Science Workshop with Sliding Vocal-Tract Model

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ABSTRACT

In recent years, we have developed physical models of the vocal tract to promote education in the speech sciences for all ages of students. Beginning with our initial models based on Chiba and Kajiyama's measurements, we have gone on to present many other models to the public. Through science fairs which attract all ages, including elementary through college level students, we have sought to increase awareness of the importance of the speech sciences in the public mind. In this paper we described two science workshops we organized at the National Science Museum in 2006 and 2007 in Japan.

Index Terms: speech production, vocal-tract model, science workshop, sliding three-tube model, education in acoustics

Figure 1: *Arai's models: cylinder type (left) and plate type (right) [1,3]*

Figure 2: *Arai's cylinder-type models at the Science Museum in Shizuoka City, Japan*

1. INTRODUCTION

The latest guidelines for education at elementary schools in Japan have fewer hours for science and none for "sound" in the curriculum. Therefore, the role of museums and science workshops is becoming more important. At the same time, many attractive scientific subjects are around us. Speech science is one such subject. In our daily life, we communicate verbally, so speech science should be a familiar subject, even to children.

Our goal is to develop educational tools and programs because visualizing physical phenomena is intuitive and teaching with physical models is very effective. And ultimately, we are hoping that introducing topics in speech science by using an intuitive approach with physical models will increase children's interest in science. We are also hoping we can improve their logical thinking skills, teach the importance of speech and language, and raise their consideration for people with speech and language disorders.

We have developed physical models of the human vocal tract. One of the early models [1], shown in Fig. 1, was based on Chiba and Kajiyama [2]. These models are used in several places including my lectures and demonstrations, and we confirmed their effectiveness as educational tools [3]. Our physical models are also installed in an exhibition at the Science Museum in Shizuoka City, Japan, where we contributed to the development of the exhibition. We later extended the set of models to include lung models and head-shaped models (Fig. 3) [3,4]. By using these models together, we can help learners to understand the complete speech production system [3].

The physical models that we have developed were originally designed for college students. However, since the physical phenomena that our models produce are intuitive and fun to watch, we organized a science workshop twice for children at the National Science Museum, Japan: once in 2006 and once in 2007. This paper examines our one-and-half-hour National Science Museum workshop entitled "Wonderful World of Sounds: Let's Create our Voice."

2. OUTLINE OF THE WORKSHOP

2.1 Three themes

We presented the following three themes to the children in the workshop: 1) What is sound? 2) What causes a change in the pitch of sound?, and 3) Does voice differ from other types of sound? The contents of the workshop were designed to test the three themes.

2.2 First activity

First, we played recorded sound files of many different sounds around us: the sounds produced by people, animals, nature, and musical instruments. Then, we played some actual musical instruments. We demonstrated the vibration of a harp string by using a strobe, so the children could watch the vibration in slow motion. The children were also allowed to feel the vibration by touching the vibrating components. Then, we introduced reed vibration and air-reed vibration. We next had them do a handicraft: a straw flute made from a straw and a plastic film container.

2.3 Second activity

Next, we asked the children to tell us which sound among the musical instruments has a higher pitch. We explained that the longer a musical instrument, the lower its pitch, and vice-versa. The children then made a second handicraft: a slide whistle. The slide whistle consists of a cylinder with the straw flute from the first activity along with a slider. The slider is made from another film container, clay (or paper) and a wire.

2.4 Third activity

After building up their interest, we presented the last and main topic: speech production mechanisms. First, we demonstrated vowel production using the human-shaped model (Fig. 3). With this model, we slowly pulled down the center of the diaphragm to inflate the "lungs," which were actually two balloons. Pulling down the diaphragm increases the volume of the thoracic cavity, thereby creating negative air pressure inside the cavity. Air flows into the lungs to equalize the pressure in the lungs with the pressure in the atmosphere, simulating inhalation. Pushing up on the diaphragm decreases the thoracic cavity volume, causing air to flow out of the lungs, simulating exhalation. A whistle-type artificial larynx above the lungs produces a glottal sound during exhalation. Once the glottal sound is fed into a vocal-tract model, a vowel-like sound is produced.

The third handicraft was a sliding vocal-tract model [5] consisting of a cylinder, the slider from the second activity, and a reed mouthpiece. The mouthpiece is made from another film container, bamboo and a sheet of plastic. Since the children already had the cylinder and the sliding part, they only needed to make the mouthpiece. A glottal sound is made when one blows directly into the mouthpiece, but once the mouthpiece is put into the cylinder, we can produce different qualities of vowels by working the slide. When we move the constriction to the back of the cylinder, we obtain the /a/ sound. When we move it to the middle, we obtain the /u/ sound. When we slide it to the front, we obtain the /i/ sound.

