Effect of Vibration Characteristics of Skull in Mastication of Crispy Foods on Food Texture

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***Abstract*—It is important to clarify characteristics of sounds in mastication of foods because the food texture is affected by them. This study deals with food texture of crispy foods focusing on two types of chewing sounds in eating the foods, which are air conduction sound and bone conduction sound. Five kinds of snack foods were used for this study. Air conduction sound was recorded from microphones and bone conduction sound around cheekbones was measured with a headphone-like instrument in which acceleration sensors were embedded. The two types of sounds were analyzed by FFT and power spectra were obtained. Finite element models were also applied for examining vibration characteristics of human skull. The computational results of modal analysis show that size of human skull affects bone conduction sound, which was identified as different power spectra from experimental data of an adult and a child. These results suggest that biomechanical factor of skull affects eating quality of foods.**

***Index Terms*—food texture, snack foods, air conduction sound, bone conduction sound, FE model, modal analysis**

I. Introduction

Food texture is important to evaluate food quality. Especially crispy foods are definitely deserved by food texture. However it is not so easy to discuss food texture quantitatively because many factors are complex. It needs integrated research to evaluate food texture. Fig. 1 illustrates our approach from two viewpoints. One is a study from viewpoint of mechanical characteristics of foods. The other one is a study of human factors related to food texture.

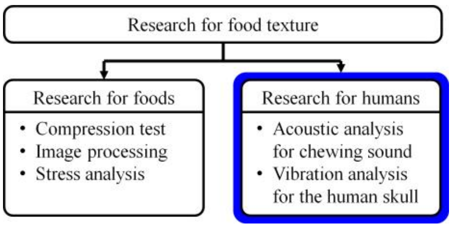

Figure 1. Biomechanical approach for food texture

The former part is examination of food properties by compression test and image processing based on inner structure of food. There are many reports on this theme [1], [2]. Most of researches focused on macroscopic mechanical characteristics. The authors pointed out the importance of microscopic mechanical properties of food. It is shown that the microscopic Young's modulus is much larger than that of macroscopic value [3].

The latter part is research for humans. Two types of sounds are produced in mastication, air conduction sound and bone conduction sound. These sounds may greatly contribute to food texture because we are fond of crispy sounds. The air conduction sound is directly transmitted in air when foods are crushed in mastication. There are also many reports on the theme [4]-[7]. On the other hand, the bone conduction sound is transmitted through bone. Some parts of the sounds are probably emphasized by mechanical resonance phenomena of the human head. The resonance effect may depend on scale of the skull due to vibration factors of the head. The bone conduction is expected to be different between adult and child due to difference of scale of skulls. There are few studies on this theme.

Japan has a variety of crispy snack foods. Adults also like the foods as well as children. But the preferences of adults and children seem to be different. If the different preference is affected by the bone conduction sound, it will become an important clue in developing a new snack food. This study focuses on the sounds in mastication of snack foods, and clarifies characteristics of the sounds by engineering methods.

II. Method

Five kinds of Japanese snack foods were used for the examination. We selected stick-like snack foods so that shape of snack foods does not affect mastication of foods as little as possible. Fig. 2 shows the snack foods and the cross sections. We can see a variety of microstructures in them.

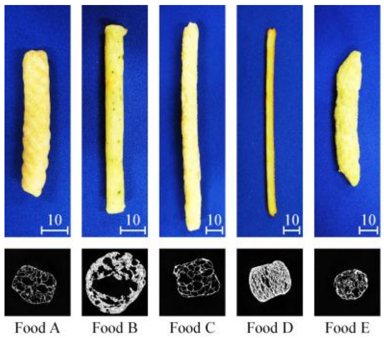

Figure 2. Five snack foods and the cross sections

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A. Measurement of Sounds

We use two microphones to record air conduction sounds in mastication of foods. The microphones are mounted on a cap that a test subject wears. To measure bone conduction sound, we developed a headphone-like instrument. Two acceleration sensors are attached to the both ends. Air conduction sound and bone conduction sound are measured at the same time as shown in Fig. 3.

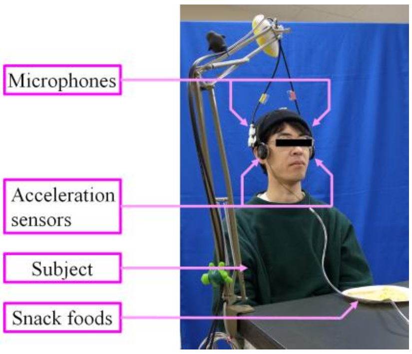


Figure 3. Appearance of examination

B. Analytical Models of the Human Skull

To examine the effect of scale of human skull to bone conduction sound, we provide two types of finite element models. Fig. 4 shows one of the finite element models for examining characteristics of mechanical resonance of a skull. The human skull is regarded as hemispherical dome shell with a hole under a flat plate. Two sizes of models are provided. Table I shows the parameters of the finite element model. Scale of the radius and thickness of the model was determined by geometric similarity. As the boundary condition, only the periphery of the bottom surface was constrained by rotatable fixing. The constraint has three rotational degrees of freedom on each nodal point. The other one is the human skull model as shown in Fig. 5. The model is used for examining how the skull is transformed in mastication. Young's modulus = 8.75 GPa and Poisson's ratio = 0.25 were set for the model. Using the two models, we performed modal analysis by MD Nastran.

