The Flow and Pressure Relationships in Different Tubes Commonly Used for Semi-occluded Vocal Tract Exercises

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Summary: This experimental study investigated the back pressure (P_{back}) versus flow (U) relationship for 10 different tubes commonly used for semi-occluded vocal tract exercises, that is, eight straws of different lengths and diameters, a resonance tube, and a silicone tube similar to a Lax Vox tube. All tubes were assessed with the free end in air. The resonance tube and silicone tube were further assessed with the free end under water at the depths from 1 to 7 cm in steps of 1 cm. The results showed that relative changes in the diameter of straws affect P_{back} considerably more compared with the same amount of relative change in length. Additionally, once tubes are submerged into water, P_{back} needs to overcome the pressure generated by the water depth before flow can start. Under this condition, only a small increase in P_{back} was observed as the flow was increased. Therefore, the wider tubes submerged into water produced an almost constant P_{back} determined by the water depth, whereas the thinner straws in air produced relatively large changes to P_{back} as flow was changed. These differences may be taken advantage of when customizing exercises for different users and diagnoses and optimizing the therapy outcome.

Key Words: Semi-occluded vocal tract exercises–Straw–Resonance tube–Lax Vox tube–Voice therapy–Flow–Pressure–Back pressure.

INTRODUCTION

Voice exercises with a semi-occluded vocal tract are widely used in voice therapy and training. The semi-occlusions can be achieved by constricting the vocal tract, for example, when phonating into different types of tubes or straws,[1] using lip[2] and tongue trills,[3] or the so-called hand-over-mouth technique.[4,5] Semi-occluded vocal tract exercises (SOVTEs) differ by the type and level of occlusion applied to the vocal tract. Trills presenting an oscillatory semi-occlusion have been used in voice therapy for centuries to improve voice quality.[2] The hand-over-mouth technique adds a large resistance caused by the constriction of the hand, only allowing a small passage for the air between the fingers.[4] Tubes and straws varying in length, diameter, and material elongate the vocal tract, thus changing its acoustics and resistance.[1]

Phonation into tubes can be carried out keeping the free end of the tube in air or water. The method of phonating into tubes submerged into water was first described by Sovijärvi in the 1960s. He developed the so-called resonance tube method[6] using glass tubes submerged into a bowl of water. The method has been further developed by voice clinicians, and the most common exercise is to phonate through the tube while keeping the free end submerged 1–2 cm below the water surface.[7] An alternative technique is the Lax Vox technique, which has been used since the 1990s and in which phonation is performed into a silicone tube in a water bottle.[8] Recent research shows that a major feature provided by these exercises consists of the fact that submerging the tube end into water causes an intraoral pressure modulation produced by the bubbling of the water.[9,10]

Because of the positive clinical experiences with SOVTE, an interest for scientific explanations on the mechanics and acoustics of the methods has emerged. Theoretical studies using computer models have shown effects of different types of semi-occlusions on the impedance and reactance of the vocal tract.[1,11–14] In addition, studies with human subjects have found effects of SOVTE on muscle contraction in the vocal tract[13] and vocal tract configuration,[14–17] that is, lowering of the vertical larynx position, widening of the pharynx, and narrowing of the aryepiglottic opening.

A common characteristic of SOVTE is the static component of the intraoral pressure produced by the vocal tract semi-occlusion. In some cases, an oscillatory component is introduced by a secondary source. On the basis of this idea, SOVTEs were classified into two groups according to the number of vibratory sources in the vocal tract: single source (eg, straw phonation) and dual source (eg, tubes in water or lip trills).[18] Exercises with a dual source of vibration showed modulation of the vocal fold vibrations and were associated with the massage effect.[18,19] Another SOVTE classification was further suggested in which a series of SOVTE was rank ordered based on the intraoral pressure levels produced by each SOVTE.[20]

Although great progress has been made toward better describing the differences among SOVTE, little is known about the influences of volume flow (U) on the oral pressure produced by SOVTE that make use of phonation into tubes. Nevertheless, both static and oscillatory components are dependent on flow.

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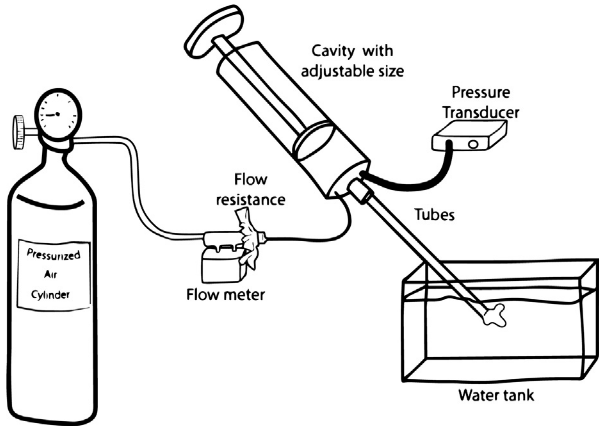

FIGURE 1. Flow-driven vocal tract simulator.

