Many athletes experience a change in taste sensitivity due to physical fatigue. Nutrition is an important factor during training and recovery. Previous reports have described the ideal alimentation for athletes, however, the alimentation appropriate for physical fatigue has not been investigated. As a part of gustation research aimed at formulating an ideal alimentation for fatigue, we investigated the relationship between fatigue and taste sensitivity to sweet substances. Athletes were asked to perform a half marathon to induce physical fatigue. We used a triangle test to determine the detection threshold for sucrose solutions before and after running. The results revealed that the threshold decreased after the half marathon. Thus, we confirmed that taste sensitivity to sweetness increased as a consequence of physical fatigue. To avoid either a lack or excess in nutrient intake during post-exercise physical fatigue, an alimentation regime that takes into consideration this change in taste sense is necessary.

Keywords: physical fatigue, taste, sweet, threshold, sucrose
who participated in the Kyoto City Half Marathon. All the subjects were of normal weight, non-smokers, and in good physical health. They had run the complete marathon or half marathon. All psychophysical tests followed the regulations for sensory evaluation established by Kyoto University.

Sensory evaluation  Subjects performed a triangle test in which they were presented with cups containing 30 mL of sample solution. One sample set consisted of 3 cups: 1 glass of sucrose solution and 2 glasses of distilled water. The subjects were provided a sample set and were asked to select the cup containing the sucrose solution. We prepared 6 sucrose solutions of differing concentrations (40, 20, 10, 5, 2.5, and 1.25 mM), ranging from a clearly detectable level to an undetectable level. Sample sets were provided in descending order of sucrose concentration. The subjects were informed that only 1 of the 3 cups contained sucrose solution and that the sucrose concentration gradually decreased. The subjects were tested using all the solution sets regardless of giving a right or wrong answer for any particular set. All the solutions were poured into plastic cups and presented at ambient temperature. For each tasting test, the subjects were asked to rinse their mouth thoroughly with distilled water, sip the stimulus solution, swirl it around in their mouth for several seconds to taste it, and then spit it out. A rinse with deionized water was interspersed between tasting the samples. For 1 h prior to the test, the subjects ingested no food or drink except for water. The protocol was approved by the ethics committee of Kyoto University, and written informed consent was obtained from all subjects. The sensory evaluation was performed indoors. The ambient temperature and humidity were 20°C ± 3°C and 40% ± 5%, respectively.

The subjects were requested to subjectively assess their degree of physical fatigue using a scoring method in which the degree of physical fatigue was graded on a scale of 1 to 10 – a high score implying intense physical fatigue. These tests were performed once before and once after the half marathon. The subjects performed the test one hour before the start and just after finishing.

Sucrose was purchased from Nacalai Tesque (Kyoto, Japan). Distilled water purified using an Elix water purification system (Millipore, Bedford, MA, USA) was used as stimuli and mouth rinse.

Data analysis  The data obtained from the triangle test were analyzed by both a test for the proportion and probit analysis. From these data, the threshold for the subject group was calculated.

Test for the proportion  The triangle test is a method designed to detect a difference between 2 types of sample. The test was used to analyze the number of correct answers per subject for each concentration. Since the number of correct answers given by a subject obeys a binomial distribution ($P = 1/3$), a significant difference between the 2 types of sample can be determined. Our study included 35 subjects; therefore, if a correct answer is given by more than 18 subjects, this indicates that there is a difference between the samples at the 5% level of significance. For a sample size of 35, significance was demonstrated at the 5%, 1%, and 0.1% levels when the number of subjects who correctly chose the sugar solution was greater than 18, 19, and 22, respectively (Furukawa, 1994).

Probit Analysis  Probit analysis is used to analyze binomial data (Finney, 1971). When probit analysis is used to determine a threshold, the maximum likelihood estimates of the intercept is calculated at a 50% response value. However, even if the subjects are not able to distinguish the taste of a sample correctly and answer randomly, the correct answer rate in the triangle test is one-third. Therefore, there is a one-third probability for a random occurrence in the triangle test and the proportion of apparent correct identifications can be adjusted to obtain the estimated proportion of true identifications. This proportion is determined as follows.

Let $P_0$ and $p$ be the proportion of apparent correct identifications observed in the test and the proportion of the actual correct identifications over and above chance, respectively. As $P_0 = p + (1 - p) / 3$, the adjustment formula becomes $p = 1.5 P_0 - 0.5$. The $p$ values obtained for the 6 concentrations were used as the response scores representing the proportion of real identifications to obtain the dose-response curve for a given sucrose concentration.

Results  The number of subjects who correctly chose the sucrose solution in the triangle test is shown in Table 1. Table 2 presents values for the sucrose threshold obtained using the test for the proportion and probit analysis. Using the former, the sucrose detection thresholds before and after the marathon were 10 mM and 5 mM, respectively. When probit analysis was performed, the sucrose detection threshold was determined to be $11.9 ± 1.0$ mM (95% confidence interval, 10.1 to 14.2; test of goodness of fit, $p = 0.14$) before the marathon and $7.7 ± 0.8$ mM (95% confidence interval, 6.2 to 9.5; test of goodness of fit, $p = 6.8 × 10^{-4}$) after the marathon.