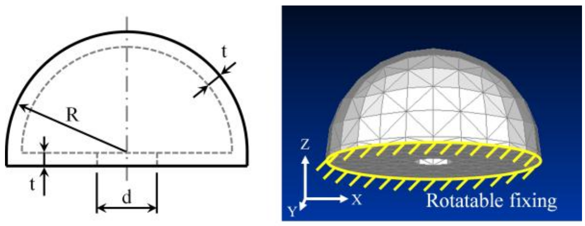


Figure 4. Simple finite element model

TABLE I. PARAMETERS OF FINITE ELEMENT MODELS

Parameters	R (mm)	d (mm)	t (mm)
Small model	70	26.25	4.375
Large model	80	30.0	5.0

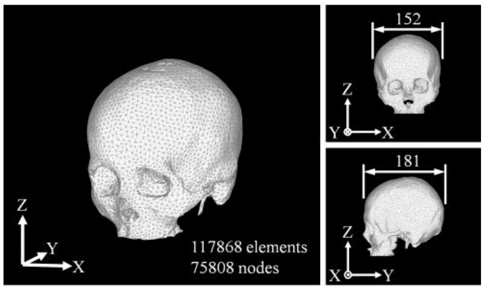


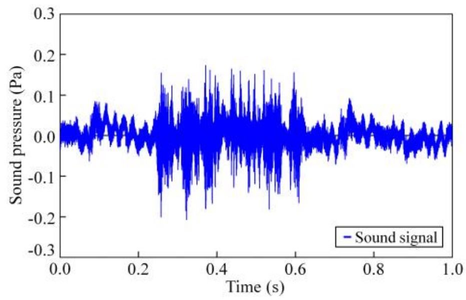
Figure 5. Finite element skull model

III. RESULT

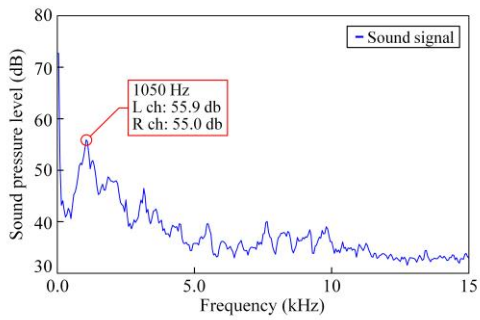
We examined characteristics of the sounds focusing on size of head. Twelve subjects were asked to eat the five kinds of snack foods and answered questionnaire about Japanese onomatopoetic words (sakusaku, karikari, paripari, garigari) to express feeling of eating the snack foods. We will show the typical results in this paper.

A. Result of Sound Analysis

Fig. 6 shows air conduction sound data and the power spectrum by an adult subject in mastication of a snack food (food A). The subject, we call subject N1, is 59 years old with 580 mm peripheral length of the head. Only left side signal is shown in the graph because both sides of signals were almost similar. The vertical line of air conduction sound denotes sound pressure [Pa], the line of power spectrum indicates sound pressure level [dB]. In the same way, Fig. 7 shows the bone conduction sound data and the power spectrum corresponding to air conduction sound. The vertical line of the sound denotes voltage of the acceleration signal that is proportional to intensity of the sound, and the line of the power spectrum indicates intensity in unit of [dB].

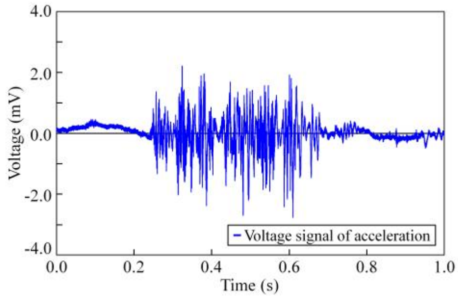


(a)Air conduction sound data (Left side)

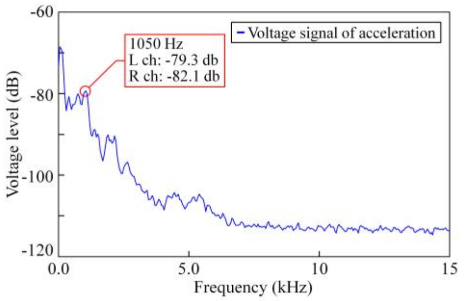


(b)Power spectrum of the data (Left side)