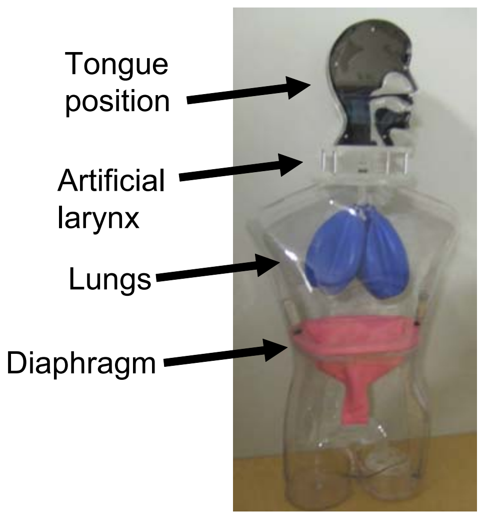

Figure 3: *Lung model and head-shaped model with an artificial larynx [3,4]*

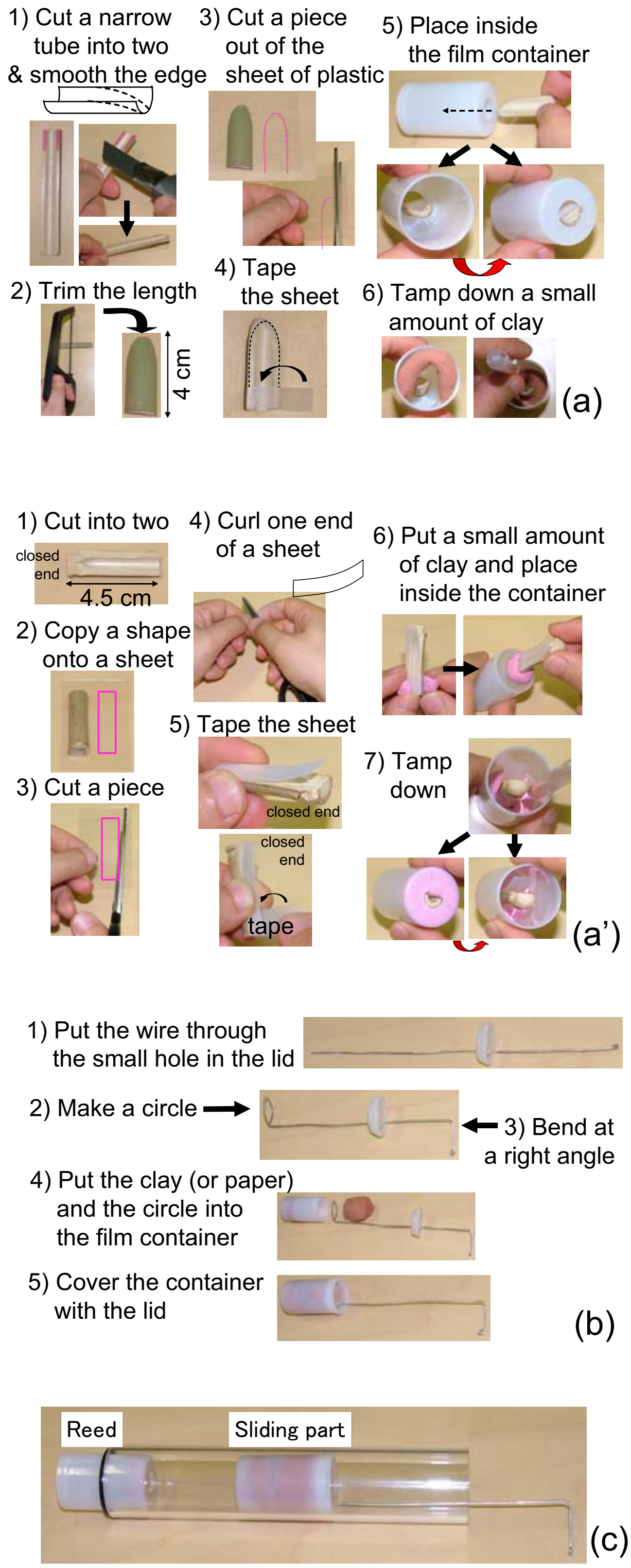

Figure 4: *How to make a handicraft of a sliding vocal-tract model*

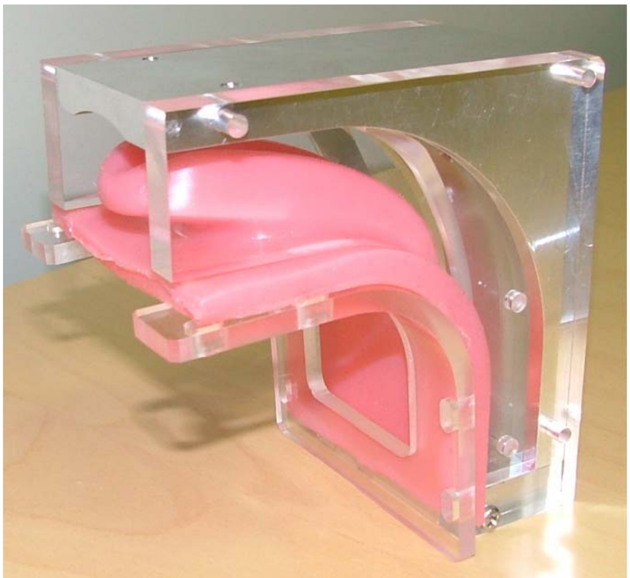

Figure 5: *Vocal-tract model with gel-type flexible tongue (from [6])*

Figure 4 (a) shows one set of instructions for making a reed mouthpiece. First, we provide a split bamboo. The children taper one edge and cut the end at 4 cm. After copying the shape of the bamboo onto a plastic sheet, they cut the sheet along the line. Then, they tape the sheet on the bamboo and insert it through the hole at the bottom of the container. Finally, they put a small amount of clay into the container for foundation and tamp down the clay.

Figure 4 (b) shows the instructions of another version. In this case, the bamboo is not tapered, but we use a piece of bamboo with a closed end and curled one end of a plastic sheet. The curled sheet is taped on the top of a piece of bamboo.

3. DISCUSSIONS

In this science workshop, 11 and 13 children, mainly aged 10-12 years old, participated in 2006 and 2007, respectively. As described in Section 2.1, we had three themes. For each theme, we combined an explanation and a demonstration of a physical phenomenon with the activity of making and testing a simple model. Our goal was not to have them understand the intricacies of the phenomena and theories but to pique their interest and take their questions home for discussion with their family or potentially to investigate the issues raised at a later date.

For the third activity, we carefully designed the order of the demonstrations of our vocal-tract models. First, we used the lung models, the neck part with an artificial larynx, and the head-shaped model [3,4]. We combined the models as shown in Fig. 3 and showed the children that a model shaped like a human vocal tract can produce human-like speech sounds. Then, we replaced the head-shaped model with the