Comparison of Vibrotactile Display and Pseudo-mastication Sound Display on Food Texture Perception

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***Abstract*—Several cross-modal augmentation research on food texture has been conducted in recent years. These results revealed that pseudo-mastication sound can affect the perception of food texture. However, there have been few studies on food texture using vibrotactile stimuli to the whole body. Thus, we proposed a method of presenting vibrotactile stimuli using mastication sound or myoelectric potential under mastication. Twelve subjects participated in the experiment and were asked to rate nine adjective-pairs related to the food texture of two types of food. The results showed that the proposed method affects the perception of the hardness, crispiness, chewiness, freshness, and thickness of certain foods.**

Keywords*—*Food Texture; Cross-modal; Vibrotactile Stimuli; Mastication Sound.

I. INTRODUCTION

In recent years, several research efforts have been conducted to improve the experience of eating by making full use of Virtual Reality (VR) technology. When people eat food, they taste the flavor, appearance, aroma, texture, mastication sound, and other elements. Therefore, eating is a cross-modal experience of the five senses. The presentation of auditory, tactile, and other information using multisensory interactions has been reported to affect the perception of food texture during the eating experience. Zampini et al. [1] proposed a method to affect the perception of the crispiness and chewiness of potato chips by amplifying and returning the high-frequency component of the mastication sound generated when eating potato chips. Endo et al. [2] reported that participants felt hardness in soft foods by presenting pseudo-mastication sound generated from electromyogram (EMG) signals of chewing movement. These studies have investigated methods for presenting sensory information, such as auditory and tactile sensation, to specific body parts.

However, few studies evaluated method of presenting vibrotactile information to the entire body. This study focuses on vibrotactile stimuli, and proposes a method to present vibrotactile stimuli by employing mastication sound or electromyogram as input signal in real-time. For comparison, we also generated pseudo-mastication sound from the two input signals described above and presented it under mastication. We conducted psychophysical experiments on two types of food to compare the effects of vibrotactile stimuli and pseudo-mastication sound on food texture perception.

The structure of this paper is as follows. This section explains the background and our approach. In Section II, we present related work. Section III describes our proposed method. Section IV describes a psychophysical experiment. Section V shows the result of the experiment. Section VI discuss the effect of proposed method on food texture. Section VII draws a conclusion.

II. RELATED WORK

The International Organization for Standardization (ISO 11036:2020) defines texture as ”all the mechanical, geometrical, and surface attributes of a product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors” [3]. Thus, tactile and auditory senses are considered to play a significant role in food texture perception.

Eating is not only an essential activity for a living but also an experience of sharing the taste, enjoyment, and pleasure of food. Meals can also be viewed as a form of entertainment. Therefore, improving the dining experience makes food more palatable and improves quality of life. Therefore, various studies have been conducted to improve the dining experience considering meals as entertainment and amusement.

Nakaoka et al. proposed a system called eat2pic [4] that encourages users to develop healthy eating habits. Chopstick sensors recognize what and how much the user eats, and the digital campus is colored according to the type of food. Chewing food slowly and consuming a well-balanced diet will result in the painting reflecting attractive colors and motivating healthy eating habits.

Narumi et al. proposed MetaCookie+ [5] that uses visual and olfactory senses to change the flavor of cookies. For example, the system superimposed a cookie of a different color than the actual one on the Head Mounted Display (HMD) wearer’s field of vision, and added an odor by olfactory display to make him perceive the same cookie as tasting differently. Many of the participants in the experiment tasted chocolate cookies even though they were eating butter cookies.

Other studies have focused on food texture. It has been suggested that the bubble structure of bread affects the food texture [6]. The brittleness of sweet potatoes varies depending on the cooking method, affecting their texture [7].

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Physical feedback-based food texture display has also been reported. Uemura et al. [8] constructed a device employing a crank mechanism and presented the texture of each food by controlling the torque. Hashimoto et al. [9] proposed a straw device, which vibrates the suction pressure in the straw and can reproduce the suction sensation of foods. Niijima et al. [10] presented food texture by presenting Electrical Muscle Stimulation (EMS) to the masseter muscle.

