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A viscoelastic figure model of tongue for understanding speech articulation

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ABSTRACT

To help understanding tongue shape and motions, I made a figure model of tongue using viscoelastic material of urethane rubber gel in the following procedure. At first, an original model of tongue was formed by baking clay which is hardened by heating. The shape of tongue was decided with multiple references of anatomy books, MRI images, educational models, and our real tongues. Next, a mold was made with silicon using the original model of tongue. Then, the final figure models were molded and duplicated with urethane rubber gel whose hardness is near to human skin. The model includes intrinsic and extrinsic tongue muscles, although the current version was made as a whole shape model of tongue body consisting of combined muscles. Compared to the current materials used in speech science education, such as drawings, pictures, videos, or human body models, the proposed tongue figure model is useful for understanding three dimensional tongue shape and internal and external tongue muscles' positions and motions, too. Because students can hold and touch the realistic tongue model and make it move and deform by pushing and pulling this viscoelastic tongue body. Pictures and explanatory texts do not make sense but the proposed model can help for students to understand anatomical structures and functions of speech articulation intuitively. From questionnaires from students in a speech science seminar, it is founded that the proposed model is an effective tool for understanding speech articulation. It can be applied not only to teach speech science, but also to elucidate speech articulation by scientists and engineers, and also to develop a tongue actuator for speaking robots.

INTRODUCTION

Speech is a physiological signal which is generated by muscular motions of lung, vocal cords, larynx, jaw, tongue, and lips. Coordinated articulatory movements of these organs are so complex that they are difficult to be understood by either students or professionals. Especially for tongue, anatomical structures and functions are well studied but speech articulatory movements can be said that they are still under investigations.

For educational purposes of speech sciences, text books are used in general. Explanation is done using textual sentences and simple figures in black and white. It is not sufficient to understand complex speech articulations. Sometimes, multimedia materials are used. Graphical representation is useful and it is better than traditional text books.

In addition, anatomy models are often used. The variety of human anatomy models can be purchased. They include head, skull, nose, oral cavity, teeth, ear, tongue, and etc. I feel that they are useful my experience of teeching speech science in class. Students can understand speech production mechanism using the 3D real materials which can be viewed from different angles and can be touched. It is much better than the limited numbers of 2D black and white figures in textbooks.

I also use vocal tarct model in class, for teaching vowel production. Chiba and Kajiyama made vocal tract model in the early age [1]. Their model was reproduced and sold [2] so that we can purchase and use it for speech science education.

Even if these anatomical models and educational aids are used, it is not easy especially for studnets to learn the human speech articulation. I felt that the anatomical models are useful but more reality is needed. If we can shape and move a soft tongue model by touching, pulling, and pushuing the model muscles, it helps to understand mechanism of speech articulation by tongue. Thus, to help understanding tongue shape and motions, I made a figure model of tongue using viscoelastic material of urethane rubber gel.

SPEECH ARTICULATION AND TONGUE MUSCLES

Speech articulation is a highly complex task of human. It imolves the coodinated use of approximately 100 muscles of the respiratory, the laryngeal, and the supralaryngeal systems [3]. Figure 1 shows speech organs. The respiratory system consists of lungs and related organs. It makes air flow as the energy source of speech acoustics. The laryngeal system including vocal cords makes voicing and nonvoicing sound sources. It also controls pitch of the sournd source. The supralyngeal system, which consists of the velum, the tongue, the jaw, and the lips, controls speech sound characteristics depending on phonemes and makes variety of speech acoustics. These supralyngeal organs (Figure 2) are called as speech articulators.

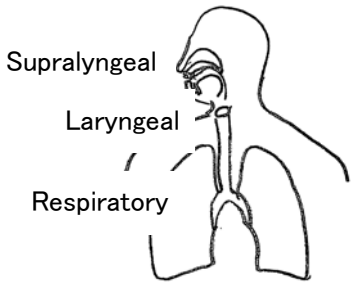

Figure 1. Speech organs.

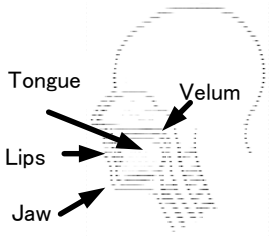

Figure 2. Speech articulators.

Tongue muscles can be classified into intrinsic and extrinsic tongue muscles [4] [5] [6]. In general, intrinsic tongue muscles shape tongue and extrinsic tongue muscles move tongue body itself and, although both types of muscles affects positions and shapes simultaniously. Figure 2 and Figure 3 **s**hows intrinsic and extrinsic tongue muscles respectively.

