ACOUSTICAL LETTER

Lung model and head-shaped model with visible vocal tract as educational tools in acoustics

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1. Introduction

Recently, we have proposed physical models of the human vocal tract for demonstrating the basic mechanisms of speech production and confirmed their effectiveness as educational tools in acoustics [1–6]. Arai [1] replicated Chiba and Kajiyama's physical models of the human vocal tract on the basis of their measurement [7] and proposed a simple but powerful demonstration of vowel production using the cylinder-type and plate-type vocal-tract models with an electrolarynx or a whistle-type artificial larynx as a sound source. A driver unit of a horn speaker can also be used as a transducer to produce an arbitrary sound source. One can feed signals to the driver unit not only from an oscillator, but also from a computer using a digital/analog converter and an amplifier, so that any arbitrary signal can be a source signal. We have also showed Umeda and Teranishi's model [8] with several sound sources fed through a driver unit in pedagogical situations [9]. In this study, we extended our previously proposed physical models of the human vocal tract to the lung models and head-shaped models.

2. Lung models

The whistle-type artificial larynx requires airflow to produce sounds. The easiest way to provide airflow during a demonstration is to blow into the whistle-type larynx. Alternatively, bellows may be used. Bellows may be preferable, in order to avoid giving students the incorrect impression that a person is phonating a vowel rather than simply blowing into the device. In this sense, bellows are useful because they are not affected by or confused with the human anatomy.

To imitate the human respiratory system with a simple device, we adopted the functional lung and diaphragm models shown in Figs. 1 and 2. With this model, students can slowly pull the knob attached to the "diaphragm" (a rubber membrane covering the bottom of the cavity) to inflate the "lungs" (represented by two balloons). The two balloons are connected to a Y-shaped tube, which simulates the trachea. Lowering the diaphragm increases the volume of the thoracic cavity, thereby creating a negative pressure in the air inside the thoracic cavity. Air flows into the lungs to equalize the pressure inside the lungs with an atmospheric pressure, simulating inhalation. Pushing the diaphragm upward decreases the thoracic cavity volume, causing air to flow out of the lungs, simulating exhalation.

3. Head-shaped models

None of the models discussed thus far, such as Arai's models [1] and Umeda and Teranishi's model [8], seemed to help students visualize how the vocal tract is positioned in the head. In response to this need, we created another vocal tract model, shown in Fig. 3. This figure shows head-shaped models for /i/ and /a/. Each of these models is made from five acrylic plates. The center (black) plate is 1 cm thick and has a schematic midsaggital cross section for each vowel. On both sides of the center plate, there are two transparent 3-cm-thick plates. These plates have holes for achieving proper area functions for the vocal-tract configurations of the vowels /i/ and /a/, with nasal cavities. The outer-layered plates are 1 cm thick and also transparent; thus, the midsaggital cross section is visible from the outside. The velum is made of rubber and can be rotated around a pivot located at the boundary of the soft and hard palates. This movable velum acts as the velopharyngeal port and allows us to simulate nasal coupling. The velopharyngeal opening is controlled using the rotating valve.

4. Modification on vocal-tract models

We confirmed that the lung and head-shaped models are effective educational tools in pedagogical situations [10]; in this section, we propose further modification of the models.

4.1. Visualizing subglottal pressure with large lung model

The subglottal pressure is typically 6–10 cm H_2O in modal phonation. To visualize such pressure range appropriate for the proper functioning of the artificial larynx, we prepared a U-shaped tube. By mounting the U-shaped tube filled with the water to the thoracic cavity, as shown in Fig. 4, we can observe the vertical movement of the surface of the water corresponding to inhalation and exhalation as a result of equalizing the pressures inside and outside the balloons. Just as the subglottal pressure must be within a certain range for the vocal folds to vibrate, the pressure under the artificial larynx must be within a certain range for the rubber membrane of the whistle-type artificial larynx to vibrate. If the pressure is too weak, the membrane does not vibrate. If the pressure is too strong, the

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web video clips: http://www.splab.ee.sophia.ac.jp/Vocal_Tract_Model/

