Palatability of Tastes Is Associated With Facial Circulatory Responses

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Abstract

To examine whether various types of taste stimuli in the oral cavity elicit unique changes in facial skin blood flow (SkBF) according to the palatability perceived by an individual, the facial SkBF was observed by laser speckle flowgraphy in 15 healthy subjects (11 males and 4 females) before and during the ingestion of bitter tea, chilli sauce, coffee, orange juice, soup, and a water control. The heart rate, mean arterial pressure (MAP), and SkBF in the index finger were recorded continuously. Subjects reported their subjective palatability and taste intensity scores after each stimulus. The vascular conductance indexes (CIs) in the face and finger were calculated as ratios of SkBF to MAP. CI in the eyelid increased significantly in response to chilli sauce, orange juice, and soup, whereas CIs in the forehead, nose, and cheek decreased in response to bitter tea. There was a significant correlation between the palatability scores and CI values in the eyelid when changes induced by chilli sauce were excluded. These results suggest that the facial circulatory response reflects the degree of palatability of a foodstuff.

Key words: autonomic nervous system, emotion, laser speckle flowgraphy, taste

Introduction

We reported previously that basic tastes elicit characteristic responses in the skin blood flow (SkBF) in the face according to the hedonic valence (pleasant or unpleasant) and the taste itself (Kashima and Hayashi 2011). When a bitter taste stimulus was applied in the oral cavity, SkBF in the nose decreased in association with the unpleasantness of the taste, whereas when sweet and umami taste stimuli were applied, SkBF in the eyelid increased in association with the pleasantness of the taste. We, therefore, assumed that the facial SkBF reflects gustatory experiences. However, when a capsaicin stimulus was applied in the oral cavity, SkBF in all facial areas increased significantly irrespective of the hedonic valence (Kashima and Hayashi 2013). Thus, the palatability of the foods containing spicy components masks facial SkBF responses associated with the hedonic valence. Most foods elicit multiple taste sensations (e.g., orange juice can taste both sweet and sour), and hence the objective assessment of gustatory appreciation requires examination of whether the tastes associated with various ingredients also elicit unique responses in the facial SkBF according to the hedonic valence. Facial SkBF measuring should be useful to objectively and nonverbally assess the palatability associated with gustatory experience. The present study investigated whether facial circulatory responses are related to the perceived palatability using commercial foods that elicit complicated taste sensations. We also evaluated a facial vascular conductance index (CI)—corresponding to the facial SkBF divided by the mean arterial pressure (MAP)—in order to correct for systemic effects of MAP, since we have previously reported that changes in MAP affect facial SkBF responses (Kashima et al. 2013). Moreover, because the blood pressure increases in states of happiness and disgust (Kreibig 2010), it may also change the facial SkBF when taste stimuli are applied.

Materials and methods

Subjects

Fifteen healthy adults (11 males and 4 females; age = 24±2 years, height = 169±9 cm, weight = 56±18 kg;
mean ± standard deviation) participated in this study. The subjects were normotensive, not smoking, not taking any medication, and had no history of autonomic dysfunction or cardiovascular disease. The Ethics Committee of the Institution of Health Science, Kyushu University, Japan approved the experimental protocol, and each subject provided written informed consent to participate prior to the commencement of the study. Subjects arrived at the laboratory after having abstained from strenuous exercise and alcohol ingestion for at least 1 day, eating for at least 2 h, and consuming caffeine for at least 6 h. Subjects were seated in a chair in a quiet room where the temperature and humidity were maintained at 23 ± 1 °C and 53 ± 1%, respectively.

The following 5 commercially available fluids (plus pure water) were used: moderately bitter tea (instant Kuding tea; Kenko Ouen), chilli sauce (sweet chilli sauce; Youki Food), coffee (Nescafe Excella; Nestlé S.A.), orange juice (Minute Maid Orange 100%; Meiji), and soup (made from granules of KK consommé; Ajinomoto). Subjects were given 5 mL of each of these 6 fluids at 40.3 ± 0.2 °C in a randomized order, with the subjects blinded to which fluid was being given. The temperature of the fluids was maintained using a constant temperature reservoir. During the experiment, the subject placed his/her chin and upper forehead on a pedestal to stabilize the face and was instructed not to move the facial muscles and to keep the eyes closed. After 115 s of resting, during which control baseline measurements were made, each fluid was applied to the subject’s oral cavity via a dropper placed in the mouth. The fluid was kept in the mouth for 30 s before swallowing it, and the mouth was then rinsed with pure water at 40 °C until the taste could no longer be perceived. The subject then reported his/her perceived palatability and intensity scores for sweet, sour, salty, bitter, and spicy tastes by ticking each of six 11-point visual analog scales: one scale for palatability, where 0 = no change in hedonic, +5 = the most pleasant taste, and −5 = the most unpleasant taste and 5 scales for taste intensities, where 0 = no perceived taste and 10 = the strongest possible perceived taste. We started the next trial after confirming that all physiological variables had returned to their baseline values.

