Effect of using chopsticks and spoon on contact order of food and oral cavity and saltiness sensitivity

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Abstract

Effect of using chopsticks and spoon on contact order of food and oral cavity and saltiness sensitivity

Aim The purpose of this study is to reveal effect of contact order of food and oral cavity and saltiness sensitivity between chopsticks and a spoon. **Methods** Prior to main study, the contact order of food and oral cavity in the uses of chopsticks and a spoon was investigated using dental model with electrical touch sensors. Fifteen healthy students ate food with chopsticks and spoons, then saltiness threshold was measured before (PRE) and after (POST) food ingestions. **Results** When using chopsticks, the food contacted to the tongue and then to the palate. Meanwhile, when using a spoon, food contacted to the palate and then to the tongue. Saltiness thresholds increased from PRE to POST for both chopsticks and spoon ($p < 0.05$). Significant higher saltiness threshold than control at POST was found in chopsticks ($p < 0.05$), but not in spoon ($p > 0.05$). **Conclusion** From these results, we suggested that using chopsticks and a spoon changes the contact order of food and oral cavity, and use of chopsticks during eating decreases saltiness sensitivity.

箸とスプーンの使用が食品と口腔内の接触順序及び塩味感受性に与える影響

目的 本研究の目的は、箸とスプーンの使用が食品と口腔内の接触順序及び塩味感受性に及ぼす影響を明らかにすることである。**方法** 本研究に先立ち、電気式タッチセンサー付き口腔模型を用いて、箸とスプーン使用時の食品と口腔内の接触順序を調査した。若齢男女 15 名が箸とスプーンを使い塩味の食品を摂取し、食品の摂取前(PRE)と摂取後(POST)に塩味閾値が測定された。**結果** 箸を使用すると食品は舌に接触した後、口蓋に接触した。一方で、スプーンを使用すると食品は口蓋に接触した後、舌に接触した。塩味閾値は箸、スプーンともに PRE から POST にかけて上昇した（$p<0.05$）。POST において箸はコントロールより有意に高い塩味閾値が見られたが（$p<0.05$）、スプーンでは見られなかった（$p>0.05$）。**結論** これらの結果から、箸とスプーンの使用により食品と口腔内の接触順序が異なり、また箸の使用は塩味感受性を下げる事を示唆した。

筷子和勺子使用対食物-口腔接触顺序和咸味敏感性的影响

目的 本研究的目的是阐明筷子和勺子的使用対食物与口腔接触顺序以及対咸味的敏感性的影响。**方法** 在口腔模型的舌头和上颚安装传感器，研究使用筷子和勺子时食物与口腔接触的顺序。15 名青年男女使用筷子和勺子摄取咸味食物，并在进食前（PRE）和进食后（POST）测量咸味阈值。**结果** 使用筷子时，食物先接触舌头，然后接触上颚。当使用勺子时，食物先接触上颚，然后接触舌头。筷子和勺子的咸味阈值从 PRE 到 POST 增加（$p<0.05$）。筷子在 POST 上显示出明显高于対照组的咸味阈值（$p <0.05$），但在勺子上没有（$p> 0.05$）。**结论** 这些结果表明，食物与口腔接触的顺序因筷子和勺子的使用而异，筷子会降低咸味敏感性。

Introduction

Salt intake has been reported to be high in the Japanese population (Ohta et al., 2005). While sodium is essential for normal human functioning, current sodium intakes far exceed recommendations for good health. WHO recommends that adult consume less than 5g of salt per day (WHO, 2020). However, according to National Health and Nutrition Survey in 2019 by Ministry of Health, Labor, and Welfare of Japan, most Japanese consume too much salt, on average 10g per day. The following points can give as reasons. First, the Japanese diet has high salt intake from seasonings, such as salt per se; soy sauce and miso; and salted foods, such as pickled vegetables and salted seafood (Tsugane & Sawada, 2014). Second, excessive exposure to high-salt foods may change the taste perception, which results in the overconsumption of sodium (Kim & Lee, 2009).

High sodium consumption contributes to high blood pressure and increase the risk of heart disease and stroke (WHO, 2020). Hence, salt reduction helps to reduce blood pressure and risk of cardiovascular disease, stroke, and coronary heart attack. As sodium reduction strategies, not adding salt during the preparation of food, and choosing products with lower sodium content have been applied. On the other hand, traditional methods of salt reduction are problematic because drastically reducing the salt content of processed meat products can lead to defects in food quality and safety (Xiong et al., 2020). Thus, there is a need for further methods that enable salt reduction by increasing the salt sensitivity of the receiver.

It is well known that saltiness sensitivity changes due to various factors. Previous studies indicated that oral temperature (Cruz & Green, 2000), contact order of food and oral cavity (De Wijk et al., 2011), food temperature (Green & Nachtigal, 2012), and umami taste (Fuke & Shimizu, 1993) affect the perception of saltiness. Changing contact order of food and oral cavity are particularly useful for incorporating into daily meals. Chopsticks and spoons are mainly used in many countries when eating (Dorota et al., 2016). Due to shapes of chopsticks and spoon, their delivering processes of food in oral cavity should be different between the uses of them.