While the physical presence of texture has been proposed, there are also cross-modal approaches to texture. Several studies indicate that cross-modal texture can affect appetite [11] [12]. In general, the elderly have less ability to masticate food than the young. Especially elderly people with impaired masticatory and swallowing functions often have difficulty eating hard foods and are restricted to soft foods only. However, constantaneous eating of soft foods without a crisp texture can cause appetite attenuation. Endo et al. [13] amplified the 250 Hz to 1000 Hz frequency component of the EMG acquired from the masseter muscle under mastication and generated pseudo-mastication sound feedback to the user. They reported that feedback of pseudo-mastication sound by the timing of mastication increased the perception of food hardness, the sense of comfort and satisfaction. Chewing JOCKEY [14] by Koizumi et al. is designed for a typical home dining experience. The system acquires mastication sound and provides audio feedback via bone-conducting headphones, making it less susceptible to ambient noise and conversation. The design does not obstruct conversation during meals by not covering the ears.

III. METHODS

This section explains the two display methods, pseudo-mastication sound and vibrotactile stimuli. The mastication sounds or electromyograms were used as input signals of vibrotactile stimuli.

A. Vibrotactile stimuli

Our proposed method employs whole-body vibrotactile display to enhance the food texture perception. To realize the method, we built a large vibration device by mounting a transducer and amplifier on a wooden chair. The device vibrates the user's whole body from his thighs. By employing the chair-type device, user can feel the vibration without wearing some kind of vibration motors. We used a TST239Silver Transducer (CLARK SYNTHESIS INC.) and a Nobsound TA-21 MiniBluetooth 5.0 DSP digital amplifier for the vibration device. In this study, myoelectric potential or mastication sound were used as input signals of mastication. The myoelectric potential is obtained from an electrode attached to the masseter muscle of the participant, and the mastication sound signal is obtained from a condenser microphone attached to the other masseter muscle. The input signal, either myoelectric potential or mastication sound, is amplified by an amplifier and output from the transducer as vibrotactile stimuli. When seated on a large vibrating device, users can perceive vibrotactile stimuli from their thighs to their whole body according to the timing of mastication. Figure 1 shows the large vibration device created in this study and Figure 2 shows the system configuration of the proposed method.

