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Detection of the Suppression of Saltiness by *Umami* Substances Using a Taste Sensor

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A multichannel taste sensor, i.e., an electronic tongue, whose transducer is composed of several kinds of lipid/polymer membranes with different characteristics, can detect taste in a manner similar to human gustatory sensation. In this study, we attempted to detect the suppression of saltiness by the *umami* substance monosodium glutamate (MSG) using a multichannel taste sensor. To quantify the saltiness, a principal component analysis (PCA) was applied to membrane potential data. The saltiness was expressed on the τ scale, which is the relationship between the salty strength perceived by humans and the NaCl concentration, using PCA. It was quantitatively shown that the saltiness of NaCl was weakened by MSG.

1. Introduction

Taste is comprised of the five basic qualities of sourness, saltiness, sweetness, bitterness and *umami*. To date, however, the main methods of measurement are sensory evaluations by humans and conventional chemical analyses. A multichannel taste sensor, i.e., an electronic tongue, whose transducer is composed of several kinds of lipid/polymer membranes with different characteristics, can detect taste in a manner similar to human gustatory sensation.[1–5] Taste information is transformed into a pattern composed of the electric signals of membrane potentials of the receptor. The sensor outputs are not related to the amount of specific molecules present, but rather to the taste quality, because similar patterns are obtained for substances producing the same taste quality. The taste of several food items such as coffee, beer, mineral water, vegetables and milk were studied using this sensor.[4] The taste sensor detects and quantifies interactions among tastes such as suppression,[6] which appears between sweetness or saltiness and bitterness.[7,8]

Umami is the fifth independent taste produced by monosodium glutamate (MSG) which is mainly contained in seaweed and disodium inosinate (IMP) in meat and fish. It is also known that, for substances with the *umami* taste, interactions between tastes occur, such as synergism or suppression. The combination of MSG and IMP enhances the *umami* taste, while *umami* substances suppress the intensity of the taste of salty substances.

In this study, we applied the taste sensor to salty substances in combination with *umami* substances and quantified the suppression of saltiness.

2. Materials and Methods

2.1 *Measurements using taste sensors*

Measurements were performed using the taste-sensing system SA401 (Anritsu Corp.) shown in Fig. 1. The detecting sensor consists of seven electrodes made of lipid/polymer membranes (i.e., channels). To date, several kinds of lipids have been used according to the purposes and objects to be measured. Lipids used for preparing membranes in this

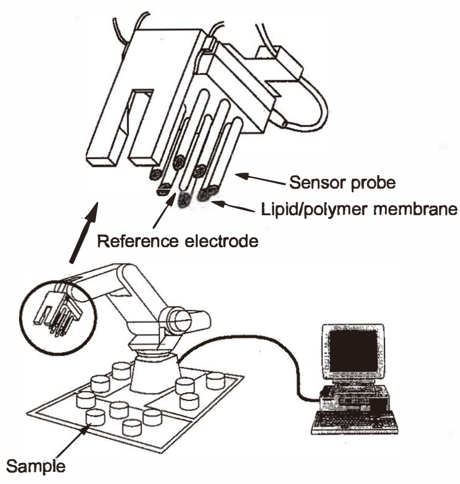

Fig. 1. Taste-sensing system (SA401, Anritsu Corp.).

Table 1
Lipids used for the membranes.

Channel	Lipid (abbreviation)
1	Decyl alcohol (DA)
2	Oleic acid (OA)
3	Dioctyl phosphate (DOP)
4	DOP : TOMA = 5 : 5
5	DOP : TOMA = 3 : 7
6	Trioctyl methyl ammonium chloride (TOMA)
7	Oleyl amine (OAm)

study are listed in Table 1. Each lipid was mixed in a test tube containing polyvinyl chloride and plasticizer (dioctyl phenylphosphonate) dissolved in tetrahydrofuran. The mixture was then dried on a glass plate that was set on a hot plate whose temperature was controlled at about 30°C. The lipid/polymer membrane was a transparent and soft film about 200 μm thick.

Each electrode consisted of an Ag wire whose surface was plated with AgCl with an internal cavity filled with 3 M KCl solution (Fig. 2). The lipid/polymer membranes were adhered to the opening of the tube. The electric potential difference between the multi-channel electrode and the reference electrode (Ag/AgCl with 3 M KCl, saturated AgCl) was obtained by a high-input-impedance amplifier connected to a computer. Chemicals freshly dissolved in distilled water with 1 mM KCl were used for the experiments. The measurements were made three times by a rotation procedure which involved one round of measurements for all the samples.

