Controlling Saltiness without Salt: Evaluation of Taste Change by Applying and Releasing Cathodal Current

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1. ABSTRACT

In this study, we evaluate the taste intensity of food when a saltiness enhancer is applied, for verifying the effectiveness of our system. In a previous study, we proposed a saltiness enhancer using a cathodal current based on the work of Hettinger et al. However, we received feedback from subjects that other tastes (e.g., sourness and bitterness) are also enhanced. Therefore, we conducted experimental tests to compare the intensity of the fundamental tastes and a metallic taste over three phases: before application of current, during application of current, and after the release of current.

Categories and Subject Descriptors

H.5.m. [Information interfaces and presentation: Miscellaneous]

Keywords

Taste; Cathodal current; Enhancing saltiness

2. INTRODUCTION

In practice, when a person wants to eat salty food, they want saltiness, not additional salt. Of course, sodium is important in our lives because it plays a role in maintaining the proper distribution of water and osmotic pressure in extracellular fluid compartments. This ion must be provided to the organism through food intake because it cannot be produced by the body.

However, the amount of sodium our bodies needs is approximately 0.5 g per day. Flegel et al. reported that some people living in the Amazon region consume less than 1 g of salt per day [1]. High sodium intake leads to hypertension and coronary disease; therefore, the WHO recommends that people should consume less than 5–6 g of salt per day [2]. However, the populations of many countries consume 10 g or more of salt per day.

The food industry has developed foods and made recipes with reduced salt. However, Busch et al. found that decreasing the salt content in foods leads to a decrease in food acceptability by consumers, because decreasing the salt content tends to make food bland [3]. Reducing salt intake tends to play a role in causing a lack of satiety, which may lead to people giving up the low salt diet.

It should be noted that we need salty food to reduce our additional appetite for saltiness, such as after ingesting the sodium our bodies need. Hence, some researchers have tried to reduce salt intake without changing for nutritional value. We also proposed a saltiness enhancer using a cathodal current. This proposal is based on Hettinger's research, which revealed that saltiness is changed if cathodal current is applied and released [4].

We found that the saltiness of food is further enhanced when cathodal current is applied and released immediately after we start to eat. However, subject feedback showed that other tastes were also enhanced (in addition to saltiness). Therefore, we conduct an experiment for evaluating the taste intensity of five fundamental tastes and metallic taste using our system.

3. SALTINESS ENHANCER

In 2009, Hettinger et al. revealed that cathodal current selectively inhibits salty and bitter-salty tastes [4]. They also found that saltiness tends to recover and increase after the release of current. This is noteworthy because electricity tends to add a slightly metallic taste.

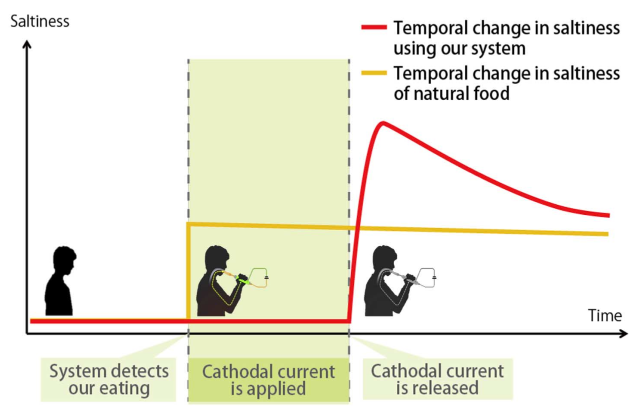

Figure 1. Saltiness expected by proposed system

We used this knowledge to develop a saltiness enhancer that includes components to detect the actions of eating and drinking and to apply a cathodal current to the tongue through food and beverages. We use the results of Hettinger et al. in a technological application; we expect that the perception of saltiness will be enhanced when cathodal current is applied and released immediately after the subject starts to eat. Therefore, we developed a system to detect eating and drinking activities and applied and released a cathodal current in response (Figure 1).

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3.1 Experimental apparatus

The proposed system includes a detection system and a cathodal current application system. The detection system monitors eating and drinking. In response, the cathodal current application system controls the cathodal current (Figure 2).