The human taste system consists of taste buds, which are groups of 50-100 taste cells that are found throughout the oral cavity (Simon & Gutierrez, 2017). Simple taste reaction time is from 50ms to 2000ms durations. Taste bud cell communicate with sensory afferent fibers and may also exchange information with adjacent cells (Roper, 2006). Once a taste signal is generated in a taste cell, neurotransmitters including adenosine triphosphate (ATP) and serotonin are secreted. ATP secreted from receptor cells also acts on neighboring taste cells to stimulate their release of serotonin (Roper, 2007). Taste buds are located throughout the oral cavity including the tongue and the palate, but Earnest & John (1961) reported most of the taste buds are on the dorsal side of the tongue. It has been widely acknowledged that responses to tastes vary across the human tongue and other parts of the mouth such as soft palate depending on kind of taste (Julie et al., 2018). It is known that the tongue is more sensitive to saltiness than the palate (Virginia, 1974). Similarly to other physiological senses, the sense of taste exhibits sensory adaptation – that is, a gradual loss of sensation during prolonged stimulation (McBurney, 1985). In the case of salt, taste intensity increases within a few hundred milliseconds and then rapidly falls (Henney et al., 2010).

The purpose of the present study is to reveal effect of using chopsticks and a spoon on contact order of food and oral cavity and saltiness sensitivity. The results from this study would be useful to propose further methods that enable salt reduction while increasing saltiness perception. We hypothesized that when eating with chopsticks, food contacts to tongue first and then contacts to palate, whereas when eating with a spoon, food contacts to palate first and then contacts to tongue. In addition, in previous study, prolonged stimulation of receptors often leads to a gradual loss of sensation, which is called adaptation. The time frame of the adaptation of sodium receptors is expected to be on the order of 100 ms to a few seconds (Busch et al., 2009). Furthermore, previous study has shown that the ingestion of salty food decreases the sensitivity of sodium receptors (Busch et al., 2009). Also, the tongue is more sensitive to saltiness than the palate due to the different distribution of taste buds (Gravina, 2009). In other words, when using a spoon, the time that the food contacts to the tongue is shorter and adaptation is less likely to occur. Moreover, it can be assumed that a spoon inhibits saltiness sensitivity of the tongue. Therefore, we also hypothesized that the decrease in saltiness sensitivity after eating with a spoon is smaller than the decrease in saltiness sensitivity after eating with chopsticks.

Materials and Methods

Experiment 1: Contact order of food and oral cavity between using chopsticks and a spoon

Experimental design

The contact order of food and oral cavity was measured with a sensor (a custom made measurement system). The aluminum foil was attached as electrical conductor to the tongue and the palate of the dental model (D216, ErlerZimmer GmbH&Co. KG., Germany) (Fig. 1) with adhesive tape. A 3.5 cm cube of simulated food was also made from aluminum foil, which is based on the shape of food used in experiment 2. The mouth of dental model was first open, and food was then put into the mouth of it using chopsticks (Maruki Co., Ltd., Osaka, Japan) and a spoon (Maruki Co., Ltd., Osaka, Japan), respectively (Fig. 2). Finally, the mouth of the dental model was closed, and chopsticks and a spoon were pulled out.

Sensor

Electrical signal from the sensor were sampled using an analog-to-digital convertor (PowerLab16/35, AD Instruments, Melbourne Australia) and synchronized with a personal computer using LabChart software (version 8.1.13; AD Instruments, Melbourne Australia). This sensor is energized when it comes in contact with aluminum foil.

Experiment 2: Saltiness sensitivity following food ingestion with chopsticks and a spoon