Measurements

The facial SkBF was recorded by laser speckle flowgraphy (LSFG-ANW-LL; Softcare) for 5 s before stimulation and at 20 s after the onset of stimulation. SkBFs in the forehead, eyelid, nose, and cheek were assessed by constructing blood flow images from the speckle flowgraphy data using commercially available software (LSFG Analyzer Cutaneous; Softcare). Each pixel in such a blood flow image is regarded as a vector of an object’s movement, and so the summed pixels within a given area correspond to the relative blood flow. The target areas used for each subject’s facial SkBF and the number of pixels were kept constant by the software.

The heart rate (HR) and MAP were monitored continuously with an automatic sphygmomanometer applied to the subject’s left middle finger (Finometer; Finapres Medical Systems). SkBF in the right index finger was measured throughout the experiment by laser Doppler flowmetry (Flo-C1BV; Omegawave). The vascular CIs in the face and finger were calculated as ratios of the respective SkBF and MAP values.

Data analysis

The data are expressed as mean and standard error of the mean (SEM) values. SkBFs and CIs in the face and finger were determined as relative changes from the baseline values. HR and MAP were determined as absolute values.

The subjective scores for palatability and the 5 perceived taste intensities were tested by one-way repeated analysis of variance (ANOVA). When a significant effect was obtained, Dunnett’s post hoc test was conducted to reveal the effect of trials relative to the water control.

The effects of time and trial on the HR, MAP, and SkBF and CI responses in the face and finger were tested by two-way repeated ANOVA. When a significant effect was obtained, Bonferroni’s post hoc test was conducted to reveal the effects of time (baseline and stimulus) and each trial.

The relationship between each subjective score and the CI response in each target area was evaluated by Pearson’s correlation. The CI responses to chilli sauce were not included in this analysis because capsaicin-containing chilli seasoning foods are known to increase SkBF in all facial areas independently of the hedonic valence (Kashima and Hayashi 2013). The level of statistical significance was set at P < 0.05. All statistical analyses were performed with SPSS (SPSS 12.0 for Windows; IBM).

Results

Subjective scores

The palatability score and the intensity scores for sweet, sour, and bitter tastes differed significantly among the fluids (Table 1). The palatability score was significantly higher for orange juice and soup than for the water control and was significantly lower for bitter tea than for the water control. The sweet intensity score was higher for orange juice than for the water control. The sour intensity score was higher for chilli sauce and orange juice than for the water control. The salty intensity score was higher for chilli sauce and soup than for the water control. The bitter taste intensity score was higher for bitter tea and coffee than for the water control.

Systemic circulatory responses

HR and MAP values before and during the presentation of all stimuli are listed in Table 2. Bitter tea, chilli sauce, coffee,
Table 1  Self-reported subjective scores of palatability and taste intensity

<table>
<thead>
<tr>
<th></th>
<th>Palatability</th>
<th>Intensity score</th>
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<tbody>
<tr>
<td></td>
<td>Sweet</td>
<td>Sour</td>
</tr>
<tr>
<td>Bitter tea</td>
<td>–4.3±0.3*</td>
<td>0±0</td>
</tr>
<tr>
<td>Chilli sauce</td>
<td>0±0.3</td>
<td>0.6±0.2</td>
</tr>
<tr>
<td>Coffee</td>
<td>–0.7±0.7</td>
<td>0.3±0.2</td>
</tr>
<tr>
<td>Orange juice</td>
<td>2.3±0.3*</td>
<td>3.5±0.6*</td>
</tr>
<tr>
<td>Soup</td>
<td>1.7±0.7*</td>
<td>0.6±0.2</td>
</tr>
<tr>
<td>Water</td>
<td>–0.1±0.2</td>
<td>0.2±0.1</td>
</tr>
</tbody>
</table>

Data are mean ± SEM values. The value for each fluid is compared with that for the water control as determined by multiple comparisons (Dunnett’s post hoc test). *P < 0.05 versus the water control.

