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Lab experiment using physical models of the human vocal tract for high-school students

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1. Introduction

Educational tools for acoustics have gradually become more accessible in Japan in recent years. We have confirmed that physical models of the human vocal tract are particularly useful for teaching acoustics [1]-[7]. Students study acoustics as a part of specialized subjects, including electrical and mechanical engineering, linguistics, architecture, and musicology [8]. We developed our educational tools to give students from various educational backgrounds an intuitive understanding of the underlying principles of phonetics [1]-[2].

Formerly we proposed two models of the vocal tract. Both the plate and cylindrical models corresponded to the Japanese vowels, /i/, /e/, /a/, /o/, and unrounded /u/. We also developed a nasalized mechanical model of /a/ [3]. All of the models were made of transparent acrylic resin, enabling the configurations of the oral cavity to be seen from the outside of the model.

In a previous study, we reported on a lab experiment in which we used these tools to teach the mechanism of vowel production to graduate students majoring in acoustics or linguistics. [2], [4]. In the present study, we discuss our experience teaching high-school students who had just finished studying basic acoustics. We focused on teaching about the speech organs and certain phonetic principles, especially the mechanism of vowel production.

2. The Vocal Tract Models

In the 1940’s, Chiba and Kajiyama measured the area functions of the human vocal cavity, and they produced artificial vowels from mechanical vocal tract models they had created based on their measurements [4]. Using Chiba and Kajiyama’s measurements [9], Arai reconstructed their vocal tract models to make new models suitable for education [1]. Arai's first model is a set of square plates [1],[2],[4]. The plates are made of acrylic and are 75x75mm square by 10mm thick. Each plate has a hole in the center; the holes are of various diameters. A set of 14 to17 disks simulates the vocal tract by forming an acoustic tube where the holes line up. Through rearrangement of the plates, students can learn the importance of the position of constriction for vowel production.

Arai's second models were cylindrical in shape and were hollowed out according to Chiba and Kajiyama's measurements. The radius at every position was approximated with a polygonal line. The models have an opening at each end corresponding to the mouth and glottis, and they are made of transparent acrylic resin so the shape of the cavity can be seen.

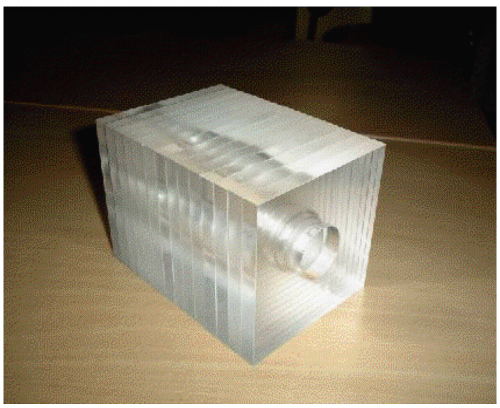

Fig. 1 Plate model of /a/

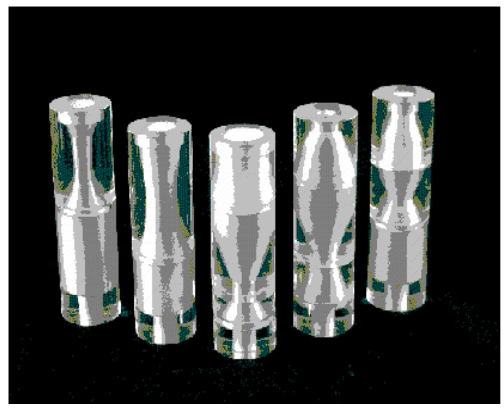

Fig. 2 Cylindrical models

In a previous study, we made four cylindrical models of the Japanese vowel /a/, which differed only in step size approximations [3]. The cylinder models had external diameters of 50mm and were 160mm long. The simulations of these four cylindrical models showed that the step sizes did not influence the formants of the outputs in a significant way. We also compared the characteristics of the plate and cylindrical type models with the same configurations [7]. Finally, we developed a model for a nasalised vowel [3].

3. Teaching high-school students

In the present study, we taught acoustics to high-school students. We lectured on the mechanism of vowel production using our plate and cylindrical models to aid in learning. The 34 twelfth-grade students in the class all expressed a desire to study in a scientific field in the future. Just prior to our lecture, the students had finished studying basic acoustics. In their studies they covered the Doppler effect, the technique for calculating the velocity of sound. They also determined the speed of sound in a column of air, for which they used their knowledge of resonance in an acoustic tube of variable length.

At the beginning of class we distributed a handout to the students containing a midsagittal view of the head with markers indicating the speech organs. Most students had not studied the speech organs before. After discussing the handout, we showed students a wooden sculpture with a hollowed out vocal tract based on Chiba and Kajiyama's measurements [9]. The sculpture could be split into left and right, so the students could see the cross section of the speech organs. By attaching a sound source, such as an electrolarynx, to the wooden model, a vowel-like sound is produced. These easily manipulated tools appeared to capture the students' interest more than the handout.

After lecturing about vowel production, we used a vinyl tube with a uniform cross sectional area as a vocal tract model. After producing the vowel /shwa/, we squeezed the tube with our hands to change its shape, and thus its speech output. This exercise emphasized the importance of cavity shape for vowel production. Since they had studied resonance in a column of air prior to this lecture, they thought only tube length was important, but this exercise confirmed that the shape of the tube also affects speech output.

Finally, we used the plate and cylinder models we developed to explained why the cavity and source sound are important for vowel production. First we explained how the models work, and why we made the two types of models. Then we produced speech with the models. After this lecture, we divided the students up into 5 groups for a hands-on experiment. Each group examined one of the 5 Japanese vowels. The students lined up the plates based on the table of the diameters given in the handout. We gave 20 plates to each group. This left the groups with some extra plates, as, for example, /a/ only needs 14 to 17 plates. Lining up the plates was simple for the twelfth-grade students, and they finished quickly. We then went around to each group and attached a sound source to the model to produce vowel sounds. We answered the students' questions during this time. Also during this small-group work, we changed the position of plates so the students could see how point of constriction affects vowel quality. At the end of the class we gave the students a questionnaire regarding the lecture.

Fig. 3 Lecture with the wooden sculpture

Fig. 4 Group work with the plate model

4.Discussion

From the questionnaires we learned that most students had not understood the importance of vocal tract shape and the vibration of vocal cords before this lecture. When asked if the lab experiment using the vocal tract models was effective or ineffective for understanding speech organs and the mechanism of vowel production, students gave positive feedback. More than half of the students chose the plate type model as the most effective or most interesting model type, because they were able to manipulate the plates to simulate constrictions. From the responses on the questionnaire it was clear that the students understood vowel production better with the models than they would have without them.

5.Summary

We confirmed that physical models of the human vocal tract are particularly useful for teaching acoustics of vowel production. The tools helped high-school students to understand the mechanism of vowel production. Also they grasped the relationship between the configuration of the vocal tract and acoustic output.

We hope these manipulative tools will be utilized at the junior-high or primary school levels, wherever acoustics is taught. We also hope to develop a new sound source and apply the nasalised model.

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