Participants

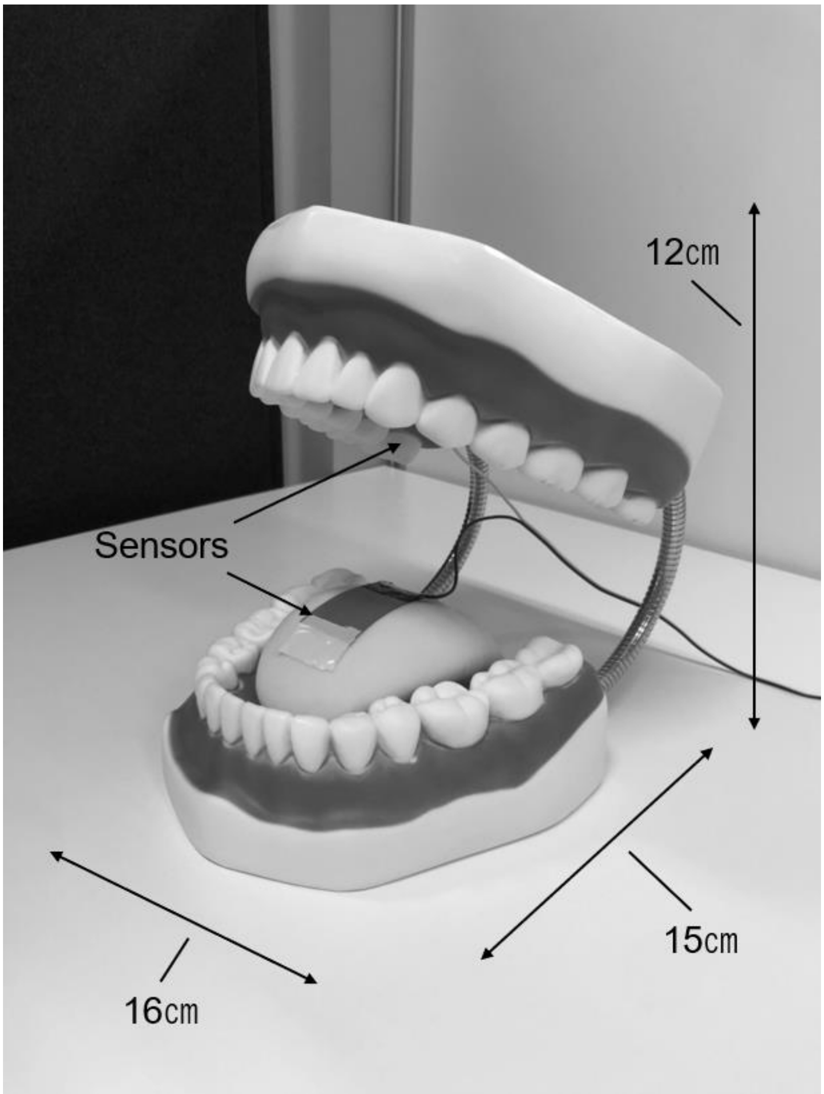

Fig. 1 A dental model and sensors.

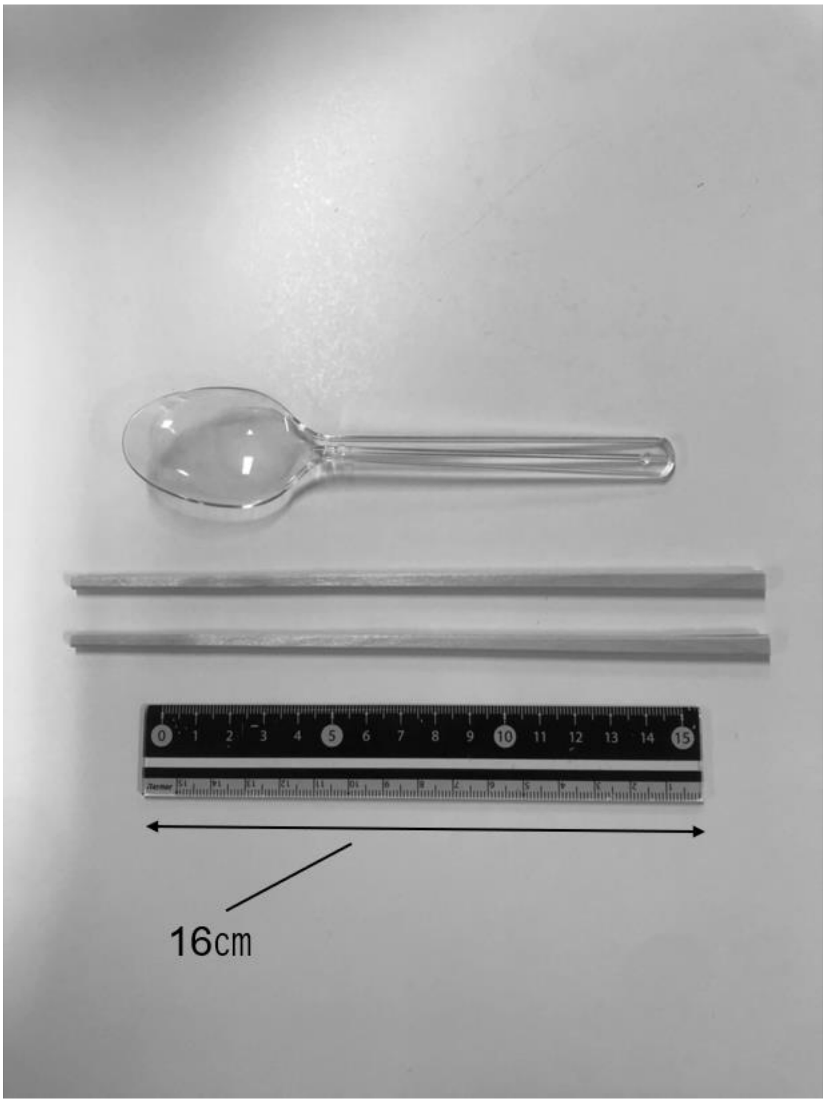

Fig. 2 Chopsticks and a spoon.

Fifteen healthy young adults (mean±SD: age: 21.1±0.8 years, height: 163.1±6.2 cm, weight: 53.9±9.7 kg) participated in this study. The participants gave written informed consent for this study after receiving a detailed explanation of the purposes, potential benefits, and risks associated with participation in this study. All participants were instructed not to smoke or eat at least one hour before the experiment to avoid the effect of smoking and diet on the saltiness threshold.

Experimental design

First, participants performed taste test to measure their saltiness threshold. After this measurement (PRE), each participant ate test food (15g) with chopsticks or a spoon. Participants were first instructed to hold the food in their mouth without chewing, after 5 seconds the food was spat out, then participants were indicated the saltiness intensity of food with visual analogue scale between one and nine (One is not present at all, nine is extremely strong). Finally, participants performed taste test (POST) again to measure their saltiness threshold. In this study, the participants had been asked to conduct four trials; ①When eating food with chopsticks, the food contacts to the tongue first and when the mouth is closed and the chopsticks are pulled out, the food contacts to the palate. We used chopsticks to put the food into the participants' mouths (CHO: chopsticks), ②When eating food with a spoon, the food contacts to the palate first, then when the mouth is closed, the spoon contacts to the tongue, and finally when the spoon is pulled out, the food contacts to the palate. We used spoon to put the food into the participants' mouths (SPO: spoon), ③When food is placed on the tongue with chopsticks, the food contacts to the tongue. We used chopsticks to put the food into the participants' mouths. (TON: tongue), ④no intervention (CON: control). In this experiment, two comparisons were made: salty food vs placebo food (Measurement A), chopsticks vs a spoon (Measurement B). In Measurement A, 5 people were targeted for each trial. In Measurement B, 15 people were targeted. The order of the trials was random. Participants were asked to gargle with water before and after each trial. Spoon was 16 cm in length, 8 mm in depth, and chopsticks was 20 cm in length (Fig. 2).