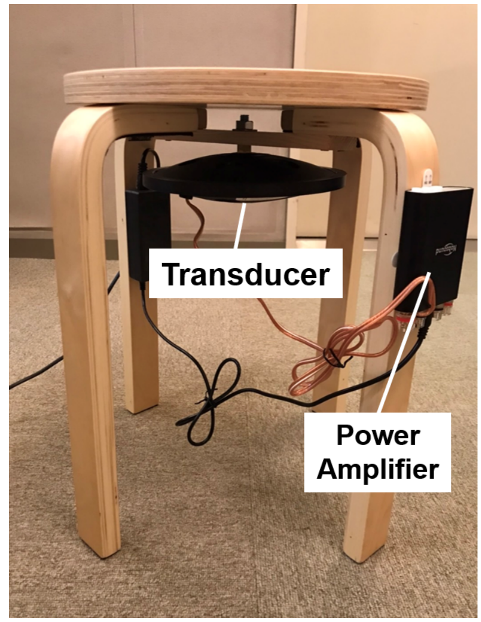

Figure 1. Vibration device

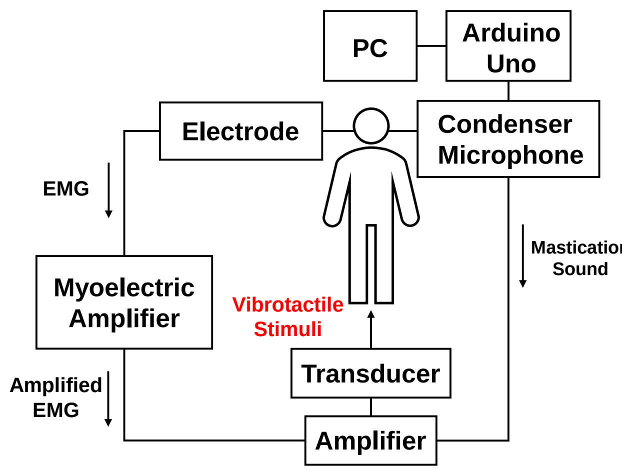

Figure 2. Presenting vibrotactile stimuli

B. Pseudo-mastication sound

We also investigated auditory stimuli for comparison with vibrotactile stimuli. We generated pseudo-mastication sound using a simplified method based on Endo et al [2]. The EMG signal detected under mastication sounds like a noise or the sound of the wind. Endo et al. generated pseudo-mastication sound by amplifying the amplitude with an equalizer using the 250 Hz to 1000 Hz frequency components of the EMG. This study applied a high-pass filter of 250 Hz to the input signals, such as myoelectric potential obtained from an electrode attached to the masseter muscle of the participant, or mastication sound obtained from a condenser microphone attached to the

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other masseter muscle, and output to headphones as pseudo-mastication sound. Figure 3 shows the system configuration for presenting pseudo-mastication sound.

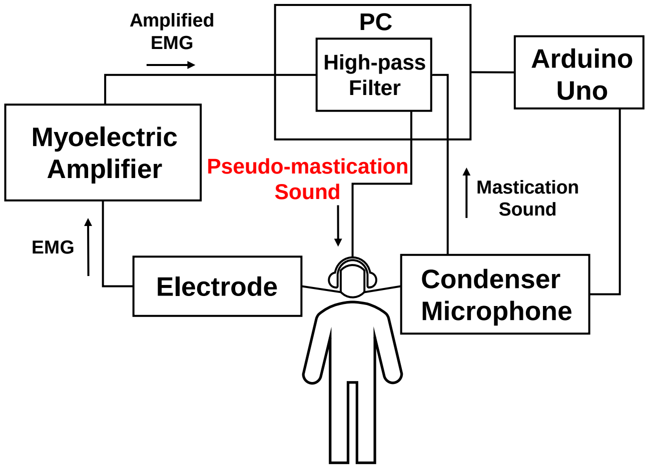

Figure 3. Presenting pseudo-mastication sound

IV. Experiment

We conducted an experiment to investigate whether the food texture perception of two kinds of foods can be affected by presenting vibrotactile stimuli or pseudo-mastication sound under mastication. Twelve participants (9 males and 3 females, with ages ranging from 18 to 22 years and an average age of 21.25 years) took part in this experiment. The same explanation was given to each participant to keep the experimental environment the same. The participants wore an eye mask to shut the visual information out. Further, the experiment was conducted in a soundproof room so that ambient noise information would not affect the perception of food texture.

First, participants were seated at the chair, and were asked to masticate food without listening to any sound by wearing the noise-cancelling headphone (BOSE QuietComfort 15). The condition was treated as control condition and named as condition A. Next, the participants experienced vibrotactile information or pseudo-mastication sound based on their own mastication sound or myoelectric potential during mastication. The conditions of each pair were named as condition B, C, D, and E (Table I).

After the experiment of each condition, they were asked to rate the following nine adjective-pairs on a 7-point Likert scale; "soft - hard," "not crispy - crispy," "sparse - dense," "thin - thick, "not chewy - chewy," "unnatural - natural," "stale - fresh," "uncomfort - comfort," and "not sticky - sticky." The conditions B to E were performed in a random order to eliminate the order effect.

As described in Section II, some foods have different textures depending on the cooking method and bubble structure. Thus, it is desirable to use foods that have already been processed and have little difference in food texture from one individual to another. We chose rice cracker (Setonosioage, KURIYAMABEIKA Co., Ltd.) and gummy (Meiji fruit gummy candy grape, Meiji Co., Ltd.). The characteristic of the rice cracker we chose is soft and crispy texture, and gummy's is elastic, but not too soft. In the experiment, we split the rice cracker in a half and made it into bite-size pieces for easy mastication.