Table 2  HR and MAP before and during the presentation of each taste stimulus

<table>
<thead>
<tr>
<th></th>
<th>HR (b.p.m.)</th>
<th>MAP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>During</td>
</tr>
<tr>
<td>Bitter tea</td>
<td>70.9±2.7</td>
<td>73.4±3.1*</td>
</tr>
<tr>
<td>Chilli sauce</td>
<td>72.0±2.6</td>
<td>75.8±2.6*</td>
</tr>
<tr>
<td>Coffee</td>
<td>71.2±2.7</td>
<td>73.6±3.2*</td>
</tr>
<tr>
<td>Orange juice</td>
<td>72.2±2.6</td>
<td>75.9±3.1*</td>
</tr>
<tr>
<td>Soup</td>
<td>72.2±2.6</td>
<td>75.1±2.9*</td>
</tr>
<tr>
<td>Water</td>
<td>71.3±2.6</td>
<td>71.2±2.7</td>
</tr>
</tbody>
</table>

Data are mean ± SEM values. *P < 0.05 versus the water control. *P < 0.05 versus before.

orange juice, and soup significantly increased HR compared with the baseline, whereas the water control did not change HR. Bitter tea, chilli sauce, orange juice, and soup significantly increased MAP compared with baseline, whereas coffee and the water control had no effect on MAP. MAP was higher for soup than for the water control. There were no significant differences among the other trials.

Facial and finger circulatory responses

The SkBF and CI responses in the face to fluid stimuli are shown in Figure 1. Bitter tea significantly increased SkBF in the eyelid relative to the baseline value and significantly decreased CIs in the forehead, nose, and cheek. Chilli sauce significantly increased SkBFs in the forehead, eyelid, nose, and cheek relative to the baseline values and significantly increased CI in the eyelid. Coffee did not change SkBF and CI in the face. Orange juice significantly increased SkBFs in the eyelid and cheek relative to the baseline values and significantly increased CI in the eyelid. Soup significantly increased SkBF and CI in the eyelid relative to the baseline values. The water control significantly increased SkBF in the eyelid relative to the baseline value.

SkBF in the eyelid was significantly higher for orange juice and soup than for the water control and significantly higher for chilli sauce and orange juice than for coffee. CI in the cheek was significantly higher for chilli sauce and orange juice than for bitter tea.

Bitter tea, chilli sauce, orange juice, and soup significantly decreased SkBF and CI in the finger (SkBF: bitter tea = –24±7%; chilli sauce = –27±9%; orange juice = –21±8%; soup = –19±8%; CI: bitter tea = –28±7%; chilli sauce = –30±8%; orange juice = –23±9%; soup = –22±8%; all P < 0.05), whereas coffee and the water control did not change SkBF and CI in the finger (SkBF: coffee = –3±7%; water control = –8±6%; CI: coffee = –4±7%; water control = –7±7%; all P > 0.05). CI in the finger was significantly lower for bitter tea and orange juice than for the water control.

Correlation between palatability scores and facial CI responses

There was a significant positive correlation between palatability scores and CIs in the eyelid when the responses to chilli sauce were excluded, and CI in eyelid increased according to an increase in palatability ratings in 13 of 15 subjects (n = 75, r = 0.34, P < 0.05) (Figure 2), whereas CI in the nose was not related to palatability scores (n = 75, r = 0.14, P > 0.05). CIs in forehead and cheek also were not related to palatability scores.

Discussion

The main findings of the present study were that orange juice and soup—both of which showed positive palatability scores—increased SkBF and CI in the eyelid and that the palatability score was positively correlated with the CI response in the eyelid. The low palatability of bitter tea elicited vasoconstriction in the forehead, nose, and cheek, as reflected by the decreased CIs in those areas. These results suggest that the facial circulatory responses
Figure 1  Relative changes in the SkBF (left panels) and vascular CI (right panels) induced by bitter tea (Bt), chilli sauce (Cs), coffee (Co), soup (So), orange juice (Oj), and the water control (W). Data are mean and SEM values. *$P < 0.05$ versus baseline. †$P < 0.05$ versus bitter tea. ‡$P < 0.05$ versus the water control. *$P < 0.05$ versus coffee.
elicited by the application of various tastes of foods in the oral cavity at least partially reflect the perceived palatability. This is consistent with our previous finding that basic tastes are related to facial circulatory responses (Kashima and Hayashi 2011).

As expected from our previous study (Kashima and Hayashi 2013), chilli sauce significantly increased SkBF in all facial areas, and this response was independent of the hedonic valence.