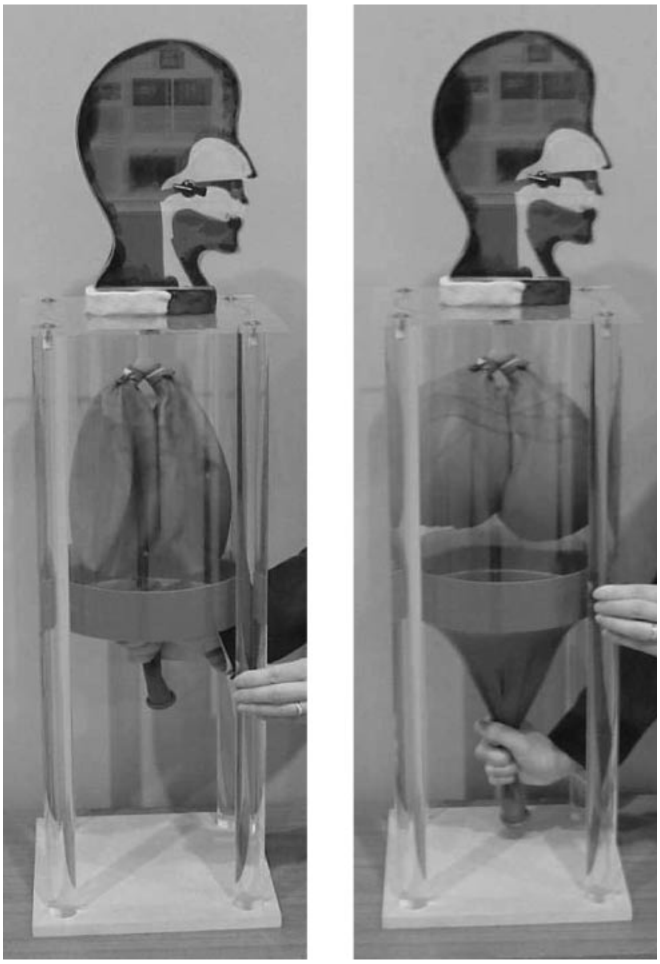

Fig. 1 Large lung models (exhalation on left-hand side and inhalation on right-hand side). The head-shaped models are set on the top of these large lung models.

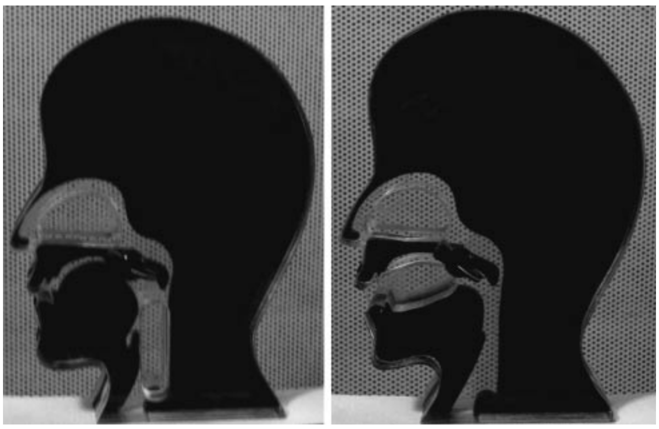

Fig. 3 Head-shaped models with vocal tract and simplified nasal passage: /i/ (left) and /a/ (right).

membrane stops vibrating. If we measure the height of the water column, such as h in Fig. 4, we know the pressure in cm H_2O. This height for the artificial larynx to stably vibrate is about within the range $h = 6$–$10\,\text{cm}$.

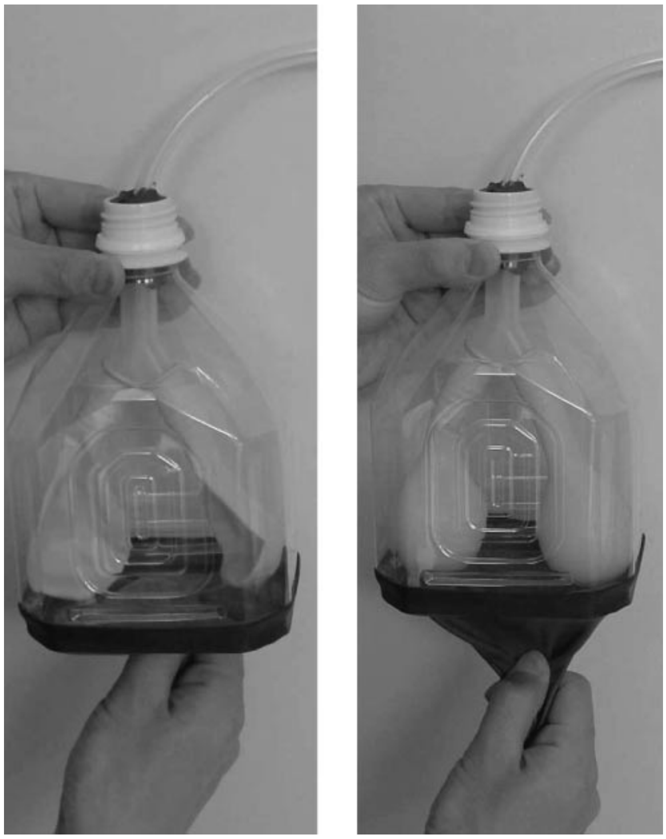

Fig. 2 Small lung models (exhalation on left-hand side and inhalation on right-hand side).