Taste tests

The quantitative clinical gustometry using filter paper discs and sodium chloride solution (Taste disc, Sanwa Chemical Laboratory Co., Ltd., Aichi, Japan) were performed. Thirteen kinds of sodium chloride solutions (0.1%, 0.3%, 0.5%, 0.7%, 0.9%, 1.1%, 1.8%, 2.3%, 2.8%, 3.3%, 3.8%, 4.3%, and 5%) were used in this study and the concentrations of sodium chloride solution were determined by preliminary experiment (Fig. 3). We measured saltiness sensitivity at the tip of the tongue because this region has a high density of taste buds and high sensitivities to taste stimuli. Taste test was performed as follows. First, a filter paper disc (8 mm diameter) soaked in salty solution was placed on the tip of the tongue with tweezers (M 025-121440-00, Kawamoto Co., Ltd., Osaka, Japan) for 3 seconds, ant then immediately we removed the disc and disinfect the tweezers with absorbent cotton (Sanicot EQ, AS ONE Co., Ltd., Osaka, Japan). The test was started from concentration number 1 and gradually increased. The lowest concentration for which the participant reported the existence

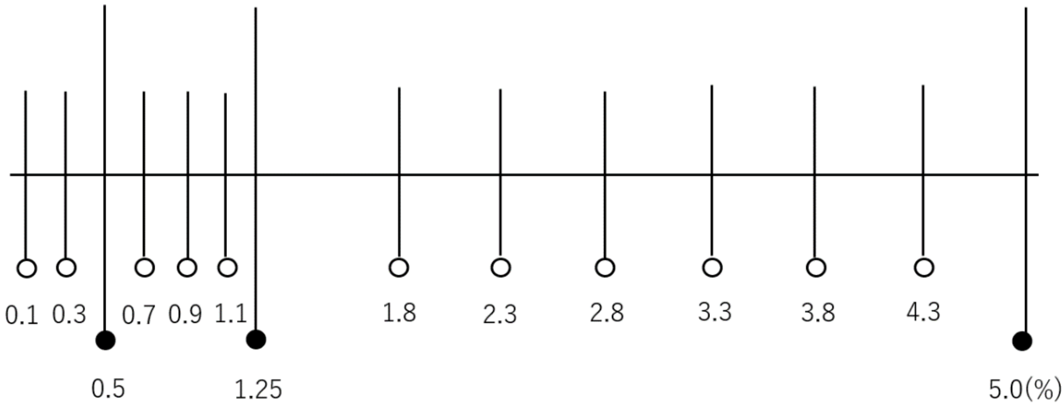

Fig. 3 Concentration of sodium chloride solution used in this study. ●original scale in taste disc. ○ modified scale in taste disc.

of saltiness stimuli was taken as the recognition threshold (Fukunaga et al., 2005). Taste tests were performed using the same method for PRE and POST.

Food

Gelatin gel of sodium chloride solution was used in this study. The concentration of sodium chloride solution was set to 1.8%. The salinity of food was determined based on a preliminary study to measure participants' saltiness threshold. This study used 15g for one bite (Zijlstra et al., 2009). Sodium chloride solution was heated at 50-60°C in a pan, and gelatin powder (granule gelatin, JELEAF Co., Ltd., Shiga, Japan) was dissolved in water. The mixture was cooled at room temperature for 2 hours and then at 4-5°C for 24 hours. Gelatin gel was cut into cubes with sides of 3 cm in length (Fig. 4).

Additional test for saltiness intensity of food

Five of the fifteen participants ingested placebo food. Water gelatin gel was used in this study. First, participants performed taste test to measure saltiness threshold, and then ate placebo food under TON, SPO, and CHO conditions. After 5 seconds the food was spat out, then participants were indicated the saltiness intensity of food on a scale of one and nine. Finally, participants performed taste test again to measure their saltiness threshold.

Statistics

All data are provided as mean and SD. Because we confirmed that data was not normally