Correlation between eyelid SkBF and palatability score indicated eyelid SkBF relates to the palatability irrespective to a type of stimuli. In addition, CI responses in eyelid to 5 fluids (except for chilli sauce) increased according to an increase in palatability ratings in 13 of 15 subjects when this responses were calculated by individual results, indicating a relationship between palatability and eyelid vasomotion, because CI reflects vasodilatation. This is consistent with our previous suggestions that the hedonic valence reflects SkBF in the eyelid in response to sweet and umami taste stimuli (Kashima and Hayashi 2011). In contrast to our previous results, MAP was significantly increased by bitter tea, chilli sauce, orange juice, and soup in the present study, which could be due to the volume of stimulus fluid added to the oral cavity being larger (at 5 mL) than in the previous study (at 1 mL).

Orange juice significantly increased SkBF in the cheek but did not change CI; these results are due to an increased MAP via sympathetic activation. We previously reported that sympathetic activation increased SkBF in the cheek along with an increased MAP during the cold pressor test (Kashima and Hayashi 2013). This observation is partly supported by a reduction in the finger SkBF. However, SkBF in the forehead was not increased by orange juice, whereas it was increased during the cold pressor test. These discrepancies make it difficult to explain the present results from the viewpoint of a single effect of the systemic circulatory response.

The sour taste component of orange juice may have been responsible for the increase in the cheek SkBF. A sour stimulus can activate transient receptor potential vanilloid-1 (TRPV1) receptors, which are also activated by capsaicin and temperatures of 43 °C and above in the oral cavity (Caterina et al. 1997; Arai et al. 2010). When TRPV1 receptors were activated by capsaicin and pinch stimuli in the oral cavity, parasympathetic vasodilatation in orofacial areas was induced by the afferent activity projected from trigeminal nerve pathway to the central nervous system (Karita and Izumi 1992). We previously reported that capsaicin and sour stimuli in the oral cavity increased SkBF in the cheek (Kashima and Hayashi 2011, 2013). Moreover, the application of painful stimuli to teeth reportedly increases SkBF in the cheek (Kemppainen et al. 2001). These observations can partly explain the neural pathway inducing the vasodilation related to sour stimuli. However, Drummond (1995) suggested that the increased SkBF in the cheek induced by spicy foods was not related to parasympathetic vasodilatation, because the presence of a facial nerve (parasympathetic nerve) lesion did not remove this SkBF response. Therefore, regulatory mechanisms of cheek circulation are complex and remain to be clarified.

Bitter tea evoked vasoconstriction in the nose. A relationship between vasoconstriction in the nose skin and unpleasantness is supported by our previous finding that the SkBF response in the nose to a bitter taste decreased with the degree of unpleasantness (Kashima and Hayashi 2011). Negative emotions were found to acutely decrease the temperature of the nose area of the rhesus monkey (Nakayama et al. 2005; Kuraoka and Nakamura 2011). Vasoconstriction in the nose was also found to be related to pain or unpleasantness induced by electrical stimulation of the finger and teeth (Kemppainen et al. 2001). Thus, negative emotions can characteristically elicit vasoconstriction in the nose.

The vasoconstriction in the nose induced by bitter tea can be attributed to anatomical characteristics. The nose area is rich in arteriovenous anastomoses (Bergersen 1993) that are controlled by adrenergic vasoconstrictor nerves, and hence the vasoconstrictive reactivity to sympathetic activation
should be stronger for the nose area than for other facial areas. The vasoconstriction was found to be stronger for nose skin than for the other facial areas during the cold pressor and static handgrip exercise tests (Kashima et al. 2013). A previous study found slight sympathetic vasoconstrictor activity in the forehead and cheek during whole-body cold exposure (Rasch and Cabanac 1993), and so it is not surprising that bitter tea evokes vasoconstriction in the forehead and cheek.

The magnitudes of the finger vasoconstriction and pressor responses were similar for bitter tea, orange juice, and soup, in the present study, and these responses have previously been observed in the presence of sympathetic activation (Hayashi et al. 2009). The pleasant and unpleasant sensations induced by the taste stimuli used in the present study could, therefore, evoke sympathetic activation.

The palatability is determined by not only taste but also olfaction. Thus, autonomic responses should be evaluated by considering both sensory inputs. The present data should contain the effects of olfactory components on facial SkBF responses.

**Conclusion**

The findings of this study demonstrate that facial circulatory responses can reflect the palatability perceived by an individual, even in the presence of complicated taste stimuli. The perception of a greater pleasantness for a particular taste stimulus results in a greater increase in CI in the eyelid. These findings imply that the facial circulatory response might be useful for objectively determining the degree of palatability of a foodstuff.

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**References**