The purpose of this study was to investigate the static back pressure (P_{back}); analogous to the intraoral pressure; and the U relationship for different tubes commonly used for voice therapy and training with SOVTE.

METHODS

Setup

A flow-driven vocal tract simulator was used to collect data on P_{back} and U for different tubes (Figure 1). The vocal tract simulator setup consisted of a pressurized air cylinder, connected via a flow resistance to a cavity with an adjustable size (large syringe) with an outlet for tube connection (Figure 2).

The pressure difference between the cavity and the surrounding air, that is, P_{back}, was measured using a differential pressure transducer 8-SOP MPXV7007DP-ND, Freescale Semiconductor, Petaling Jaya Malaysia. A second identical pressure transducer was connected to a Fleisch pneumotachograph to measure the flow through the system. After the flow meter, an additional flow resistance was added which consisted of a piece of fabric. The pressure upstream from the pneumotachograph was manually controlled by a pressure regulator.

In most cases, as the resistance of the fabric was much larger than the resistance of any of the tested tubes, the flow was largely determined by the upstream pressure and the resistance of the fabric, that is, the setup generated a flow that was largely independent of the tube resistance. This setup, produced a flow free from oscillation which is advantageous as it allows for a reliable detection of the flow-pressure profile for each of the tubes used in the study. Also, the large resistance and the constant-flow property effectively created a well-defined system isolating the tube and back cavity from the upstream part of the setup. The syringe's piston was set to 1 cm away from the outlet creating a cavity of approximately 36 cm^3 in volume. This volume was selected on the basis of published data for the volume of the vocal tract using computer tomography images.[14] To make the back volume well defined, the additional flow resistance was connected after the flow meter; otherwise, the dead volume of the flow meter might have influenced the effective volume of the back cavity. However, this arrangement introduced a systematic error because of the fact that the air expands after the flow resistance giving a slightly higher flow than that was registered in the flow meter. A calibration procedure was therefore applied, during which the actual flow was measured with a rotameter connected to the outlet of the simulator and related to the flow that was registered by the flow meter. All measurements were compensated for the deviations that were found.

Pressure calibration was performed before measurements using a syringe and a U-tube manometer. The flow meter was calibrated without the flow resistance before data collection using a pneumotach calibration unit MCU-4 (Glottal Enterprise Syracuse, NY, USA).

Recordings and analyses

The data were recorded using the Soundswell Signal Workstation Version 4.00 Build 4003 (Core 4.0, Hitech Development AB, Sweden) with an analog library SwellDSP 4.00 and DSP card LSI PC/C32. Three channels, audio, P_{back}, and U, were recorded at a sampling rate of 16 kHz per channel. The audio signal was recorded for documentation purposes only and was not further analyzed. The P_{back} and U signals were later downsampled to 5 Hz using the *Sopran* software program (Tolvan Data 2009-2014 Version 1.0.5; Tyresö, Sweden) and were further analyzed using *MATLAB* (Mathworks version 7.10.0.499 [R2010a]). The downsampling procedure reduced the amount of data and also effectively removed any frequencies above 2.5 Hz, thus reducing the pressure oscillations induced by water bubbles.

Experiment

Altogether, 10 tubes were used in this study to represent the SOVTE. Seven straws commonly used in therapy with different lengths and diameters (Table 1); a 26-cm-long resonance tube (glass) with a 9-mm inner diameter and a 35-cm-long silicone

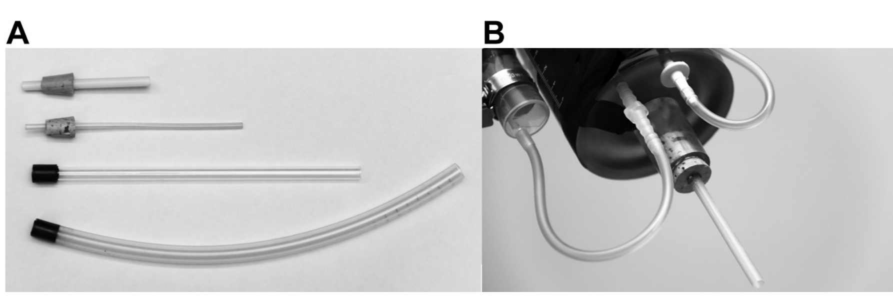

FIGURE 2. Flow-driven vocal tract simulator attachments. (**A**) Examples of straws and tubes used in the experiments, from *top* to *bottom*: a 10 cm ∅7 mm straw, a 15 cm ∅3 mm straw, a 26 cm ∅9 mm resonance tube, and a 35 cm ∅10 mm silicone tube. (**B**) A 10 cm ∅5 mm straw in air connected to the flow-driven vocal tract simulator.