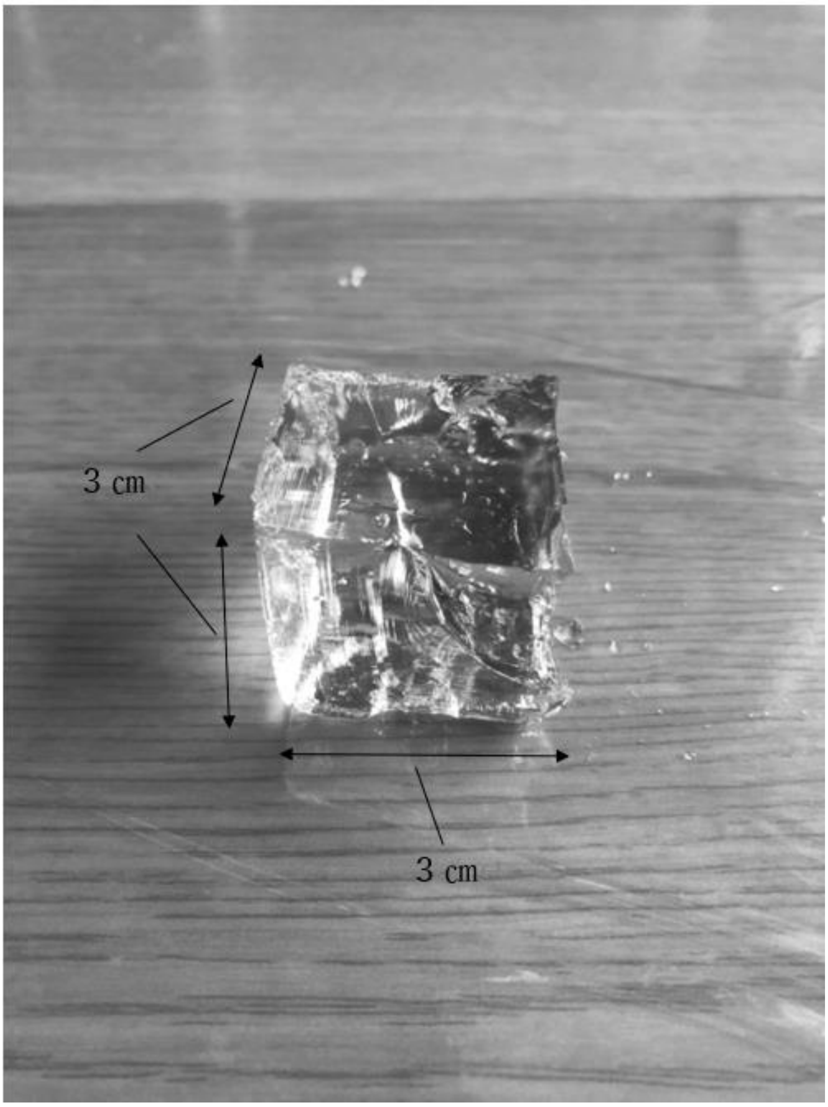

Fig. 4 Test food used in the present study.

distributed by Shapiro-Wilk test, the non-parametric analysis was used in this study. Subjective saltiness intensity of food, and saltiness threshold of PRE and POST were compared between salty food and placebo using Wilcoxon signed-rank test. Saltiness threshold of PRE and POST, and rate of changes of saltiness threshold were compared between the trials using Friedman test. When there was a significant effect in Friedman test, degree of change was compared between the trials by using post hoc test. The level of statistical significance was set at $p < 0.05$. Statistical analyses were performed using SPSS software (version 25; SPSS, Tokyo, Japan).

Results

Experiment 1: Contact order of food and oral cavity between using chopsticks and a spoon

Fig. 5 shows the contact order of food and oral cavity in simulated delivering of food into mouth with chopsticks. When using chopsticks, food contacted to the tongue and then to the palate of the dental model. Also, Fig. 6 shows the contact order of food and oral cavity in simulated delivering of food into mouth with a spoon. When using a spoon, food contacted to the palate and then to the tongue of the dental model.

Experiment 2: Saltiness sensitivity following food ingestion with chopsticks and a spoon

Significant increases in saltiness threshold from PRE to POST were observed in TON, SPO, and CHO ($p < 0.05$) but not in CON ($p > 0.05$) (Fig. 7). There was no significant difference between the groups in saltiness threshold at PRE ($p > 0.05$) (Fig. 7). A significant effect of trial in Friedman test was observed in saltiness threshold at POST ($p < 0.05$), and a significant difference was observed between CHO and CON at POST ($p < 0.05$) (Fig. 7). There were no significant difference between the groups in rate of changes of saltiness threshold ($p > 0.05$) (Fig. 8).

There were significant differences in subjective saltiness intensity between salty food and placebo in CHO and TON ($p < 0.05$), while there were no significant differences in subjective saltiness intensity between salty food and placebo in SPO ($p > 0.05$) (Fig. 9).

There were no significant differences in saltiness threshold between PRE and POST in placebo in TON, SPO, and CHO ($p > 0.05$) (Fig. 10).

Discussion

In the present study, we simulated contact order of food and oral cavity when ingesting food using chopsticks and a spoon. When using chopsticks, the food contacted to the tongue and then to the palate, and when using a spoon, food contacted to the palate and then to the tongue as expected. The present study thus confirmed that delivery process and contact of food in oral cavity is different between eating with chopsticks and spoon. Although there was no significant difference in saltiness threshold of POST between CHO and SPO ($p > 0.05$) (Fig. 7), a significant difference between CHO and CON was observed in saltiness sensitivity of POST ($p < 0.05$) (Fig. 7). These results support the