flexible-tongue model (Fig. 5) [6]. In this model, the tongue is made with a gel-type material so that its shape is highly malleable. By using this model, the children can intuitively experience how tongue position affects resulting vowel sounds. We then replaced the flexible-tongue model with the cylinder-type models [1]. Each of the cylinder-type models has a round bottle-shaped cavity corresponding to an area function of each of the five Japanese vowels. Even in a straight tube, a sound having vowel quality can be produced as long as a similar area function is used. Finally, we introduced a sliding vocal-tract model. We demonstrated that even this simpler model can produce vowel-like sounds when the position of the slider is changed. This chain of explanation with handicrafts helped the children understand the physical phenomena and it built up their interest for the main handicraft: the sliding vocal-tract model.

We had the children make the reed mouthpiece in two different ways in the two workshops: the first version in Fig. 4 (a) in 2006 and the second version in Fig. 4 (a') in 2007. In 2006, we asked the children to smooth one edge of a piece of bamboo. It turned out that this required a rather high level of skill and a good deal of supervision. This made it difficult to balance this activity with the other activities. However, at the same time, the students had a high sense of achievement. In 2007, we asked children to curl one edge of a plastic sheet. This type of reed is based on Riesz (1930) [7]. In this case, the children were able to work more quickly and with less supervision, but they did not seem to receive as a high sense of achievement. Figure 6 compares the spectral characteristics of the two versions of the reed mouthpiece. For the recordings, the microphone was placed approximately 20 cm in front of the mouthpiece, and the resulting sounds were digitally recorded with a sampling frequency of 48 kHz by a linear PCM recorder (PCM-D1, Sony). The signals were downsampled to 8 kHz.