In the experiment during mastication of gummy, the condenser microphone could not collect mastication sound. Thus, we held experiments under mastication of gummy with conditions A, D, and E, except for conditions B and C. Figure 4a and Figure 4b show the overview of experimental scenes and Table II shows the adjective pairs of questionnaires. As a caveat, this experiment was not blind to the food items because the experiments on rice cracker and gummy were conducted independently. In addition, this experiment may not be generalizable because of the male bias of the participants, the lack of control variables for age and ethnicity, and the use of specific foods.

TABLE I. EXPERIMENTAL CONDITIONS

condition	input	output
A	none	none
B	mastication sound	vibrotactile stimuli
C	mastication sound	pseudo-mastication sound
D	myoelectric potential	vibrotactile stimuli
E	myoelectric potential	pseudo-mastication sound

(a). Participant is sitting on the vibrotactile chair

(b). Participant is masticating food

Figure 4. Experimental scene

TABLE II. ADJECTIVE PAIRS OF QUESTIONNAIRES

Question	Item	Scale	Item
Q1 Hardness	Soft	1-2-3-4-5-6-7	Hard
Q2 Crispness	Not crispy	1-2-3-4-5-6-7	Crispy
Q3 Dense	Sparse	1-2-3-4-5-6-7	Dense
Q4 Thickness	Thin	1-2-3-4-5-6-7	Thick
Q5 Chewiness	Not chewy	1-2-3-4-5-6-7	Chewy
Q6 Naturalness of sound	Unnatural	1-2-3-4-5-6-7	Natural
Q7 Freshness	Stale	1-2-3-4-5-6-7	Fresh
Q8 Comfort	Uncomfort	1-2-3-4-5-6-7	Comfort
Q9 Stickiness	Not sticky	1-2-3-4-5-6-7	Sticky

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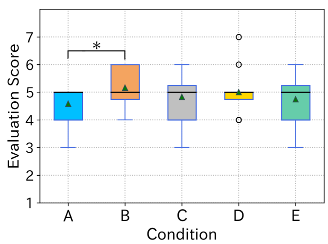
V. Result

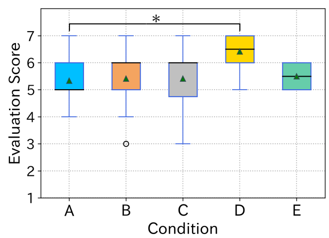
In this section we explain each result of the experiment. First we describe the result of rice cracker, followed by gummy texture result.

A. Perception of rice cracker texture

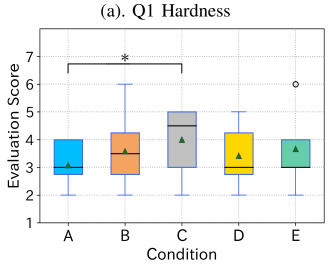
The distributions of the evaluation score in the conditions A to E under rice cracker mastication are shown in Figure 5a to Figure 5h. The triangle in the figure represents the mean, and the black line represents the median. The circle points indicate outlier. Questionnaire data were analyzed between control condition A and other conditions using Wilcoxon signed-rank test. $*$ indicates a significant difference. (p-value was 0.05.)



