Constriction modes and acoustic output in an in-vitro self-oscillating vocal-fold model

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Constriction modes and acoustic output in an in-vitro self-oscillating vocal-fold model

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An ultrahigh speed camera is used to characterize the dynamics of the cross-sectional areas defined by a self-oscillating vocal-fold latex model in correlation with the synchronically registered acoustic output. The design of the vocal-fold model has been thouroughly tested to study voice production in previous works. The aim of the setup in this study is to assess the acoustic relevance of the spatial modes of the effective glottal aperture, when certain control parameters of the experiment are varied, such as subglottal pressure, airflow density, or vocal-fold mechanical characteristics.

1 Introduction

Voiced sounds in human speech are produced by the pulsatile flow generated during the self-sustained oscillations of the vocal folds. An *in vivo* endoscopic view of the glottal aperture in motion is possible using high speed glottography (HSG). This technique allows an analysis of the vocal fold dynamics in the plane defined by the left-right (LR) and the anterior-posterior (AP) directions, while inferior-superior (IS) vibration modes remain masked by the upper vocal fold edges.

In normal phonation, the vocal folds are supposed to vibrate symmetrically in the LR-AP plane and as a whole, with vibrational nodes at the anterior and posterior commissures. For irregular vocal fold oscillations, the dynamics captured from an endoscopic view is enriched and longitudinal modes can be observed [1, 2].

Observation of irregular vocal fold oscillations using *in vitro* or *physical* self-oscillating models was reported in [3]. These mechanisms were nevertheless not disclosed in a standard acoustic spectrum.

In this study, we perform synchronised recordings of the acoustic output and of the glottal aperture for an *in vitro* model of self-oscillating “tunable” replica of the vocal folds. The design of the physical model has a long history: it was first used to study buzzing lips of the trombonist [4,5] and was then adapted to study the vocal folds [6,7].

Our recordings show that both regular and irregular vibrations can be excited in the structures representing the folds, as control parameters are varied.

A simplified (plane) representation of the excitation of different oscillation modes in the synthetic vocal folds is obtained examining the associated spatial modes of the glottal aperture, as in the case of HSG for *in vivo* measurements. The ultrahigh digital sequences that we obtain allow an accurate measurement of the evolution of the glottal aperture.

The study is performed *in vacuo*, *i.e.* without fixing a dowstream resonator on the replica, with the aim of inspecting the acoustic correlate of the excitation of these constriction modes in the audio signals.

2 Experimental setup

Our experimental setup consists of a pneumatic circuit that feeds a replica of the larynx. The replica is constructed following the physical model used in [7]. It is made of metal pieces covered with latex and filled with water under pressure. Water pressure is controlled by an independent reservoir. Air pressure is controlled by the pneumatic system, which ends up in a circular-section tube representing the trachea. With control over water pressure, one can change the replica’s mechanical characteristics and therefore its natural frequency. Unlike in [5], the variations of the constriction aperture are measured with an ultrahigh speed camera.

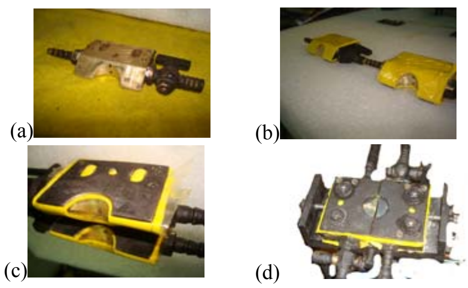

Figure 1 : Mounting the self-oscillating valve for the experiment: (a) bronze block with suply channels, (b) latex half mounted, (c) mounted latex on the two blocks, (d) endoscopic view of the mounted replica.

3 Constriction modes

We report results for an arbitrary set of values of upstream air pressure (ranging between 85-1080 mmH_2O) and water pressures (ranging between 23-560 mmH_2O). Synchronisation of the ultrahigh digital imaging and audio output is illustrated in figure 2. Even if a systematically performed parametric study is pending, the sampled parameters suffice to show that different longitudinal modes (in the LR-AP plane) can be excited in the replica. In the inspected ranges we have been able to excite the first three constriction modes: the equivalent to the normal phonation mode or mode 0, with zero nodes between the anterior and posterior commisures, a mode 1 with one node in the center of the glottis, and a mode 2 with two nodes evently distributed along the glottal length.

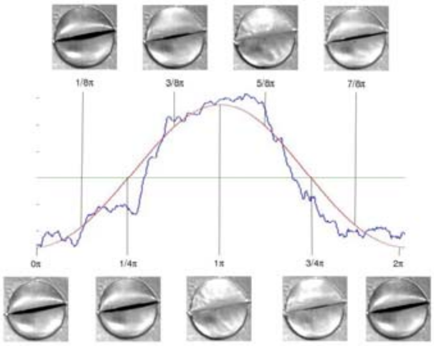

Figure 2 : Synchronic measurement of acoustic output and ultrahigh digital frames of the self-oscillating water-filled latex valve representing the vocal folds.

In order to illustrate the excitation these modes and the different type of spectra of the associated acoustic signal, consider figures 3 and 4. Figure 3 shows frames corresponding to a maximum glottal aperture as the latex folds oscillate for the following parameter values of air and water pressure: (a) 860 mmH_2O, 140 mmH_2O, (b) 435 mmH_2O, 560 mmH_2O, (c) 920 mmH_2O, 480 mmH_2O. It is worth noting that in (b), the node is stable during the oscillations since the latex folds remain in contact in this point while vibrating. This is not the case in (c). High water pressures are necessary to excite modes 1 and 2.