Intrinsic tongue muscles start from and end to inside tongue body. Longitudinalis liguae superior and inferior are located at surfaces of tongue. Verticalis and Transversus linguae are filled in the tongue body and the directions of the muscle are vertical and transverse, resectively. These four intrinsic muscles deform the tongue shape. Bending, shorting, raising tip, flatening, stretching can be done in many degrees of freedom.

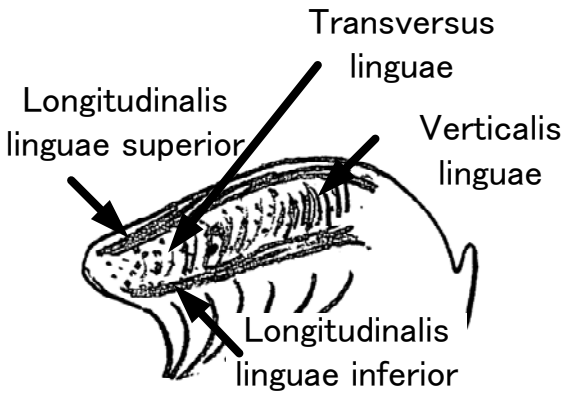

Figure 3. Intrinsic tongue muscles.

Extrinsic tongue muscles start from outside tongue and end to inside tongue. They move tongue body by pulling the attached parts of tongue. Geneoglossus (anterior) protorudes tongue or lowers the center of the tongue surface (posterior). Hyoglossus lowers tongue. Styloglossus pulls back lower sides of tongue so that tongue elevation can be done. Platoglossus lowers the soft plate and elevates tongue body. These extrinsic muscles function is particulary important to make vowels [1] [7] [8]. Because these motions drastically change the width and hight of vocal tract and prace of articulation, then air flow of the vocal tract is much influenced. Table 1 shows summarized functions of extrinsic tongue muscles.

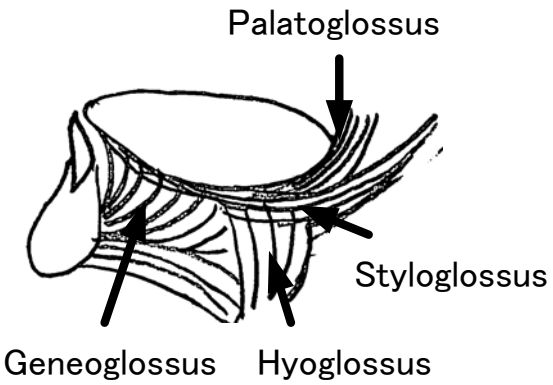

Figure 4. Extrinsic tongue muscles.

Table 1. Major functions of extrinsic tongue muscles

Muscle	From	Function
Geneoglossus	mandible	protorusion lowering center
Hyoglossus	hyoid bone	lowering
Styloglossus	styloid process	elevation pulling
Palatoglossus	platine aponeurosis	lowering soft plate elevation

TONGUE FIGURE MODELING PROCEDURE

The procedure to make the viscoelastic figure model of tongue is similar to molding procedure for plastic toys. At first, an origial tongue model is formed by baking clay which is hardened by heating. Next, a mold is made from silicon. Then, the final figure model is molded and duplicated using urethane rubber gel. Details will be described in this section.

Reference Materials

To make the original tongue model, some of reference materials were used. They were anatomy referecne books and texts, traditional human anatomy models for science education (as shown in Figure 5), multimedia and computer grahics materials, magnetic resonance image, an actual tongue viewed by a mirror. From these multiple referecne sources, most realistic shape and size were determined.

Figure 5. An example traditional human anatomy model for science education used in class.

Making an Original Model

The original model means hand knead cray model for making a mold for reproduction. Figure 6 shows main materials usef for molding the tongue figure model. Ceramic-like sculpturing compound (upper left of Figure 6) which is hardened by heating was used rather than usual oil modeling cray. Hands and tools like englaving knives for cray were used to form tongue. The modeling is carefully done by looking at referece materials. When modeling is finished, the compound was heated at 130 degree celcius in 15 minutes in a heating oven. Figure 7 shows an example of the finished original model. Shown in figure 7 is a prototype in 1/2 scaling.

Figure 6. Materials used for the molding the tongue figure models. Ceramic-like sculpturing compound, Oil cray, Silicon, urethan gel, and barrior coating liquid.