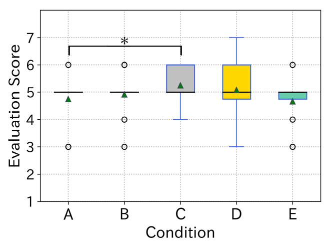
(a). Q1 Hardness



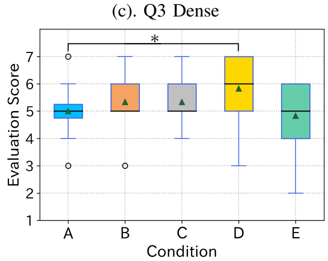
(b). Q2 Crispness



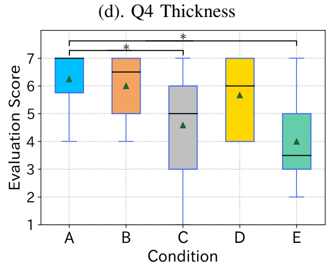
(c). Q3 Dense



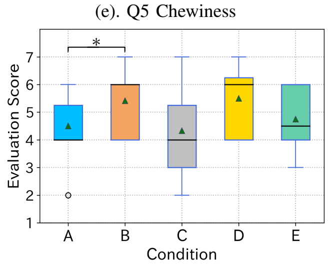
(d). Q4 Thickness



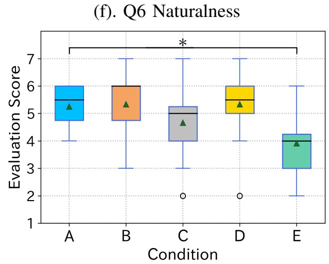
(e). Q5 Chewiness



(f). Q6 Naturalness



(g). Q7 Freshness



(h). Q8 Comfort

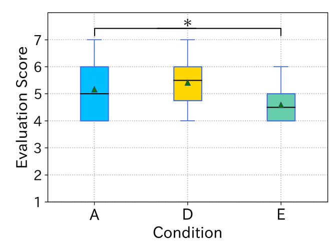
Figure 5. Evaluation score of each condition during rice cracker mastication

Comparing the conditions of A and B, the perceived hardness (questionnaire 1: "soft - hard") was shown significantly greater in condition B (p = 0.0196). Also, perceived freshness (questionnaire 7: "stale - fresh") was significantly greater in condition B (p = 0.0412). Comparing the conditions of A and C, although food texture of rice cracker was perceived as dense (questionnaire 3: "sparse - dense" (p = 0.00496)) and thick (questionnaire 4: "thin - thick" (p = 0.0339)) in condition C, participants perceived the sounds of pseudo-mastication sound as unnatural (questionnaire 6: "unnatural - natural" (p = 0.0313)).

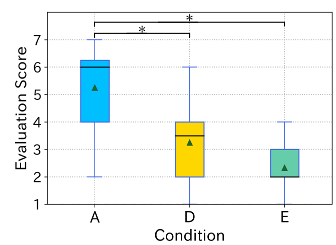
Furthermore, among the conditions of A and D, the judged crispness (questionnaire 2: "not crispy - crispy") was presented significantly greater (p = 0.00589), and the judged chewiness (questionnaire 5: "not chewy - chewy") was shown significantly greater (p = 0.00830) in condition D. In condition E, participants perceived the sound of the rice crackers as unnatural (questionnaire 6: "unnatural - natural" (p = 0.00310)) and perceived uncomfort (questionnaire 8: "uncomfort - comfort" (p = 0.0199)). Therefore, the analysis revealed that vibrotactile stimuli and pseudo-mastication sound presented during mastication affected the food texture perception of rice cracker.

B. Perception of gummy texture

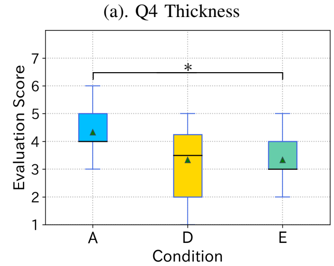
The distributions of the evaluation score given by the participants in conditions A, D, and E during gummy mastication are shown in Figure 6a to Figure 6c. The triangle in the figure represents the mean, and the black line represents the median. The circle points indicate outlier. Questionnaire data were analyzed between control condition A and other conditions using Wilcoxon signed-rank test. $*$ indicates a significant difference. (p-value was 0.05.)



(a). Q4 Thickness



(b). Q6 Naturalness



(c). Q8 Comfort

Figure 6. Evaluation score of each condition during gummy mastication

Among the conditions of A and D, participants perceived the sound as unnatural (questionnaire 6: "unnatural - natural" (p = 0.0311)) in condition D. Moreover, among the conditions of A and E, the perceived thickness (questionnaire 4: "thin - thick") was shown significantly greater (p = 0.0384) ,and participants perceived pseudo-masticaion sound as unnatural (questionnaire 6: "unnatural - natural" (p = 0.00210)), and uncomfort (questionnaire 8: "uncomfort - comfort" (p = 0.0422)). Thus, the analysis showed that vibrotactile stimuli and pseudo-mastication sound presented during mastication affected the food texture perception of gummy.