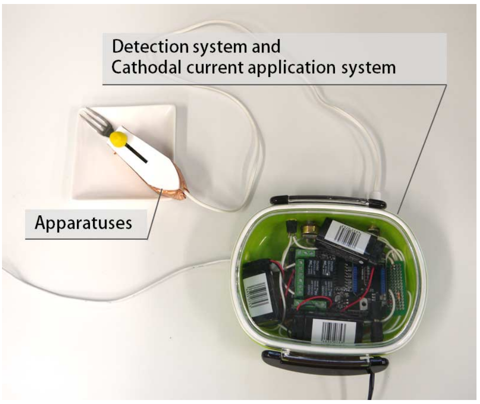

Figure 2. Prototype of saltiness enhancer

3.1.1 Detection system

We previously proposed a system with electric taste adding apparatuses that detects eating and drinking activities [5]. Single-pole apparatuses have one electrode attached to the food and one electrode attached to the subject's body (Figure 3). The circuit is completed when the subject eats or drinks, allowing the detection of activity.

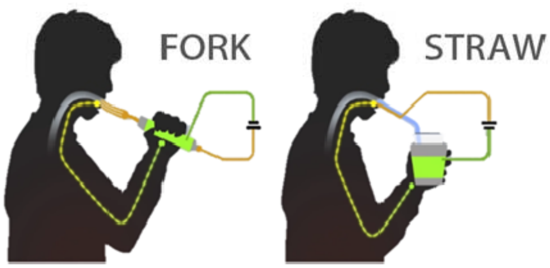

Figure 3. Circuit of single-pole type apparatuses

The detection system monitors the voltage shifts in a circuit composed of a battery and electric taste adding apparatuses. We use a voltage-dividing circuit whose output is fed into the AnalogIn port of an Arduino microcontroller. The user is deemed to be eating or drinking when this voltage exceeds a certain threshold. The threshold varies between individuals, and thus, we must calibrate the system for each user.

3.1.2 Applying cathodal current

This system applies cathodal current briefly when the user eats or drinks. The circuit uses a relay shield for Arduino (made by SeeedStudio) between the battery and the taste-adding apparatuses.

When the detection system detects eating or drinking, the relay is triggered and completes the circuit. Shortly afterwards, the relay switches back to the open state, stopping the current. The length of the cathodal current pulse can be adjusted by the user. The detection system can malfunction if it detects the voltage applied by the cathodal current system. Therefore, we deactivate the detection system while the cathodal current is applied, using a relay in the line between the detection system and the battery.

In addition, we made the apparatuses look like eating utensils (cups and forks) to improve acceptability (Figure 4). These apparatuses each have a potentiometer to control its output voltage. We can use a DC battery (18 V), waveform output system (post-amplifier), and a polarity reversing circuit to control the output voltage and pattern without requiring a potentiometer. For safety, we used a silver fork and a silver pole as electrodes in contact with food and drink.

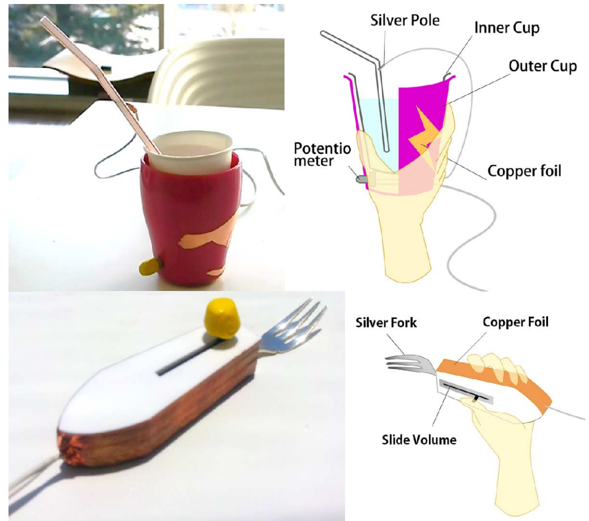

Figure 4. Apparatuses

4. PRELIMINARY EXPERIMENT

In a previous study, we conducted a preliminary experiment to verify the effectiveness of our system [6]. We investigated two issues: whether the subject could feel the differences in taste during the application and release of cathodal current, and whether the subject could taste increased saltiness after the release of the cathodal current.

We conducted this experiment with 14 subjects (13 males, aged between 21 and 25) who had given prior consent to receive electric stimuli. After the calibration trial to adjust settings and the main trial to apply and release the cathodal current, the experimenter asked the subjects whether they could perceive any change in the taste when the food was in contact with the tongue. If they did, the experimenter asked when they felt the taste and saltiness increased. The experimenter also casually asked about the features of the taste as a free answer question. After the main trial, the experimenter had the subjects taste the attached food with a fork, without applying a cathodal current. The experimenter asked which taste was stronger, the taste after the release of the cathodal current or the food's natural taste.

Results showed that subjects perceived a difference in taste in 39 trials (92.9%). 11 subjects could perceive the difference every time, and three subjects could perceive it two times. In all the trials where subjects perceived a difference, they felt that the taste after the release of current was stronger and saltier than that during the application of current. Furthermore, 10 subjects felt that the taste after the release of current was stronger than the natural taste of the food.