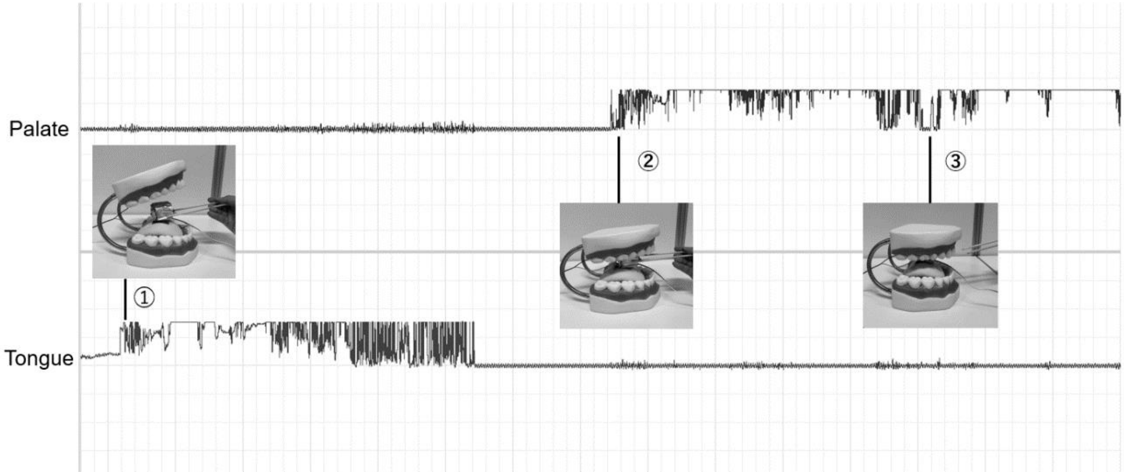

Fig. 5 The contact order of food and oral cavity when using chopsticks determined by electrical signal. ①When eating food with chopsticks, the food contacted to the tongue and a sensor attached to the tongue of the dental model reacted. ②When the mouth of dental model was closed, the food contacted to the palate and a sensor attached to the palate of the dental model reacted. ③The chopsticks were pulled out.

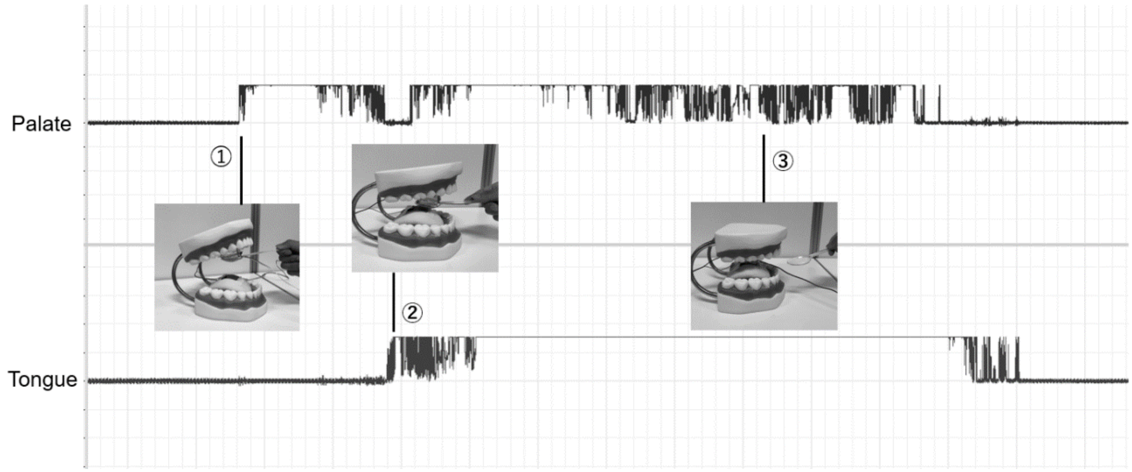

Fig. 6 The contact order of food and oral cavity when using a spoon determined by electrical signal. ①When eating food with a spoon, the food contacted to the palate and a sensor attached to the palate of the dental model reacted. ②When the mouth of dental model was closed, the spoon contacted to the tongue and a sensor attached to the tongue of the dental model reacted. ③When the spoon was pulled out, the food contacted to the palate.

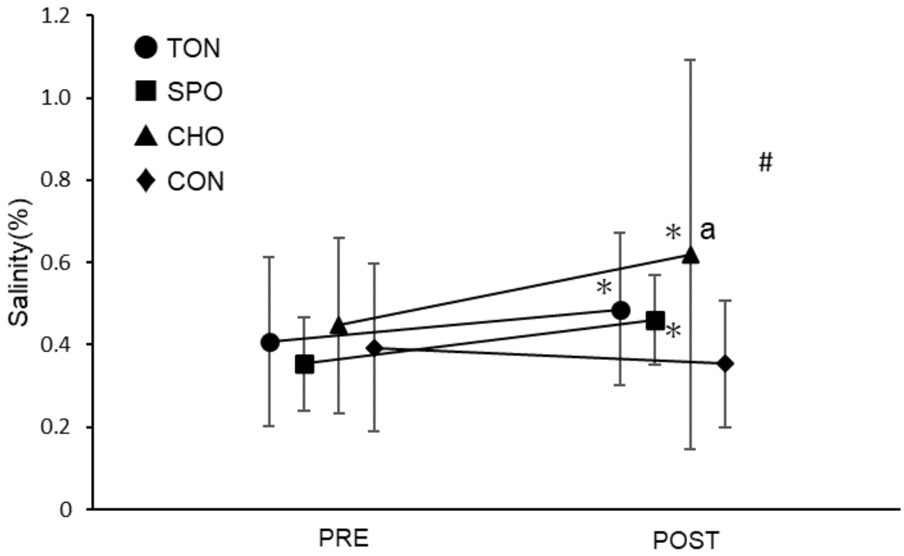

Fig. 7 Mean (±SD) of saltiness threshold in salty food between PRE and POST in tongue (TON), in spoon (SPO), in chopsticks (CHO), and in control (CON). * $p < 0.05$ between PRE and POST (Wilcoxon test). # $p < 0.05$ at POST (Friedman test). a $p < 0.05$ vs CON.