2.2 *Materials*

The samples were NaCl and MSG as salty and *umami* tastes, respectively, which were of the highest analytical grade (Kanto Chemical Co., Inc). For studying the suppression of saltiness by the *umami* taste, 1 mM and 10 mM MSG, plus NaCl at different concentrations, were measured.

Fresh 1 mM KCl solution was used as a reference sample and also as a rinsing fluid for the electrodes after every measurement. The response electric potential of the sample was measured as the difference between the potentials of the sample and 1 mM KCl solution as the reference. Each measuring time was set to 10 s, and the rinsing of electrodes after each measurement was repeated 15 times for about 60 s. Each sample was measured three times.

2.3 *Sensory evaluation*

Sensory evaluations of samples were performed three times on different days; 15, 17 and 15 panelists tasted the NaCl solution and its combination with MSG. Pair tests were carried out for three terms: one was selected from two samples (pure NaCl solutions and those consisting of NaCl and MSG) in terms of taste such as "having a very strong taste," "having a salty taste" and "having an *umami* taste."

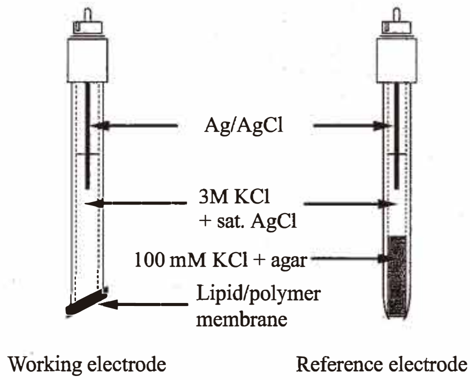

Fig. 2. Working and reference electrodes.

3. Results and Discussion

Figure 3 shows the response patterns for NaCl at different concentrations and illustrates the systematic change of the response potentials according to the NaCl concentration. Standard deviations are shown by error bars. As the NaCl concentration increased, the response potentials of the DA (ch. 1), OA (ch. 2) and DOP (ch. 3) membranes increased, whereas those of the 3 : 7 (ch. 5), TOMA (ch. 6) and OAm (ch. 7) membranes decreased. The increase in chs. 1–3 occurs because Na^+ cations have an electric screening effect on the negatively charged membranes. The decrease in chs. 5–7 is brought about by Cl^- anions.

Figure 4 shows the response patterns for 1 mM and 10 mM MSG. The response potential of the 5 : 5 membrane (ch. 4) is negative; this is characteristic of substances with an *umami* taste.[9] Similar response patterns were obtained for other *umami* substances such as disodium inosinate (IMP), disodium guanylate (GMP), disodium succinate hexahydrate and sodium aspartate monohydrate (data not shown). The response potential for 1 mM MSG is very small, because the maximum is about 10 mV at most.

Figure 5 shows the response patterns for the mixed solutions, which contain 1 mM MSG and NaCl at three different concentrations of 30, 100 and 300 mM. The response patterns for the mixed solutions clearly shift downward in chs. 1–3 due to the presence of 1 mM MSG, while they shift upward in chs. 6 and 7. This change can be considered to reflect the decrease in NaCl concentration compared to Fig. 3, i.e., a suppression of the saltiness by MSG.

A principal component analysis (PCA) was applied to these data to confirm this expectation and quantify saltiness according to a previous report.[6] This analysis is a multivariate analysis that reduces the dimensional space without losing information. Data points are expressed in seven-dimensional space in this case because there are seven-channel outputs and then become expressed in lower-dimensional space.

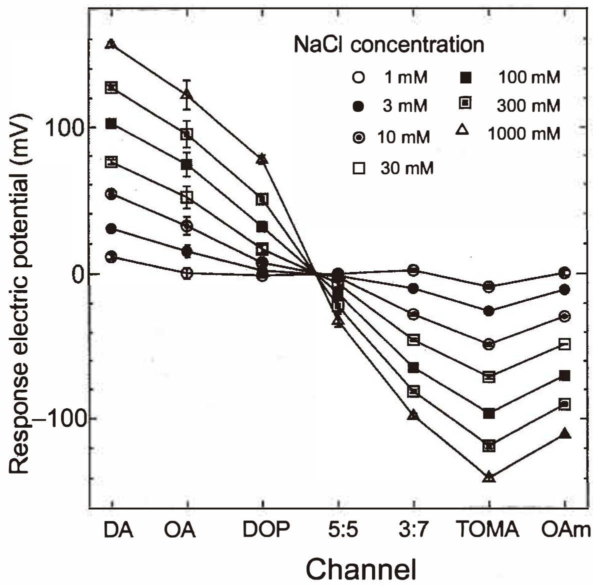

Fig. 3. Response patterns for NaCl.