In the free answer test, seven subjects commented on the saltiness of the food. One participant felt that the saltiness resembled that of Japanese pepper. Furthermore, two subjects felt a difference in texture, and one participant each felt a difference in sourness and in temperature between during and after the current application. In addition, one subject said that the taste became stronger after the current was released, and decreased in intensity over time.

Furthermore, three subjects commented that the second and third trials gave a more natural flavor than the first trial.

5. FEEDBACK FROM EXHIBITS

We exhibited our systems at several conferences and events (CHI2013, interaction2013, wiss2013, and MFT2012). Over 200 attendees experienced the effects of our devices. At these times, attendees who agreed with our consent agreement participated in our demonstration (Figure 5).

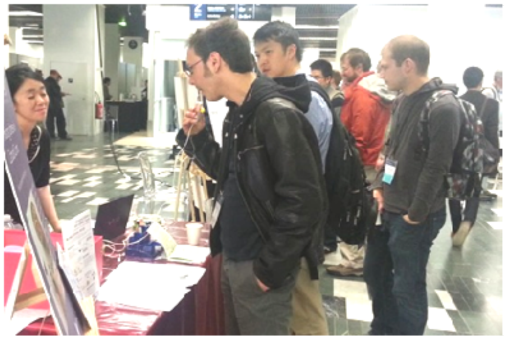

Figure 5. Exhibits at the conference

The data recorded at our exhibits show that our system can be used as a saltiness enhancer because most attendees perceived a change in saltiness when using the devices. However, some attendees could not perceive the effects we expected. We categorized this feedback into three cases: in two cases, attendees could not perceive the effects we expected, and in one case, they perceived other effects than a change of saltiness.

Several attendees could not perceive any change in taste. Attendees said that they could perceive a slight change in taste, but thought that they would not notice if these stimuli were used during daily meal. A few subjects in the preliminary experiment also described a similar reaction. We consider that the reason for this case is the person's environment, i.e., the attendee's eating habits. In these exhibits, we did not ask about attendees' eating habits and salt intake. Hence, we should attempt an experiment that includes daily logging or eating habits and taste sensitivity.

Additionally, some attendees reported a metallic taste and a tingling sensation. These sensations decreased with decreasing intensity in cathodal current, and the users could feel the effects of the proposed system. This effect might be caused by the individual variability of body resistance. Body resistance varies with the situation; for example, if we sweat, the body resistance decreases. A certain level of cathodal current inhibits saltiness; however, strong cathodal currents tend to result in bitterness, a metallic taste, and a haptic stimulus. Therefore, we will improve our system to allow adjustment of the output voltage with respect to the resistance of the human body.

In the last case, some attendees perceived that other tastes like sourness and bitterness were enhanced (in addition to enhanced saltiness). This case is similar to that observed in the study by Hettinger et al.: they reported that a chloride solution's sourness, sweetness, and bitterness were also slightly altered when a cathodal current is applied and released.

However, the composition of the material we use is more complex than used by Hettinger et al. Therefore, in this study, we evaluated the effect on both saltiness and the other tastes of foods.

6. EXPERIMENT IN TASTE INTENSITY

In the experiments in the previous study, we revealed that our system could control saltiness by applying and releasing a cathodal current. However, a third type of feedback was received: some attendees perceived an enhancement of other tastes in addition to the change in saltiness. Therefore, we tried an experiment that measures the five basic taste intensities (sweetness, saltiness, sourness, bitterness, and umami) and a metallic taste to evaluate the enhancement of taste with our system.

6.1 Subjects

Ten subjects (6 male, 4 female), aged between 21 and 23 years and with a normal sense of taste were tested. The prior consent of all subjects to receive electric stimuli was gained.

6.2 Food and stimulus

Food: A commercially available fish sausage (Nissui, Japan) was used as the test food. The experimenter cut and stuck each piece on the fork apparatus and instructed the subject to bring the food into contact with their tongue.

Stimulus: The system applied approximately -5.1 V and 250 µA to the food, which was applied and released by the experimenters.

6.3 Procedure

Subjects were seated in front of the experimenter. Before we started the experiments, the experimenter asked the subject to drink water to rinse their mouth. Subjects answered taste intensity in three phases: before application of current, during application of current, and after the release of current for each trial. Our system can automatically apply and release the cathode current, followed by detection; however, in this trial, the experimenter controlled the current manually because the system continually applies current until the subject answered (Figure 6).

The subjects answered only one taste category per trial that we chose from the five fundamental tastes (sweetness, saltiness, sourness, bitterness, and umami) and metallic taste (thus, we conducted six trials). The order of tastes each subject answered for was randomized for each subject.

