Norimaki Synthesizer: Taste Display Using Ion Electrophoresis in Five Gels

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CHI 2020 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA.

ACM ISBN 978-1-4503-6819-3/20/04.
DOI: https://doi.org/10.1145/3334480.3382984

Abstract
This study describes the production of a novel taste display which uses ion electrophoresis in five gels containing electrolytes that supply controlled amounts of each of the five basic tastes to apply an arbitrary taste to the user's tongue, analogous to optical displays that produce arbitrary colors from lights of three basic colors. When applied to the tongue with no voltage, the user can taste all five tastes. However, when an electric potential is applied, the cations in the gel move to the cathode side and away from the tongue, so that the flavor is tasted weakly. In this way, we have developed a taste display that reproduces an arbitrary taste by individually suppressing the sensation of each of the five basic tastes (like subtractive synthesis.) Our study differs from previous work in that it uses an electric current for electrophoresis rather than electrically stimulating the tongue, and it does not involve ingestion of a solution to deliver the taste.

Author Keywords
Taste Display; Electric Taste

CSS Concepts
• **Human-centered computing~Human computer interaction (HCI)**; *Interaction devices*

Background

Research on electric taste in the HCI field has grown in popularity ever since Nakamura et al. proposed the idea of "Augmented Gustation" [1], in which the taste of food and drinks is altered by chopsticks and straws that conduct electricity. A variety of approaches have been proposed, including changing the taste of soup by means of a spoon that conducts electricity [2], controlling taste by applying electrodes to the face [3][4], and inserting a device in the mouth and using the force applied when chewing to generate power [5]. Such devices are primarily intended to influence eating and drinking behaviors. For example, one anticipated application is to make lightly salted foods taste much saltier, which could support a healthier lifestyle by preventing excessive salt intake [6].

It is often assumed that all "electric taste" research is based on the same principle, but this is a misunderstanding. For example, the design proposed in [6] is premised on cathodic stimulation and saline water in the mouth, whereas Nimesha et al. [7] applied two electrodes directly to the tongue and then varied the frequency of stimulation.

Aoyama et al. [8] summarized various approaches to "electric taste" research and elucidated the principle of cathodic stimulation in particular. This research revealed that tasting ions in the mouth migrate (ion electrophoresis) and detach from the taste sensors on the tongue, thereby inhibiting the perception of taste. Aoyama et al. further demonstrated that this inhibitory effect changes with the intensity of the electric current (the correlation coefficient was 0.9 or higher). In their experiment, they attached a cathode to a straw and an anode to the back of the subject's neck and then applied electric currents, while making the subject ingest aqueous solutions of NaCl (salty), glycine (sweet), $MgCl_2$ (bitter), citric acid (acidic), and glutamic sodium (umami).

This experiment demonstrated that electrolytes could be used to control the strength of the five basic tastes. However, it is not easy to control them individually to create a "taste display" capable of generating an arbitrary taste like a synthesizer. For example, if all five of the above electrolytes were dissolved in a cup, they would mix together in the mouth as well as in the cup. In this case, if the intensity of the electric current was changed, the user would experience a change in all five basic tastes at once. Furthermore, the aqueous solutions must by nature be kept in the mouth or continuously consumed, to fill the straw with liquid and form an electrical circuit.

In this work, we propose using a gel instead of an aqueous solution, to solve to the aforementioned problems. We prepared five different types of gels by dissolving NaCl, glycine, and other electrolytes in separate solutions, and hardened them to prevent them from mixing. When the gels are isolated from each other by walls, each gel can be given a different current intensity to individually control its taste. In addition, because the gel is only applied to the tongue, it does not have to be held in the mouth or swallowed.

Our initial concern was whether the gel form would even allow migration of the ions to occur. However, when we prepared the five gels and carried out the experiment, we found that all the electrolytes exhibited ion migration, and were able to produce a distinct change in taste. This study describes the development of a prototype "taste display" system using electricity and five gels made of dissolved electrolytes. We also verified the basic functionality of the system.

In the experiment by Aoyama et al., the electrode was attached to the back of the neck, but in principle, the electrode can be placed anywhere so long as it stays in contact with the body. We therefore designed a device wrapped in copper foil like a "Norimaki" (a sushi roll wrapped in dried seaweed) so that the electricity flows whenever the user holds it.