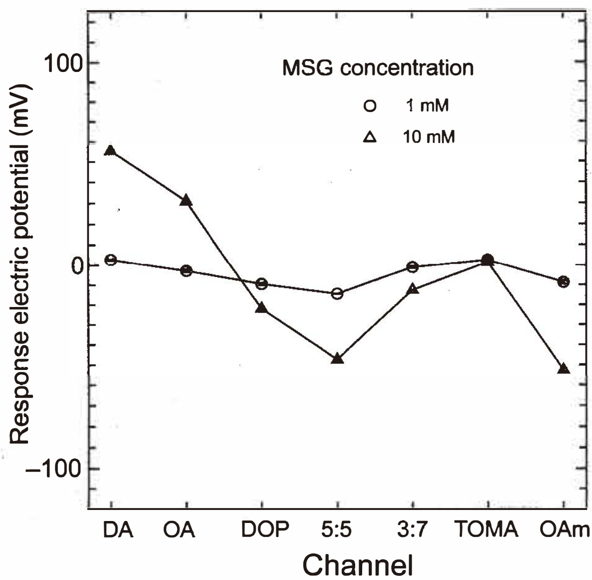

Fig. 4. Response patterns for MSG.

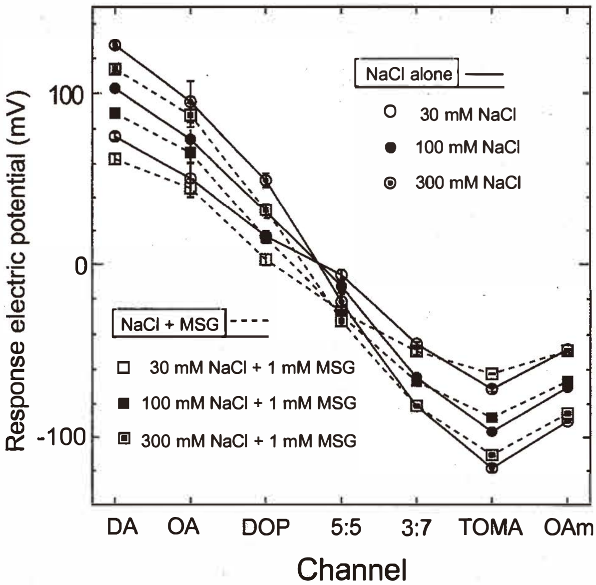

Fig. 5. Response patterns for the NaCl solutions and mixed solutions of NaCl and MSG.

The largest element of data contained in the original data is transformed into the first principal component (PC1), and the second and third largest items are transformed into the second and third principal components (PC2 and PC3), respectively; in this way, we extract information from the original data in order of its importance.

Figure 6 shows the relationship between PC1, which was obtained by applying this method to Fig. 3, and the NaCl concentration. The contribution rates, the relative magnitude of transformed information, of the original data to PC1, PC2 and PC3 were 98.9%, 0.7% and 0.4%, respectively. This indicates that PC1 characterizes the patterns in Fig. 3 and we can discuss these data using only PC1.

The PC1 is expressed by the formula

$$PC1 = a_1(v_1 - v'_1) + a_2(v_2 - v'_2) + \cdots + a_7(v_7 - v'_7), \quad (1)$$

where a_i is the factor loading, v_i the response potential of channel i, and v'_i the response potential of channel i averaged over the measured samples.