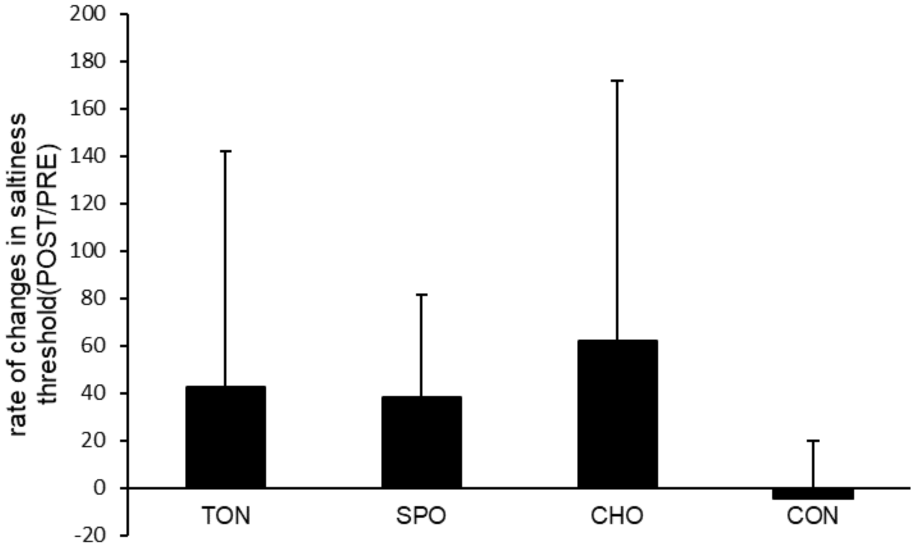

Fig. 8 Mean (±SD) of rate of changes in saltiness threshold between tongue (TON), spoon (SPO), chopsticks (CHO), and control (CON).

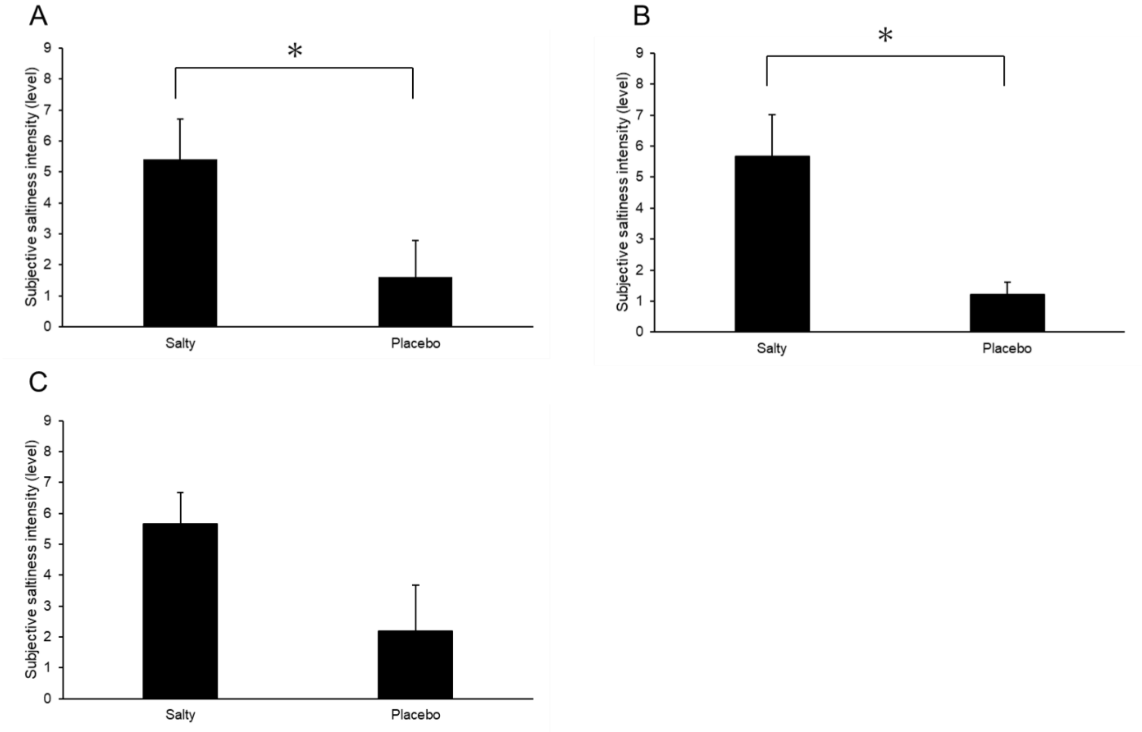

Fig. 9 Mean (±SD) of subjective saltiness intensity between salty food and placebo in tongue (TON) (A), Mean (±SD) of subjective saltiness intensity between salty food and placebo in chopsticks (CHO) (B), Mean (±SD) of subjective saltiness intensity between salty food and placebo in spoon (SPO) (C). $^{*}p < 0.05$