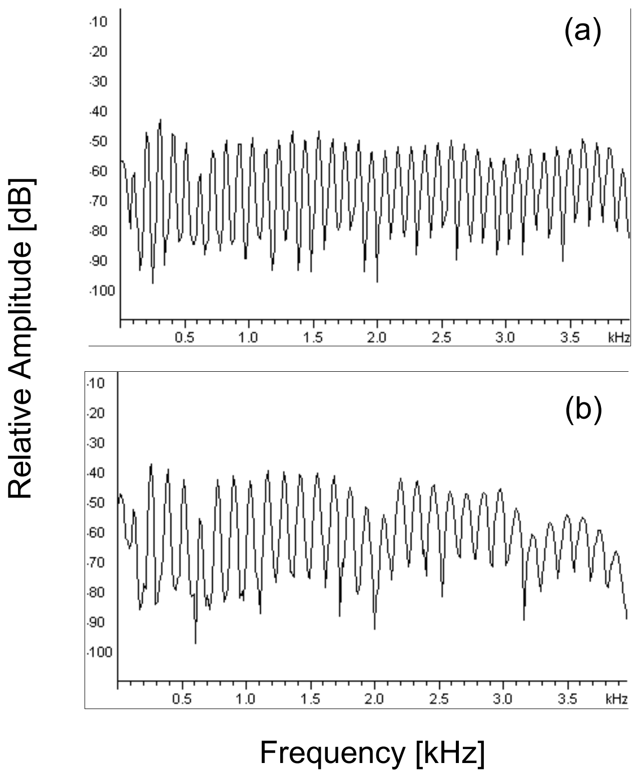

Figure 6: *Spectral characteristics of the two versions of the reed mouthpiece: (a) the version in 2006, and (b) the version in 2007*

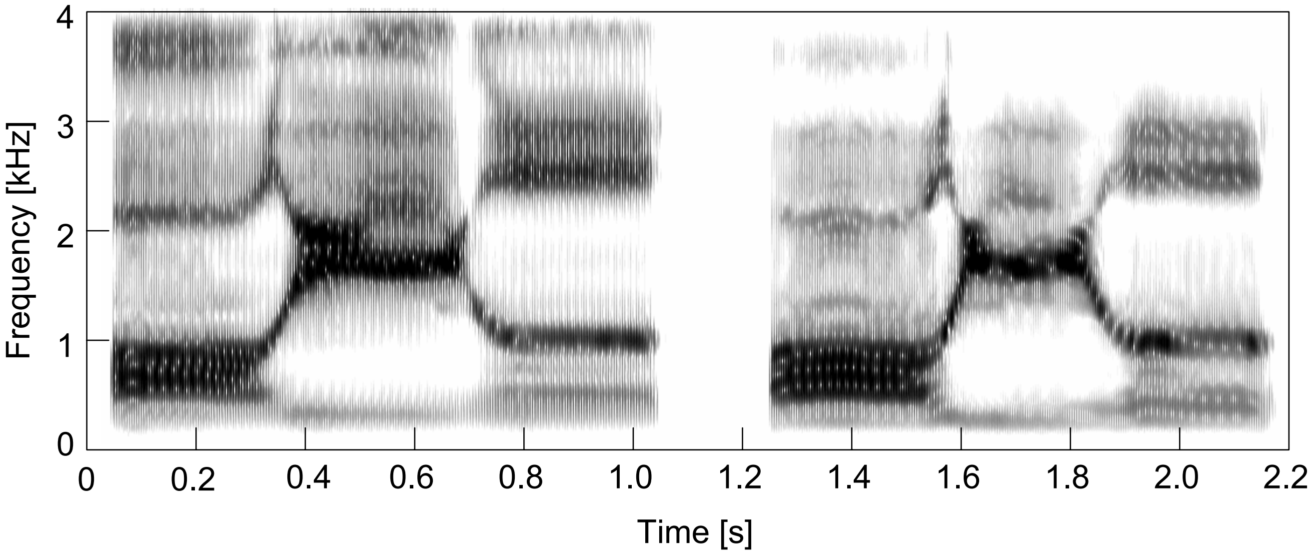

Figure 7: *Spectrograms of an utterance of three concatenated vowels: /a/, /i/, and /u/, produced by the sliding vocal-tract model with the two versions of the reed mouthpiece: the version in 2006 (left) and the version in 2007 (right)*

The spectrogram was obtained by Wavesurfer. Although the both versions show relatively flat spectral characteristics, the first version has less fluctuation in frequency as shown in Fig. 6 (a). Figure 7 shows the spectrograms of an utterance of three concatenated vowels: /a/, /i/, and /u/, produced by the sliding vocal-tract model with the two versions of the reed mouthpiece. For the recordings, the same setup was used as those for Fig. 6. Although the output sounds were both intelligible, the one with the first version of the mouthpiece (in 2006) was slightly clearer.

The "sliding vocal-tract model [5]" was based on the three-tube resonator model by Fant [8]. This model can also be used for the lab experiment for college and graduate students, where they can measure the formant frequencies and compare with those derived from the theory of speech production.

4. CONCLUSIONS

Speech science is one of many scientific subjects that are attractive to children. Visualizing physical phenomena is intuitive, and physical models are very effective. Through the workshops, we confirmed that introducing topics in speech science by means of intuitive experiences helps to develop children's interest in science. Based on the results of a questionnaire after each of the workshops, the most popular models were the sliding vocal-tract model and the human-shaped model. The field of speech science is not a part of required elementary or junior high curriculum. Based on the workshops, however, we are confident that this field is very attractive to children. We hope through our workshops more children will become interested in human communication, as this topic is familiar and relevant to every human being.

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