Figure 7. An original tongue model made from Ceramic-like sculpturing compound.

Preparation of Making a Mold

Using the original tongue model a mold was made. At first, the model was looked at carefully to decide upper and lower halves. A border line was drawn at the border between upper and lower.

A plastic frame was made about 1 cm bigger than the model. Oil cray (shown in upper right of Figure 6) is spread higher than the border line. It is cut by the frame so that the bottom half of the frame is filled with oil cray. The cray is digged to sink the model.

The lower half of the model was sinked to the oil cray. Spaces between cray and the model are pushed and filled with cray. In addtion, pouring and airing holes and dwelling holes are digged (Figure 8).

Figure 8. The bottom half of the original model was sinked in oil cray in the frame. Dwelling holes were made using a stick.

Making a Mold

Then, sillicone in liquid (lower left of Figure 6) was poured into the frame. It takes about 8 hours to fix the sillicone. When the sillicone was fixed, these were rotated up side down. Oil cray is removed completely (Figure 10). Then, barrior coating liqued (lower right of Figure 6) was coated on the surface of sillicone to separate upper and lower sillicon molds. Then, sillicone in liquid was poured again on the fixed sillicone. Waiting for 8 hours, the mold is finished. Upper and lower halves wer separated and the original model was removed. Air bubbles and other troubles were checked. Finally, the mold was made.

Figure 9. Sillicone was poured to the upper half of the model.

Figure 10. The upper half of the mold was made.

Reproduction of the Tongue Figure Model using the Viscoelastic Material

For the reproduciton by molding, the viscoelasitic material of urethan rubber gel (lower center of Figure 6) was used. This material has similar viscosity and elasticity to human skin. The hardness is 0 in durometer (at Type C). Main liquid and curing agent must be mixed at the rate of 3:1 precisely. Otherwize, the liquid may not be coagulated.

The upper and lower molds were fixed tightly using wooden board and rubber bands (Figure 11). The liquid of urethan rubber gel is poured from the pouring hole, very slowly and carefully. Through the tube of the pouring hole, the liquid is flowed into the inside of the molds. The air in the mold was flowed out from the air hole. All air inside the mold must be out from the air hole. Otherwize bubbles remain in the re-

produced figure model. For coargulation, it takes more than 5 hours.

Figure 11. Upper and lower halves of the mold was tightly put together. One hole is for pouring urethan rubber gel and the other one is for removing air.

When the gel is coargulated after more than 5 hours of waiting, the molds are pulled out. Finally, the figure model is appeared. Since the urethan rubber gel is sticky, talc powder or coating liquid is painted on the surface of the final model.

Figure 12 shows the tongue model in 1/2 scale. Prototyping in 1/2 scale is repeated until the good quality model is made to save material.

Figure 12. A viscoelastic figure model of tongue (1/2 scale).

Figure 13 shows the full scale model. Since prototyping must be repeated several times, 1/2 scale models were made several times. When the prototyping was succeeded, the full scale (1/1 scale) model (shown in Figure 13) was made.

Figure 13. A viscoelastic figure model of tongue (full scale version). Pictures taken from front, back, and upper side.

USE OF THE MODEL

At this time, he model was used mainly for speech science education in class in university. Compared to the current materials used in speech science education, such as drawings, pictures, videos, or human body models, the proposed tongue figure model is useful for understanding three dimensional tongue shape and internal and external tongue muscles' positions and motions, too. Because students can hold and touch the realistic tongue model and make it move and deform by pushing and pulling this viscoelastic tongue body. Pictures and explanatory texts do not make sense but the proposed model can help for students to understand anatomical structures and functions of speech articulation intuitively. From questionnaires from students in a speech science seminar, it is founded that the proposed model is an effective tool for understanding speech articulation. It can be applied not only to teach speech science, but also to elucidate speech articulation by scientists and engineers, and also to develop a tongue actuator for speaking robots (such as in [9]).

SUMMARY AND CONCLUSION

A tongue figure model using viscoelastic material was made. The model can be touched, pushed, pulled, and deformed by students. It helps for them to understand complex articulations of tongue that are hard to be understand from pictures. At this time, as the first step, the model was made as a whole shape. The next model will be devided into multiple parts (an early prototyping was reported [10]). Each muscle will be molded independently. Then, these parts are assembled. In future, speech articulation of tongue will be reproduced by an advanced tongue figure models. It is expected that the models help to elucidate speech articulation mechanism, to use for educational purposes, and to develop acutuators of tongue robots.

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