In Fig. 6, a straight line is drawn using the least-squares method. The value of PC1 increases in proportion to the NaCl concentration logarithmically. This relation agrees with the τ scale, which is the reported relationship between salty strength (τ) and NaCl concentration:[10]

$$\tau_D = 2.83\log(\phi_D/0.056), \quad (2)$$

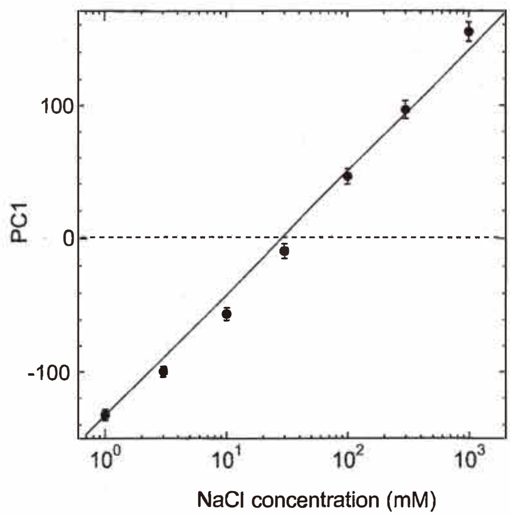

Fig. 6. Relationship between PC1 and NaCl concentration.

where ϕ_D is the NaCl concentration in g/100 cm^3. The τ scale has also been prepared for other taste qualities such as sweetness, sourness and bitterness with different values of the coefficient. It can represent the subjective strength of a taste in solution. The least-squares line in Fig. 6 is given by

$$\mathrm{PC1} = 81.26 \log C - 121.1, \tag{3}$$

with C denoting the molar concentration; hence we can obtain the relationship between τ_D and PC1 as

$$\tau_D = 0.0348 \times \mathrm{PC1} + 1.44. \tag{4}$$

If the PC1 value is calculated, we can estimate the strength of saltiness expressed on the τ scale. The strength of saltiness can then be obtained from the response potentials of samples which contain MSG using eq. (4). The result is shown in Table 2 as a decrease in saltiness.

We observe a decrease in the strength of saltiness by adding 1 mM MSG to the NaCl solutions. The salty strength is decreased from 1.40 to 0.19 in a 30 mM NaCl solution by the addition of 1 mM MSG.

This result implies the satisfactory detection of the suppression of saltiness by MSG. A similar suppression was found for other mixtures with 10 mM MSG.

Table 3 summarizes the sensory tests in humans for a 100 mM NaCl solution and its

Table 2
Estimation of salty strength for NaCl alone and its mixture with MSG expressed on the τ scale.

NaCl concentration (mM)	NaCl alone	Mixed solution (NaCl + 1 mM MSG)
30	1.40	0.19
100	2.88	1.64
300	4.23	2.85

Table 3
Results of sensory evaluations for 100 mM NaCl solution and its mixtures.

	Intensity	Salty	*Umami* taste
NaCl alone[a]	3	13	1
+ 5 mM MSG	12	2	14
Paired *t*-test	***	**	*
NaCl alone[a]	2	9	2
+ 10 mM MSG	15	8	15
Paired *t*-test	**	/	**
NaCl alone[a]	0	10	1
+ 20 mM MSG	15	5	14
Paired *t*-test	*	/	*

[(a)]Sensory evaluations were performed on different days.
*$p < 0.001$ **$p < 0.01$ ***$p < 0.05$

mixtures with MSG. The suppression of saltiness by MSG appeared at the lowest MSG concentration. In fact, 13 persons stated that 100 mM NaCl alone was more salty, while only two persons reported a more salty taste for 100 mM NaCl + 5 mM MSG. Increasing MSG concentrations in the mixed solutions made it difficult to distinguish between two samples with respect to saltiness.

It was reported by sensory evaluations that a suppression of saltiness by ***umami*** substances was not observed, whereas a decrease in saltiness can also be found at low MSG concentrations.[(11)] This observation relating to low MSG concentrations does not contradict the results herein.

In this study, it was shown that the suppression of the saltiness of NaCl by MSG could be quantified using a multichannel taste sensor. The suppression of saltiness by MSG was observed even for mixtures at a high ratio such as 300 mM NaCl to 1 mM MSG. The results of sensory tests in humans agreed with this result because the suppression effect clearly appeared at low MSG concentrations. This appears to suggest that the taste sensor is so sensitive that it is possible to detect the suppression of saltiness.

The same measurements and procedures described here were carried out on a bitter-tasting drug.[(6)] As a result, the decrease in the bitter taste of the drug with increasing sucrose concentration was quantified. The taste sensor can provide a novel, automated method to measure the strength of the bitterness of a drug in place of sensory evaluation.

In addition, studies of the interaction of tastes using this sensor, which utilizes lipid membranes, will contribute to the clarification of receptors in the human gustatory system.

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