The degree of subjective physical fatigue before and after the marathon is shown in Fig. 1. The degree of physical fatigue increased significantly from $5.6 ± 0.3$ before the marathon to $8.9 ± 0.2$ after the marathon (Student’s $t$-test, $p = 1.4 × 10^{-15}$). With an increase in the degree of physical fatigue, the sucrose threshold shifted to a lower concentration.
Table 1. Results of the Triangle Test (n = 35).

<table>
<thead>
<tr>
<th>Sucrose Conc. (mM)</th>
<th>40</th>
<th>20</th>
<th>10</th>
<th>5</th>
<th>2.5</th>
<th>1.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Marathon</td>
<td>35**</td>
<td>31**</td>
<td>22**</td>
<td>17</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>After Marathon</td>
<td>35**</td>
<td>32**</td>
<td>32**</td>
<td>24**</td>
<td>16</td>
<td>11</td>
</tr>
</tbody>
</table>

For a sample size of 35, significance was demonstrated at the 5% (**), 1% (**), and 0.1% (***), levels when the number of subjects who correctly chose the sucrose solution was greater than 18, 19, and 22, respectively.

Table 2. Detection Threshold of Sucrose.

<table>
<thead>
<tr>
<th>Detection Threshold (mM)</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test for the Proportion</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Probit Analysis</td>
<td>11.9 ± 1.0</td>
<td>7.7 ± 0.8</td>
</tr>
</tbody>
</table>

The values represent the mean ± SE.

Discussion

As a consequence of running a half marathon, the sucrose detection threshold of runners was shifted to a lower concentration. We determined the sucrose threshold using 2 statistical methods; namely, the test for the proportion and probit analysis. The same tendency was observed, even when different statistical methods were applied to the data, and suggests that sensitivity to sucrose was increased by physical fatigue.

Taste is physiologically classified into 5 basic categories: salty, bitter, sour, umami, and sweet. Each taste serves a role in nutrition. A bitter taste can often signify the presence of poison in food, whereas a sour taste indicates unripe or spoilt foods. Animals instinctively avoid bitter and sour foods, preferring salty, umami, and sweet tastes. Salty, umami, and sweet tastes signify the presence of minerals, proteins, and energy, respectively (Kurihara, 2000). Generally, the threshold for bitter and sour substances, which are warning signals, is low, and the threshold for certain sugars that are ingested in large quantities is comparatively high (Yamaguchi, 1994). For example, Yamaguchi et al. (1995) reported that although the threshold for sucrose is 0.16%, that for quinine sulfate (bitter) and tartaric acid (sour) is 0.0001% and 0.00092%, respectively. In this study, we observed a tendency for sucrose sensitivity to increase during physical fatigue. Since a considerable amount of energy is consumed during rigorous exercise, a corresponding increase in the sensitivity to carbohydrates, which serves as an energy source, might be anticipated.

The relationship between fatigue and taste palatability has been investigated by Nakagawa et al. (1996), who evaluated the effect of mood on taste sensitivity. Following the induction of mental stress, the perceived duration of bitter, sour, and sweet taste sensations was shortened in the induced group compared to that in the control group. Further, the total amounts of bitter, sour, and sweet tastes were significantly reduced. The maximum taste intensity for bitter taste was also significantly reduced. There was, nevertheless, no significant difference between bitter and sweet sensations following physical stress. However, the duration of the aftertaste of sourness was significantly increased (Nakagawa et al., 1996). Horio and Kawamura (1998) examined the change in palatability and threshold of various taste solutions after the induction of exercise stress. Although the palatability of sweet and sour tastes increased, that of salty, bitter, and umami tastes did not change after exercise. In addition, it has been reported that the threshold of all tastes does change with exercise (Horio and Kawamura, 1998). However, in the present study, there was a significant difference between the sucrose detection threshold before and after exercise. Compared with the exercise intensity imposed on subjects in this study, that imposed on the subjects in other studies was non-intense and of short duration. In this study, we did not inves-
tigate the change in palatability. However, since a change in taste palatability during moderate exercise has been reported, there is a possibility that this property would change after a half marathon.

Thresholds of detection depend strongly on the method of measurement and the study population. Our study subjects were amateur runners who performed sensory evaluations for the first time. Therefore, these factors may have had a bearing on the results obtained. Pfaffman et al. (1971) reported that the sucrose detection threshold is 5 – 16 mM, and we consider that the results of this study provide a general value. In the future, it will be necessary to perform tests that take into consideration various factors such as sex, age, and athletic career. In our further studies, we will also investigate changes in sensory thresholds for other tastes, as well as changes in palatability, caused by intense physical fatigue.

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References