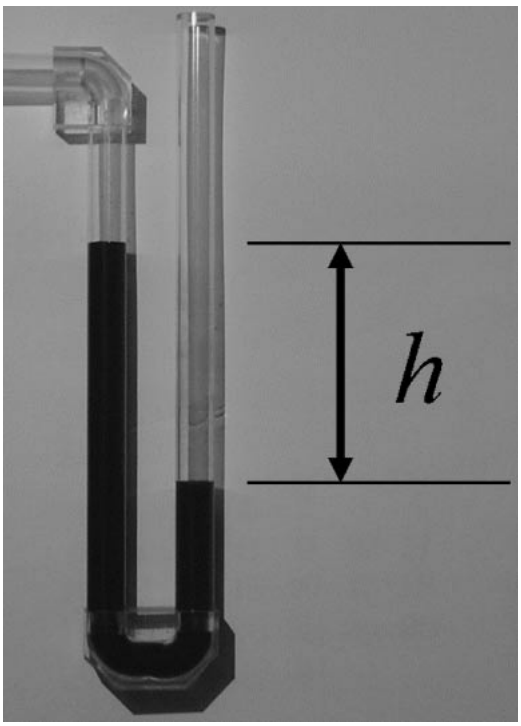

Fig. 4 U-shaped tube filled with colored water (attached to lung models).

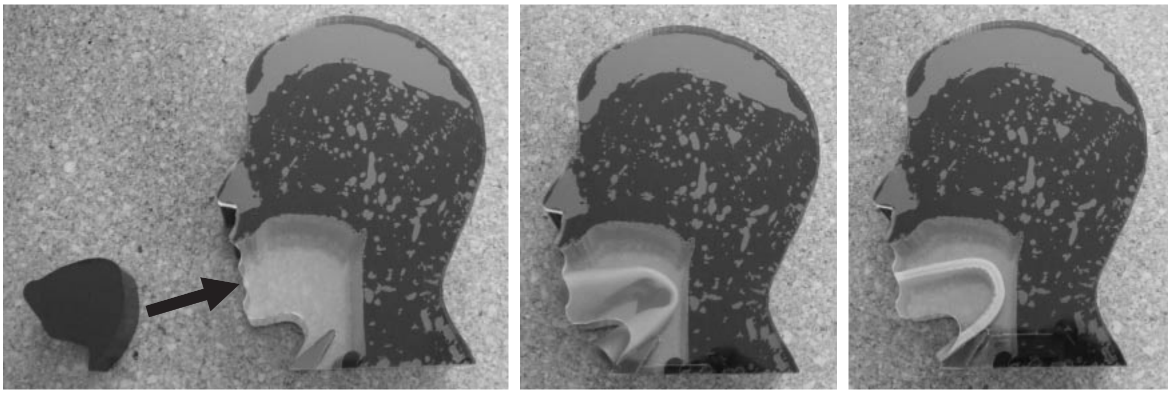

Fig. 5 Head-shaped model with manipulable tongue. The tongues are made of acrylic resin (left), bent rubber tube (center), and felt (right).

4.2. Head-shaped model with manipulable tongue by hands

This is an extended version of the head-shaped model described in the previous section, but the main difference is the manipulability of the tongue position of the model. In the previous head-shaped model, or "fixed model", the vocal tract shape was fixed, thus we had to switch to another model to produce different vowels. On the other hand, for the newly proposed head-shaped model, or "manipulative tongue model", a learner is able to change the vocal tract shape by manipulating the tongue part by hands, and furthermore understand the dynamics of speech production. Figure 5 shows the head-shaped model with manipulable tongue. The tongues are made of acrylic resin (left), bent rubber tube (center), and felt (right) in this figure. In either case, the tongue position is movable in the rest of the head-shaped model made from acrylic plates.

5. Summary

In this paper, the lung models and head-shaped models with a visible vocal tract are described as effective educational tools in acoustics. The lung models with the whistle-type artificial larynx visualize the human respiratory system. The head-shaped models auralize vowel sounds and visualize how the vocal tract is positioned in the head. The combination of the lung models, artificial larynx, Arai's cylinder-type and plate-type models, Umeda and Teranishi's model, and the head-shaped models with nasal cavities provides the basis for an effective, comprehensive education in speech production. This makes learners understand the basic concept of speech production systematically not only in speech fields but also in musicology, speech pathology, and language learning.

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