow relationship (4–7). Owaki *et al.* (7) used a rubber model of vocal folds to measure the impact of material stiffness and elongation. Shaw *et al.* (6) compared silicone-based vocal-fold models with and without embedded fibers, highlighting the impact of material anisotropy on strain-induced variations in f_0 and pressure onset (P_{on}). Tur *et al.* (4) designed a multilayer fiber-reinforced silicone model as a close representation of human vocal folds, exploring the effects of changing diameter, resistance and tension of the ligament fibers, which resulted in a very promising frequency range of 200-520 Hz. Finally, Luizard *et al.* (5) developed an extensible vocal-fold replica with tunable material properties (using silicones or gelatin-based hydrogels), and evidenced a relationship between f_0 and fold stiffness. Yet, the range of f_0 was much lower than expected for human speech, and it did not vary much with longitudinal elongation, calling for further investigation.

In this paper, we present an improved version of the testbed developed in Luizard *et al.* (5), allowing both anterior-posterior elongation and medial-lateral compression. Flow-induced oscillations were characterized on a homogeneous silicone model with varying longitudinal and lateral strain conditions, and airflow rate.

Methods:



Figure 1: (a) Vocal folds and the 3D-printed inner mold, (b) Applied pre-strains, (c) General view of the testbed

Vocal fold replica. An existing articulated larynx testbed with folds actuation in longitudinal stretching was used as a starting block (5). Improvements were made on the artificial larynx and its actuation in lateral compression. Laryngeal envelope and vocal folds were molded into a single block of homogeneous silicone rubber of shore hardness 00-30. The folds' length at rest was 12mm and their thickness was 1.5mm. Their geometry was inspired from M5 models (8), corresponding to a simplified two-circle version of Microvoice model (5).

Vibroacoustic characterization. The laryngeal replica was loaded by adjustable strains in the anterior-posterior direction (ϵ_{ap}) and medio-lateral one (ϵ_{ml}). Airflow rate (ϕ) was controlled by means of an electromechanical valve actuator, as in (5). Several parameters characterizing the oscillatory behavior were measured: subglottal pressure (P_{sg}), fundamental frequency of oscillation (f_0), sound pressure level (SPL).

Results:

As shown in Figure 2a, an increase of 0.30 in longitudinal strain ϵ_{ap} results in an increase of 40 Hz in fundamental frequency f_0 of oscillation within the whole airflow range. This qualitative trend is consistent with (4, 6) in case of fiber-reinforced folds. Previous vocal-fold models with homogeneous and isotropic material properties such as those used in (5, 6) did not show an increase in frequency f_0 with the applied anterior-posterior pre-strain.

For a given pre-strain, varying the mean airflow rate has minimal effect on f_0 , which varies at most in the range of 10 Hz, consistent with (5).

As evidenced in Figure 2b, the mean subglottal pressure increases non-linearly with the mean airflow rate ϕ up to 2L/s (depending on the pre-strain level), then reaching a stable state. On the other hand, pressure decreases with increasing pre-strain, contrary to (4,5) but in line with (6) who found a decreasing onset pressure with increasing length for linear models.

These discrepancies between previous articulated larynx testbeds are attributed to the critical role played by the boundary conditions applied to the folds, which differ particularly in the medial-lateral and inferior-superior directions.

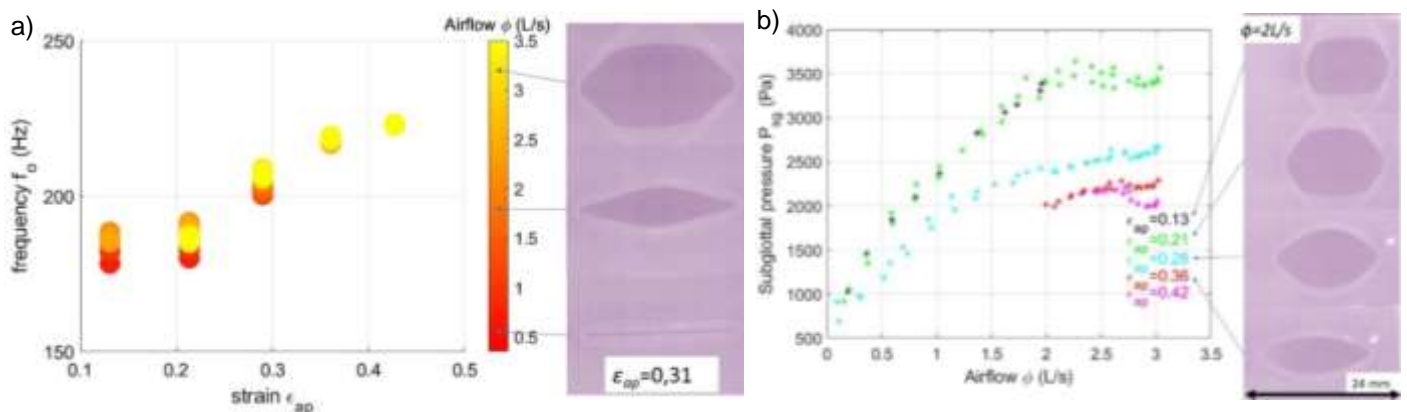


Figure 2: (a) Relationship between fundamental frequency f_0 and anterior-posterior strain ϵ_{ap} , colored by values of mean airflow rate ϕ . (b) Relationship between mean subglottal pressure P_{sg} and ϕ , colored by strain ϵ_{ap} . Fold's snips correspond to maximum glottal apertures.

Conclusions:

This study introduces an articulated *in vitro* larynx testbed, allowing a quantitative control over both anterior-posterior pre-elongation and medial-lateral pre-compression. These developments show encouraging results on the f_0 -variations obtained by activating such articulations, while demonstrating the importance of boundary conditions for accurate replication of previous aero-acoustic results.

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