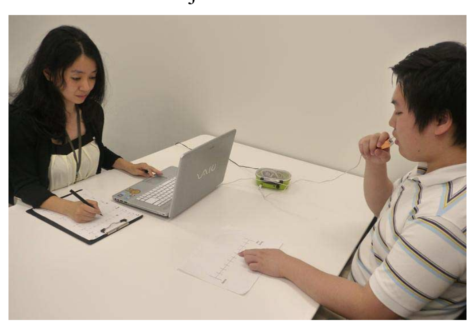

Figure 6. Experimental environment

For each sample, subjects were asked to rate the taste intensity on a dedicated linear scale (0 = none and 10 = extremely strong; cf. [7]). Subjects cannot answer vocally because they have food in contact with their tongue. Therefore, the experimenter asked them to point at a linear scale in front of the subject. Between each trial, the experimenter asked the subject to drink water to rinse their mouth, and replaced the test food with a new piece.

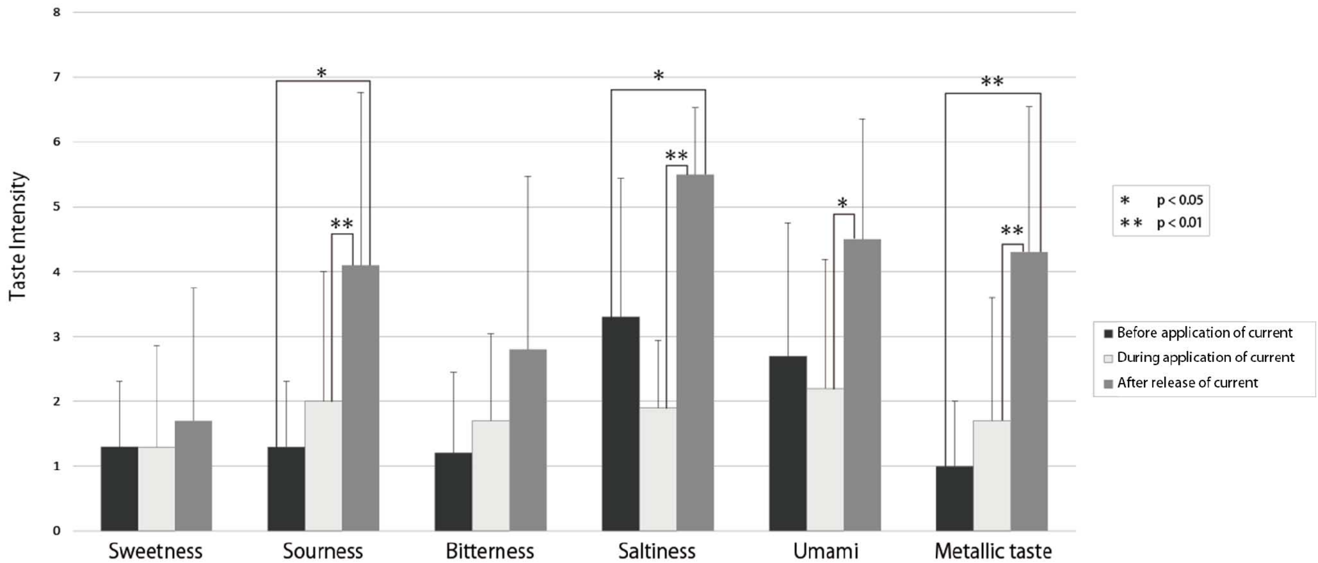

Figure 7. Intensity of taste (before application of current, during application of current, after release of current)

6.4 Data analysis

For each taste, the taste intensity data were analyzed with one-way analysis of variance (ANOVA). We also used a nonparametric multiple comparison, which exhibits a significant interaction with the ANOVA results.

7. RESULT

For saltiness, sourness, and the metallic taste, the ANOVA revealed a very significant effect between the cases of before application of current, during application of current, and after release of current ($F(2,18) = 6.01$, $p < 0.01$). Umami also showed a significant effect ($F(2,18) = 3.55$, $p < 0.05$). Bitterness had a weaker (but still significant) effect ($F(2,18) = 2.62$, $p < 0.1$), but no significant difference was found for sweetness (Figure 7).

In addition, according to the nonparametric multiple comparison of the means of the metallic taste, saltiness, and sourness showed that taste intensities after cathodal current release were stronger than those before cathodal current application (metallic taste, $p < 0.01$; saltiness and sourness, $p < 0.05$). In addition, the metallic taste, saltiness, sourness, and umami were stronger than those during the application of cathodal current (metallic taste, saltiness, and sourness, $p < 0.01$; umami, $p < 0.05$).