Figure 6. Air conduction sound in mastication of food a by subject N1 (adult)

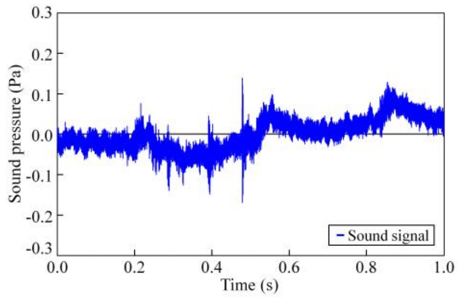


(a) Bone conduction sound data (Left side)

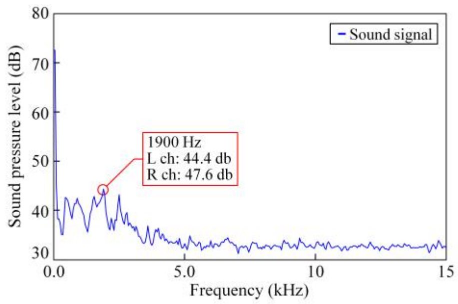


(b) Power spectrum of the data (Left side)

Figure 7. Bone conduction sound in mastication of food a by subject N1 (adult)

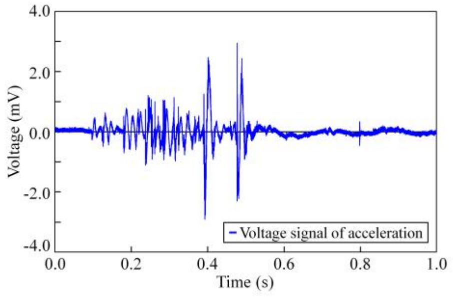


(a) Air conduction sound data (Left side)

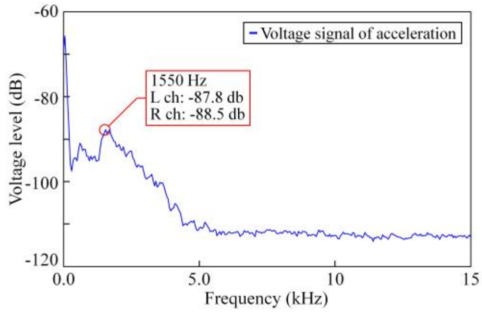


(b) Power spectrum of the data (Left side)

Figure 8. Air conduction sounds in mastication of food a by subject N2 (child)



(a) Bone conduction sound data (Left side)

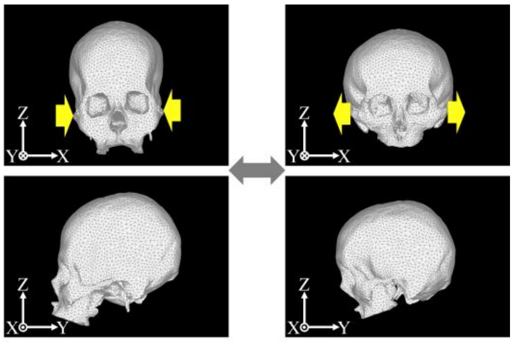


(b) Power spectrum of the data (Left side)

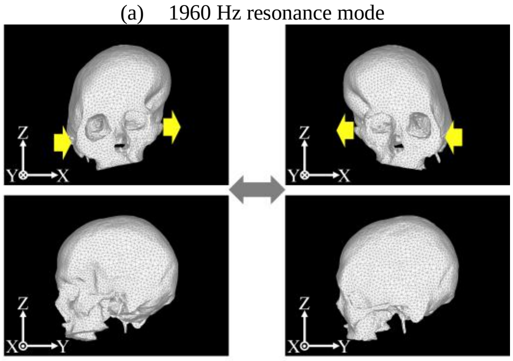
Figure 9. Bone conduction sounds in mastication of food A by subject N2 (child)

Then we will also show the result of other subject (subject N2) who is 5 years old with 500 mm peripheral length of the head. Fig. 8 shows the air conduction sound and the power spectrum and Fig. 9 the bone conduction sound and the power spectrum.

Comparing the results of the child to those of the adult, there are some differences between them. For air conduction sound, several peaks appear in the both spectra, however, frequencies at the highest peak are not same, which are about 1050 Hz for the adult, about 1900 Hz for the child. For bone conduction sound, the power spectrum of the child has clear peaks about 1550 Hz, but that of the adult takes a decreasing intensity curve to the frequency though there exist several weak peaks.