VI. Discussion

Our results show that the perception of rice cracker and gummy texture are affected both by the vibrotactile stimuli and pseudo-mastication sound during mastication. In particular, vibrotactile stimuli affected food texture perception, which is different from that of pseudo-mastication sound.

A. Effect of vibrotactile stimuli on food texture

When the vibrotactile stimuli were provided, participants were more likely to evaluate rice cracker as having the property of hardness, crispness, chewiness, and freshness. Condition B, in which mastication sound was used as the input signal, affected the perception of the hardness and freshness of the rice cracker. Under the condition B, some participants commented that "I felt the food to be hard more than usual." and "I felt vibration from the chair as if something hit the bottom of the chair."

Condition D, in which a myoelectric potential was used as the input signal, affected the perception of the crispness and chewiness of the rice cracker. Under the condition D, some participants reported that "I felt like I was eating with my whole body." and "I felt the enhanced chewiness of rice cracker."

Regarding the gummy texture, when the vibrotactile stimuli were provided, participants evaluated the perceived sound as more unnatural. Under the condition D, some participants reported that "I felt strange between the vibrotactile stimuli and gummy texture." Since gummy is relatively soft food, the vibrotactile stimuli presented during mastication was different from that of the usual eating environment, and it is thought that some participants felt a sense of discomfort. Under the condition in which vibrotactile stimuli were presented, there was no commonality among the texture perception that showed significant difference between rice cracker and gummy. This suggests that the low-frequency component (0-200 Hz) is significant in these texture perceptions, and affected them differently for rice cracker and gummy.

B. Effect of pseudo-mastication sound on food texture

When the pseudo-mastication sound was provided, participants tended to evaluate rice cracker as denser, thicker, unnatural sounding, and uncomfort. Under the condition C, some participants commented that they heard a chewing sound and felt that the volume of rice cracker had increased when masticating rice cracker.

The pseudo-mastication sound was generated from the air-conducted sound of masticating rice cracker and presented to the headphones of participants. Thus, it is likely that the pseudo-mastication sound modified by the high-pass filter enhanced the perception of density and thickness in condition C. Under the condition E, some participants commented that the pseudo-mastication sound was uncomfort and sounded like an ASMR (Autonomous Sensory Meridian Response) of earpick. The pseudo-mastication sound is generated by applying high-pass filter to myoelectric potential in condition E.

Under the condition E, some participants reported that they felt the pseudo-mastication sound was unnatural, and that they perceived gummy texture more than no sound.

Under the condition in which pseudo-mastication sound was presented, the texture perception, "unnaturalness of sound" and "discomfort" that showed significant difference have a commonality between rice cracker and gummy. This suggests that the high-frequency component of the auditory information may have influenced these texture perceptions. As described in Section VI-A, there was no commonality among the affected texture perception in rice cracker and gummy. Therefore, different frequency bands in vibrotactile information auditory information could have led to differences in affected attributes. In addition, this experiment did not blind to the food items. Since this may have little influence on the result, we consider conducting the study under blind conditions such as randomly presenting food items.

VII. Conclusion

This study proposed a method to present vibrotactile stimuli to the whole body by employing mastication sound or electromyogram as input signal. We investigated whether the food texture of rice cracker or gummy can be affected by presenting vibrotactile stimuli or pseudo-mastication sound during mastication.

The analysis revealed that when the vibrotactile stimuli were provided, participants tended to be perceived the rice cracker texture as harder, crisper, fresher, and the sound as unnatural compared to control condition. In the case of gummy texture, they perceived the sound as unnatural more than usual.

On the other hand, under the presentation of pseudo-mastication sound, participants tended to be perceived the rice cracker texture as denser, thicker, unnatural sounding and uncomfort compared to control condition. In the case of gummy, they were more likely to perceive gummy texture as thicker, unnatural sounding, and uncomfort.

Consequently, our research showed that proposed method affects the food texture perception, and presenting vibrotactile information throughout the body has the potential to improve the eating experience.

Acknowledgement

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