Hence, as a result of our experiment, our system can enhance saltiness, i.e., users feel that foods, after release of the cathodal current, are more salty than natural foods.

8. DISCUSSIONS

The result of our evaluation shows that saltiness, sourness, and the metallic taste show significant effects when we use the proposed system. In addition, the tastes after the release of the current are enhanced relative to either before or during application of the cathodal current. Therefore, our system can enhance saltiness, even if we use foods.

However, our system also enhanced sourness and the metallic taste. This result is in agreement with feedback from demonstrations and a previous study by Hettinger et al. Hettinger et al. also revealed that cathodal current enhances some tastes, but they did not examine the effect when the cathodal current is applied and released with foods for daily way. Therefore, the evaluation in this study gives a better indication of daily eating habits.

Initially, we developed this system as a saltiness enhancer, i.e., to enhance our perception of saltiness without adding salt. The result that sourness and the metallic taste were also enhanced seems to be an adverse effect of our system, because the only purpose of our system is preventing people from adding more salt. Therefore, one aspect of enhancing taste is the inclusion of saltiness, meaning this system might support a low salt diet. Thus, this system is for preventing users from adding additional salts.

9. RELATED WORK

9.1 Approaches for measurement and use of electric taste stimulation

Electric taste stimulation was discovered by Sulzer in 1754 when he placed two different metals on his tongue. Volta later hypothesized that this taste was attributable to an electric stimulus flowing from one metal to the other metal through the taste sensors on the tongue [8].

Many studies have analyzed the qualities of electric taste stimulation and its thresholds. Plattig measured the taste sensation of electric taste stimulation with a silver electrode using five young subjects. The results provided some noteworthy and significant responses for the sour taste (22.2%) and some small responses for the bitter taste (3.8%) and salty taste (1.8%) sensations [9]. Tomiyama et al. also reported that the voltage threshold increased with age; they reported no significant variation with bilateral differences, sexual differences, smoking history, artificial dentition, or metallic dental crowns. They reported that the most commonly perceived tastes were, in order, metallic, salty, and sour tastes, and that humans can perceive AC stimuli [10]. Another study reported that the quality of the metallic taste when using AC stimuli is stronger than that of copper pennies [11].

In the most famous use of electric taste stimulation, Rion Co., Ltd. produced an Electrogustometer to test our taste functions [12]. In addition, BrainPort, a tongue output system, was proposed to interpret visual images that would strengthen the electric stimuli and provide an output to the tongue [13]. This system enables a visual image to be seen based on the strength of the electric stimulus. It can also be used in evaluation experiments to support surgery [14]. Furthermore, Ranasinghe et al. proposed a system that could digitally stimulate the sense of taste (gustation) in humans using an electric taste stimulus [15], namely, a device that attaches two electrodes to the tongue. In these studies, an electrode was attached directly to the tongue to present an electric taste stimulus; in contrast, we added electric taste stimuli to food and drink via a utensil or cup.

9.2 Controlling saltiness

As described before, Hettinger et al. revealed that cathodal currents control the salty taste [4]. They found that saltiness decreases during cathodal current application, and it is recovered and enhanced after releasing the cathodal current. They conducted some experiments, including electrophysiological experiments, using hamsters and performed taste quality evaluation using humans. Nasri et al. proposed methods to enhance saltiness with olfactory sensations. Some aromas enhance saltiness; they measured the effectiveness of sardine aroma, which has the possibility of enhancing saltiness, using water, NaCl, KCl, and mixtures of these [16].

10. FUTURE WORK

Eating is not only required for survival, but also gives mental satisfaction. We notice that these two facts are important when considered together. People often face situations where they must sacrifice the desire for one to satisfy the other, when balancing health and mental satisfaction. Thus, we sometimes eat healthy foods we do not like, and sometimes eat satisfying foods that are not healthy; for example, eating anything we want or eating with friends.

However, should we really be sacrificing either? Our answer is no. Technology might offer help to allow us to choose both aspects. Furthermore, people who must carefully consider their health because of health disorders also receive satisfaction when eating. Sometimes, appetites are hard to control with self-discipline. Therefore, we should improve those techniques that enhance both the health and enjoyment aspects of eating. For example, Narumi et al. enhanced the sensation of satiety to control the size of food eaten using an AR technique [17]. Their system helps protect against obesity without relying on self-control. Our system also helps reduce additional salt without relying on self-control. Thus, our study also contributes to the user’s health and mental satisfaction in the short term. Future work will evaluate long-term use for various foods.

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