(a) 1960 Hz resonance mode



(b) 2550 Hz resonance mode

Figure 10. Transformation of skull at resonance modes

B. *Result of Finite Element Analysis*

We examined vibration characteristics with the simple hemisphere model. Two sizes of the models with R = 80 mm and 70 mm which correspond to the two subject (adult and child) are provided for the analysis. Table II shows the computational results of resonance modes. There are several resonance frequencies for both cases. The small head has higher frequencies compared to the large model. The lowest resonance frequency as the first mode is 645 Hz for the large model. The first mode appears as concentric circular vibration of disk placed in the bottom surface of the model. However the human skull is difficult to cause such transformation due to reinforced shell structure, which firmly supports the brain in the skull. Frequencies at more than 1200 Hz are feasible.

We also analyzed transformation of a skull using the finite element model as shown in Fig. 5. Fig. 10 shows the exaggerated transformation figures at two resonance frequencies of 1960 Hz and 2550 Hz. The frequency mode at 1960 Hz transforms both sides of cheekbones in opposite phase. On the other hand, the mode at 2550 Hz synchronously transforms them. It is expected that the mode at 1960 Hz takes a stronger peak than that of 2550 Hz mode in the power spectrum because the accelerometers pick up the movement around cheekbones.

These resonance frequencies are roughly in consistency with experimental data reported by other researchers [8], [9].

TABLE II. RESONANCE FREQUENCIES (HZ)

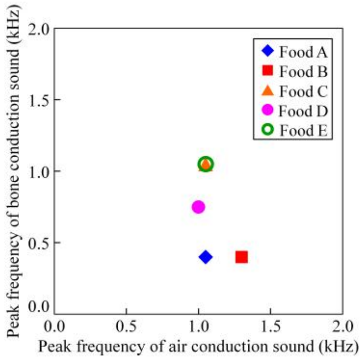
Mode number	1	2	3	4
Small model	739	1470	2190	2390
Large model	645	1280	1920	2090

IV. DISCUSSION

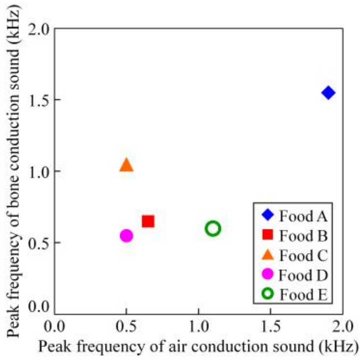
There are some different characteristics in power spectra between the two subjects. For air conduction sound, the strongest peak is 1050 Hz and 1900Hz for the subjects N1 (adult) and N2 (child) respectively. It seems that higher frequency zone of the power spectrum of subject N2 is enhanced compared to that of subject N1. The difference is probably caused by resonance effect though it is unlikely related to mechanical vibration of skull. We expect that the effect is phenomenon of Helmholtz resonance. The phenomenon is important for design of acoustic speakers. According to the Helmholtz theory, resonance frequency is inversely proportional to square root of volume of resonance box. This means that smaller volume of resonance box enhances higher frequency zone of sound. It is presumed that buccal cavity of a human corresponds to sound box. As the subject N2 has a smaller buccal cavity than that of subject N1, it may cause the enhancement at the higher frequency zone. We often noticed clear and crispy sounds in the experiment when a child was eating snack foods.

For bone conduction sound, the computational result of resonance frequency shows that a smaller head produces higher resonance frequencies. The result suggests that the skull of a child enhances higher specified frequencies by resonance effect. This presumption accords with the experimental result that a strong peak around 1500Hz appeared in the power spectrum of subject N2 though more detailed analyses are needed for further discussion.

In this study, we used five types of snack foods. First, we try to examine these snacks from viewpoint of resonance of air and bone conduction sounds. Fig. 11 shows maps of snack foods taking two frequencies at the strongest peak in the power spectra of air and bone conduction sounds. The plotted points of snacks from the child data are scattered with each other, whereas that from adult data is not so much. Second, we try to categorize them into onomatopoetic words as mentioned above using the experimental results. Table III shows the categorization with resonance peaks of air and bone conduction sounds based on questionnaire survey for 5 children. We can see that the onomatopoetic words are useful to categorize the various snack foods. Our future work is to connect the sensory evaluation to biomechanical characteristics in mastication of foods.



(a) Adult



(b) Child

Figure 11. Maps of peak frequencies

TABLE III. RESULTS OF EXAMINATION TESTS

Texture words	Sakusaku	Karikari	Paripari	Garigari
Food A	2	2	1	0
Food B	0	1	0	4
Food C	0	0	0	1
Food D	0	2	1	0
Food E	3	0	3	0

V. CONCULUSION

To evaluate food texture of crispy foods, we examined vibration characteristics of air and bone conduction sounds in mastication. The experimental results show that size of head gives effect on these sounds. Characteristics of resonance frequencies are different between skulls of an adult and a child. This knowledge will be useful for development of a new crispy food for specified age. The detailed study is our future work.

ACKNOWLEDGMENT

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