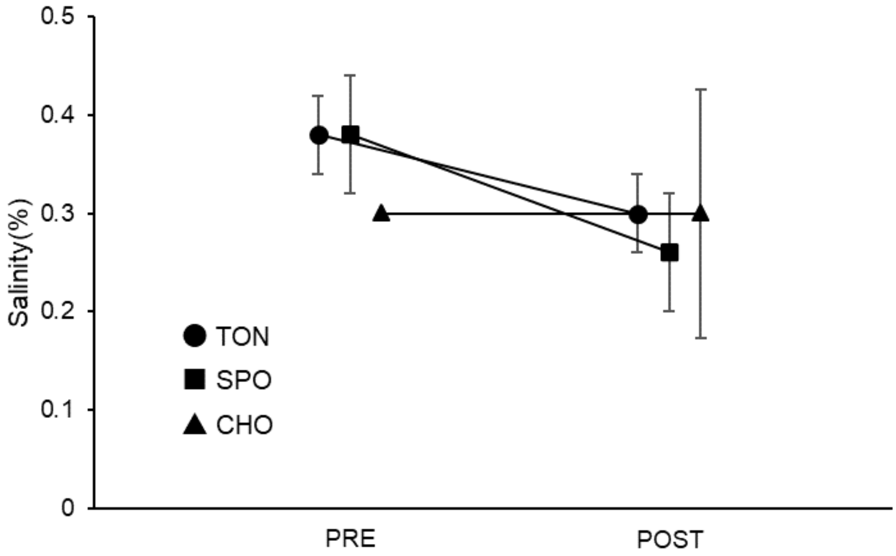

Fig. 10 Mean (±SD) of saltiness threshold in placebo between PRE and POST in tongue (TON), in spoon (SPO), and in chopsticks (CHO).

hypothesis that the decrease in saltiness sensitivity after eating with a spoon is smaller than the decrease in saltiness sensitivity after eating with chopsticks.

There was no significant difference in saltiness threshold between PRE and POST in CON. Due to high sensitivity of saltiness in taste sensors, it was assumed that saltiness threshold may be changed even by slight stimulus of taste such as the taste test (Funahashi, 2012). However, no significant differences in saltiness threshold between PRE and POST was found in CON ($p > 0.05$) (Fig. 7). This means that saltiness threshold could be unchanged following taste test used in the present study.

On the other hand, There were significant differences in saltiness threshold between PRE and POST in salty food in CHO, SPO, and TON ($p < 0.05$). These results show that sensitivity of saltiness becomes lesser following salty food. In addition, previous study has shown that the ingestion of salty food decreases the sensitivity of sodium receptors (Busch et al., 2009), and it was confirmed that salt sensitivity changes with food ingestion in this study.

Significant greater decrease in saltiness sensitivity comparing to CON was observed in CHO ($p < 0.05$), but not in SPO and TON ($p > 0.05$). There was no significant difference in saltiness threshold of POST between CHO and SPO. In previous studies, the saltiness sensitivity of the palate is significantly lower than that of the tongue (Virginia, 1974). In a preliminary experiment, we measured the saltiness threshold of the palate by filter paper method. However, all participants were unable to recognize existence of saltiness stimuli at the highest concentration of sodium chloride solution (20%). These results indicate most of the salty perception can be from the tongue. The two main reasons for the difference between chopsticks and spoons were whether the food touched the tongue first, and whether the food touched the tongue directly or after a substance other than food touched the tongue. The former idea could be based on the difference between CHO and TON; the difference between CHO and TON is whether or not the mouth was closed after the food was placed on the tongue. This could mean that contact with taste receptors other than the tongue could have affected saltiness sensitivity. However, there was no significant difference in the saltiness threshold between CHO and TON. Therefore, it is possible that food contact with the palate is not as important for the perception of saltiness. The latter idea is considered from an additional experiment using placebo and salty food. There was no significant difference in subjective saltiness intensity between salty food and placebo in SPO ($p > 0.05$), while significant differences between salty food and placebo were found in TON and CHO ($p < 0.05$) (Fig. 9). Since most participants didn't feel salty in placebo food and felt salty in salty food, SPO inhibits saltiness sensitivity of the tongue. Frey (2008) reported that taste perception was evoked even when the control stimulus is an apparently tasteless one (e.g., water). Hence, it is possible that some intervening substance altered the sense of taste.

There was no significant difference in saltiness threshold between PRE and POST in placebo in CHO, SPO, and TON. Appelqvist et al. (2016) reported that residues of foods and beverages often coat the oral mucosa after consumption, which may impact on the temporal perception during eating. Once a taste signal is generated in a taste cell, neurotransmitters including ATP and serotonin are secreted. ATP secreted from receptor cells also acts on neighboring taste cells to stimulate their release of serotonin, which spreads the taste in the oral cavity (Roper, 2007). In other words, prior contact of the food with the oral cavity other than the tongue when consuming the food with a spoon may have altered the taste of the food.

There was no significant difference in the rate of changes of saltiness threshold. This result can be explained by very large inter-individual differences as the rate of changes was very scattering data (Standard deviation, CHO: 109.7, SPO: 43.2, TON: 99.2 and CON: 24.1).

In conclusion, we compared the contact order of food and oral cavity and saltiness sensitivity between chopsticks and a spoon. When using chopsticks, food contacted to tongue and then to palate. Meanwhile, when using a spoon, food contacted to palate and then to tongue. In addition, significant increase in saltiness threshold than control was found after the use of chopsticks ($p < 0.05$), but not after the use of spoon ($p > 0.05$). Thus, we suggested that using chopsticks and a spoon change the contact order of food and oral cavity, and use of chopsticks during eating decreases saltiness sensitivity.

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