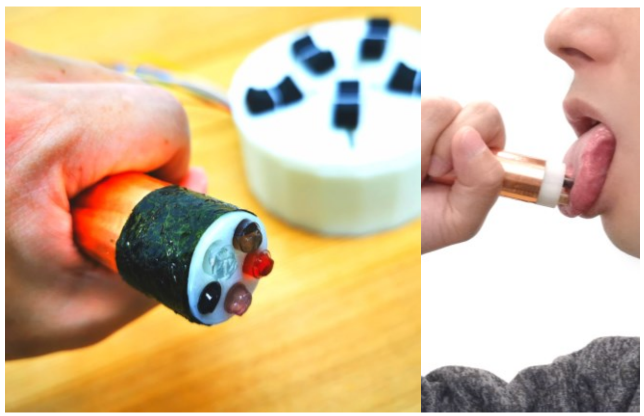

Figure 1: (Left) Proposed System "Norimaki Synthesizer." Five gels are popping out. The controller that adjusts the taste is visible on the back. The device is wrapped in copper foil, and also wrapped in dried seaweed in this case. Presenting taste of salty and sour with seaweed scent causes illusion of actually eating sushi. (Right) Copper foil acts as an electrode, and the user holds the assembly in their hand. Norimaki Synthesizer reproduces an arbitrary taste by individually suppressing the sensation of each of the five basic tastes (like subtractive synthesis).

System

The system uses the same electrolytes used by Aoyama et al., namely glycine, $MgCl_2$, citric acid, NaCl, and glutamic sodium. Each electrolyte was dissolved in a small amount of water to prepare a highly concentrated solution. Agar was added to the solution and it was inserted into a tube with a diameter of 6 mm, to harden it into a gel.

Figure 2: (Upper left) Five types of electrolytes dissolved and condensed into five gels, added food coloring. Brown gels are $MgCl_2$, pink gels are glutamic sodium, black gels are NaCl, red gels are glycine, yellow gels are citric acid. (Upper right) The amount of gel exposure in contact with the tongue. (Below) Production process. We added solution to heated agar, inserted tubes, and chilled them in the refrigerator.

We tried to make it with gelatin but it was sticky, and pure durability. We also tried hardening the solution using egg whites, by hard-boiling them or heating them in a microwave oven. This method can also be used to prepare a gel quickly, but the heating should be performed so gently.

Once the gel hardens, the amount of exposure in contact with the tongue can be adjusted by inhaling or exhaling with the tube. We inserted Pt wire electrodes into the other ends of the five tubes containing the five types of gel, and then assembled them into a bundle with a diameter of 20 mm. To make this act like an electrode; it was wrapped with copper foil.

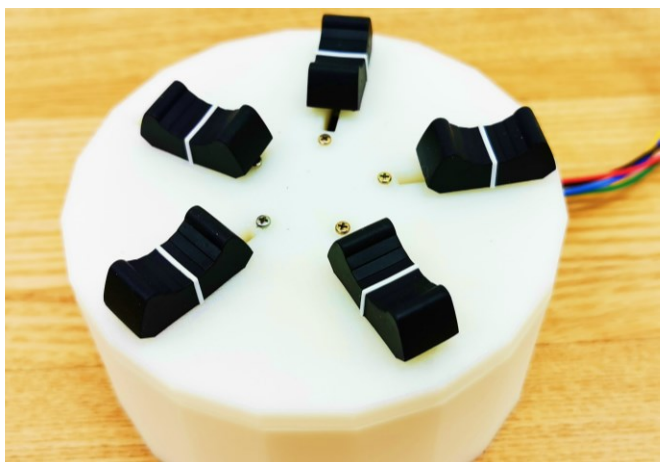

Figure 3: Controller. Variable resistors are connected to the ends of each of the five gels. It is shaped like a pentagonal radar chart of taste.

To use as a controller, we connected variable resistors to the ends of each of the five Pt wires, and connected them to the cathode of the power supply. We then connected the copper foil to the anode of the power supply.

