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What happens when a self-oscillating vocal-folds replica phonate into a straw?

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Introduction

Vocal exercises using semi-occluded vocal tract, such as phonating into a straw, are commonly used in voice training and therapy (Titze, 2006). The technique of phonation-into-straw is even investigated as a possible way to measure phonation threshold pressure (Titze, 2009), or to map the voice similarly to the voice range profile (Titze and Hunter, 2011).

Several physiological aspects of these techniques have been studied on human subjects, such as the impact on laryngeal muscle activity and glottal adduction (Laukkanen et al., 2008), the articulatory and acoustical adjustments (Vampola et al., 2011; Laukkanen et al., 2012). Understanding the physics of phonation into straw is complex, as human subjects do adapt their vocal gesture to the phonatory situation. What would happen in the case of a self-oscillating vocal-folds replica coupled to a vocal-tract tube, when the tube end is semi-occluded with a straw? The purpose of this paper is to investigate such a situation, and bring complementary understanding of phonation-into-straw.

Method

The experimental set-up is a simplified replica of human vocal apparatus, designed for its physical relevance to human phonation (Ruty et al., 2007). It is constituted of a pressure reservoir (lung replica) attached by a tracheal tube to a self-oscillating vocal-folds replica. The laryngeal replica is connected to a 17cm cylindrical Plexiglas tube (vocal-tract replica). The vocal-tract tube is either left open at its end, or it can be occluded by a straw mounted on a plate. Three straws have been used, similar in length (15cm) but different in diameter (5mm, 6.5mm and 9.5 mm). The self-oscillating vocal-folds replica was made of latex filled with water. Both the air pressure upstream the replica (subglottal pressure) and the water pressure within the replica (internal pressure) could be controlled. They were gradually varied by the experimenter.

Results

For the range of internal water pressure studied here, the replica was able to oscillate in all cases. The air pressure necessary for oscillation was greater for the smallest straw diameter (range 1.5-2.5 kPa) and smaller for the biggest one (0.5-1 kPa) than for the open-tube configuration. In the open-tube case, the fundamental frequency of the vocal-folds replica increased linearly from 145 Hz to 200 Hz with increasing internal water pressure. At a fixed internal water pressure, a frequency drop was observed when the vocal-tract tube was partially occluded with the straw, ranging from 20Hz to 60Hz and depending on the straw diameter.

Discussion

As shown by Bailly et al. (2008), a vocal-tract constriction can either facilitate or impede glottal vibrations. In this experiment, the constriction due to the 9.5mm straw seems to facilitate the replica's vibrations (less subglottal pressure required than in the open-tube case), whereas the 5mm- and 6.5mm-straw constrictions impede them (greater subglottal pressure required). In the case of this replica, the fundamental frequency of oscillation does not depend only on its own stiffness (internal water pressure), but also on the laryngeal aerodynamics.

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