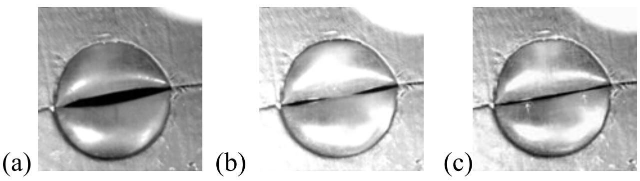

Figure 3 : Excitation of constriction modes with 0, 1 and 2 nodes between the anterior and posterior commissures of the vocal fold artificial valve.

The acoustic output of the examples of figure 3 are shown in figure 4. A Fast Fourier Transform is computed for each of the signals. If sound recordings are performed *in vacuo*, the spectrum may help infer how the valve is vibrating. For mode 0 vibrations, we systematically observe a spectrum which spans between 0 and 1000 Hz, with exponentially decreasing amplitudes for the harmonics in the spectra. For mode 1 vibrations, the fundamental frequency jumps to value which approximately doubles that of mode 0, and the harmonics in the spectrum present a broadband modulation around the peak of about 1250 Hz. The fundamental frequency of mode 2 is close to that of mode 1 but the spectrum is characterized by low amplitud peaks which were absent in the previous cases.

Combination of these three modes are also observed. In some cases, the valve opens in mode 0 and closes in mode 1 (1030 mmH_2O, 265 mmH_2O), or opens in mode 1 and closes in mode 2 (920 mmH_2O, 560 mmH_2O).

Irregular vibration can also occur. Figure 5 shows two frames belonging to two different measurements in which there are asymetries in the LR and the AP directions.

The valve has also been used in heliox experiments. For identical air and water pressures, lowering the airflow density produces oscillations with larger maximum glottal apertures. The onset of oscillations is also eased by heliox.

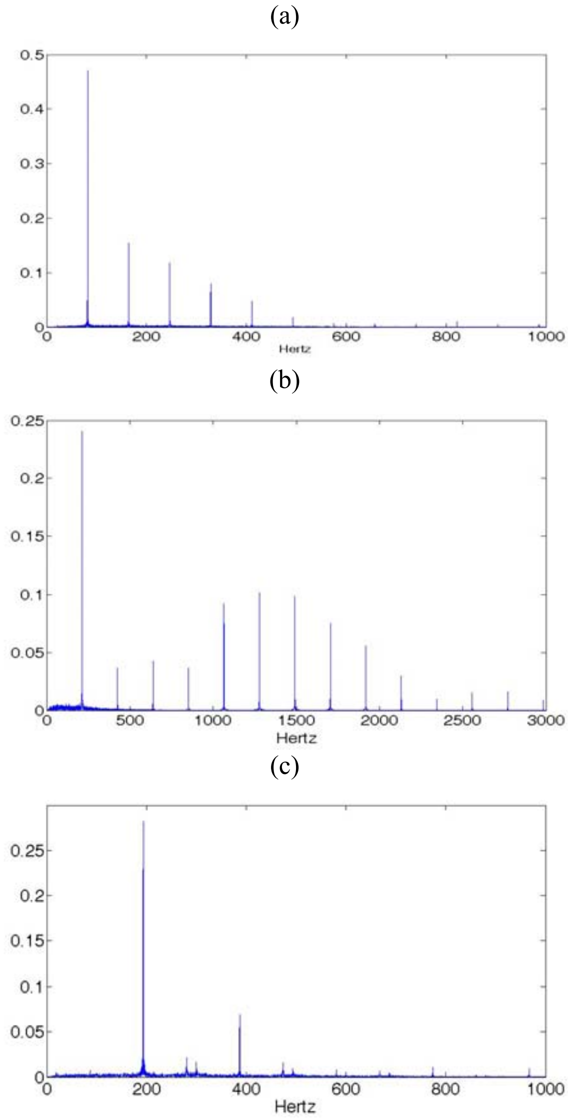

Figure 4 : Spetra of the acoustic signal recorded for the examples shown in figure 3 (a-b-c).

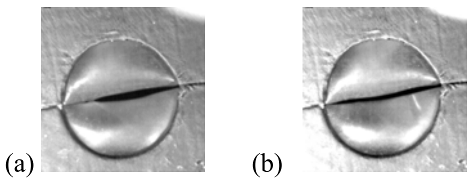

Figure 5 : Irregular vibration with asymetries in the Anterior-Posterior direction (a) and in the Left-Right direction (b).

4 Conclusions

We use ultra-high speed imaging to characterize the constriction modes of an *in vitro* self-oscillating model which has been used in the literature to study both, lip buzzing and human phonation. In this model the vocal folds are represented by two latex cavities filled with water under pressure. Airflow density, upstream air pressure and water pressure in the folds can be varied.

We report the observation of three main longitudinal modes of vibration of the vocal folds in the plane defined by the left-right and the anterior-posterior directions, in the absence of a downstream resonator. Each of these modes is characterized by an acoustic spectrum with different features. Desynchronisation of the vibrational modes is also found to occur for certain parameter values. A systematic study in terms of the three control parameters and a modal analysis of the constriction modes make part of our work in progress.

Acknowledgments

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