The copper foil wrapping is an anode, and the Pt wire in each gel is a cathode, which together with the human body form an electrical circuit (Figure 4). When an electric potential is applied, therefore, the cations in the gel move to the cathode side and away from the tongue, so that the flavor is tasted weakly.

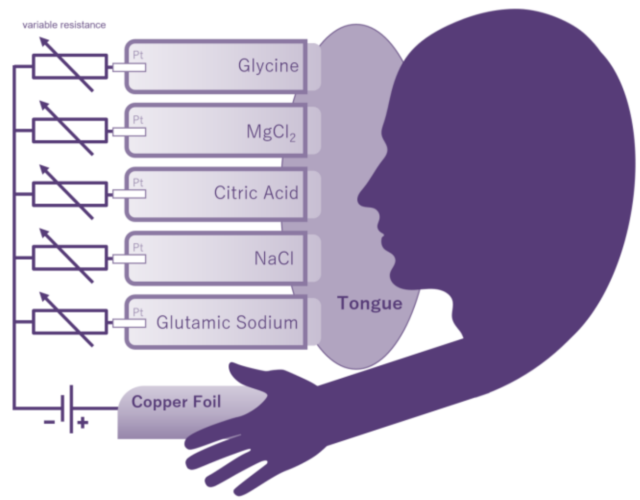

Figure 4: The system forms an electrical circuit together with the human body.

Result and Discussion

We used the prototype device to confirm how the taste was actually experienced. When the resistance values of all the variable resistors were increased, thereby reducing the flow of electric current, all the five gels could be tasted at the same time. However, when the resistance value of a variable resistor was reduced to increase the flow of current, the cations in the corresponding gel moved away from the tongue and the taste became more difficult to perceive. When the resistance was reduced in all the gels, none of them could be tasted. A definite metallic taste could be detected from the cathode stimulus, but it was not overwhelming.

By manipulating the variable resistances, it was possible to change and transition between tastes, for example by presenting a sweet taste like gummy candy after presenting a taste of sushi that was salty and sour. When we wrapped the device in dried seaweed, presenting taste of salty and sour with seaweed scent causes illusion of actually eating sushi. In addition, we succeeded in achieving different taste formulations by using sliders to adjust the resistance values. After 30 minutes of continuous use, none of the gels lost taste.

Due to the large diameter of the tubes, the sensation at times felt like a mixture of each taste, and sometimes it felt like multiple flavors of food were in different areas of the mouth. By reducing the diameter of the tubes and using more than one tube per taste, it should be possible to eliminate the variation in taste in different areas of the tongue. We tried prototyping a thin-tube version, but this caused more frequent internal disconnections. Successful deployment of a thin-tube version would require a better production process.

Based on the results of Hettinger et. al [9], it should be possible to express a taste intensity that is greater than the original solution by stopping the flow of electric current. In fact, we were able to confirm this finding with the fast fader operation of our system. In this work, we started with strong tasting gels and then created tastes by reducing their strengths in a subtractive manner. However, additive manner should also be possible; expressing a taste intensity that is greater than the original gel by stopping the flow of electric current to increase the user's sensitivity to the taste.

Conclusion

In the field of HCI in recent years, research has been conducted to change the taste of food and drink by allowing electricity to flow through the fork etc., to reproduce a taste or improve health by reducing the salt intake, with electrical stimulation of the tongue. We propose a taste display using ion electrophoresis in five gels, and this system can reproduce an arbitrary taste by individually suppressing the sensation of each of the five basic tastes. Our study differs from those studies because electricity is used only for the purpose of electrophoresis within the gel, rather than for electrical stimulation of the tongue. Since the proposed system does not involve swallowing an aqueous solution, and merely applies the tip of the device to the tongue, it is unrelated to drinking or eating behavior.

If it becomes possible to calibrate the gel concentrations to the user's experience of taste, it should be possible to reproduce the tastes measured by taste sensors. Like an optical display that uses lights of three basic colors to produce arbitrary colors, this display can synthesize and distribute arbitrary tastes together with the data acquired by taste sensors. We believe that this paper will be of interest to the researchers because it opens new possibilities for HCI, allowing the addition of a whole new medium to multimedia experiences.

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