Chem. Senses 23: 417–421, 1998

Influence of Physical Exercise on Human Preferences for Various Taste Solutions

Tsuyoshi Horio and Yojiro Kawamura

College of Nutrition, Koshien University, 10-1 Momijigaoka, Takarazuka, Hyogo, 665-0006, Japan

Correspondence to be sent to: Tsuyoshi Horio, College of Nutrition, Koshien University, 10-1 Momijigaoka, Takarazuka, Hyogo, 665-0006, Japan

Abstract

The effects of physical exercise on preference for various sapid solutions was studied in 58 healthy university students. After 30 min of exercise using a bicycle ergometer at 50% $\dot{V}O_{2max}$ (maximal oxygen uptake) intensity, a rating scale test on taste hedonic tone and the triangle test for taste absolute threshold were done. The test solutions were sucrose, NaCl, citric acid, caffeine and monosodium glutamate (MSG). Preference scale values for sucrose and citric acid increased after exercise, whereas the values for NaCl, caffeine and MSG were not changed. The absolute thresholds for all the sapid solutions did not differ for pre- and post-exercise. These findings indicate that in humans preference for sucrose and citric acid increase after physical exercise.

Introduction

Taste preferences for food and beverages differ with physiological desires. Vazquez *et al.* (1982) showed that malnourished infants consumed more soup to which casein hydrolysate had been added than soup alone, whereas well-nourished infants showed the opposite response. A preference for a bitter taste was suggested to be related to mental stress (Nakagawa *et al.*, 1996). A specific sodium appetite related to the depletion of body sodium was shown in animal studies (Richter, 1936). A preference for NaCl and L-lysine was induced under L-lysine deficiency in rats (Mori *et al.*, 1991). A feedback mechanism to the taste system may act to stimulate consumption. Human infant acceptance of mother's breast milk after exercise decreased with an increase in the lactic acid concentration (Wallace *et al.*, 1992). Children undertaking intermittent bouts of cycling prefer grape-flavored rather than unflavored water (Bar and Wilk, 1996). Preference for taste substances after exercise, however, have yet to be thoroughly evaluated.

We studied the effects of physical exercise on the preference for sucrose (sweet), NaCl (salty), citric acid (sour), caffeine (bitter) and monosodium L-glutamate (MSG, umami taste) in healthy university students. Preliminary results have been reported in part in Horio and Kawamura (1995, 1997).

Materials and methods

Fifty-eight healthy Japanese university students aged from 19 to 21 years were tested. None had participated in regular exercise programs during the past 1 year. The students were ordered not to take any food and drink for at least 1 h prior to the test. The solutions used in the preference test consist of: 0.029, 0.058, 0.116, 0.232 and 0.464 M sucrose (sweet); 0.019, 0.038, 0.076, 0.152 and 0.304 M NaCl (salty); 0.0024, 0.0048, 0.0096, 0.0192 and 0.0384 M citric acid (sour); 0.0009, 0.0018, 0.0036, 0.0072 and 0.0144 M caffeine (bitter); and 0.02, 0.04, 0.08, 0.16 and 0.32 M MSG (umami taste). MSG (purity 99.9%) were supplied by Ajinomoto Company (Tokyo, Japan). The other chemicals were all of reagent grade. The solutions were all prepared with distilled water and kept at 37°C using a thermostatically controlled bath to ensure a constant temperature. The distilled water (Wako Pure Chemical Industries, LDD, Tokyo) used was odorless, and contained a residue of <2 ppm after evaporation. The taste test was conducted just before exercise, then repeated beginning 3 min after exercise and ending 20 min after exercise. Two or three taste solutions were tested per day. Ten milliliters of the test solution was applied over the entire oral area. Distilled water was used twice for oral rinsing between each trial. Subjects received samples of all the concentrations of the solutions in random order. After each trial, the subjects reported the taste hedonic tone.

For the preference test, a seven rating test scale for taste hedonic tone was used: 7, extremely pleasant; 6, moderately pleasant; 5, slightly pleasant; 4, neither pleasant nor unpleasant; 3, slightly unpleasant; 2, moderately unpleasant; and 1, extremely unpleasant.

The test solutions used in the triangle test for the taste absolute threshold were 0.0006, 0.0012, 0.0024, 0.0048, 0.0096 and 0.0192 M sucrose; 0.00015, 0.0003, 0.0006, 0.0012, 0.0024 and 0.0048 M NaCl; 0.00001, 0.00002, 0.00004, 0.00008, 0.00016 and 0.00032 M citric acid; 0.00009, 0.00018, 0.00036, 0.00072, 0.00144 and 0.00288 M caffeine; and 0.0002, 0.0004, 0.0008, 0.0016, 0.0032 and 0.0064 M MSG.

A triangle test series was conducted. The subjects were given six discrimination sets, each of which consisted of one glass containing the test substance at a given concentration and two glasses of distilled water only. From each set they were asked to pick out the glass with the tastant. The six sets were repeated at each concentration. Concentration was started from the clearly detectable level and ended at the clearly indetectably level. Sets were given in descending order.

The data obtained were analyzed by probit analysis (Finney, 1971). The subject's individual threshold may be less than the true threshold, because chance permits correct identification. Because the probability for such occurrence is 0.33, the proportion of apparent correct identifications can be adjusted to produce the estimated proportion of true identifications. Let P_0 and p respectively be the proportion of the apparent correct identification observed in the test and that of the actual correct identification over and above chance. As $P_0 = p + 0.33(1 - p)$, the adjustment formula becomes $p = 1.5P_0 - 0.5$. The p values obtained for the six concentration levels were used as the response scores representing the proportion of real identifications to obtain the dose–response curve for a given taste substance. Probit analysis was used to calculate the maximum-likelihood estimates of the intercept at 50% response.

The tests were conducted at room temperature 26 ± 3°C and a humidity of 57 ± 10%. Exercise was performed on a bicycle ergometer (Matsushita Electric Works, Ltd, EP351) at a pedaling rate of 50 r.p.m., and heart rates were monitored. The ergometer load was changed with the

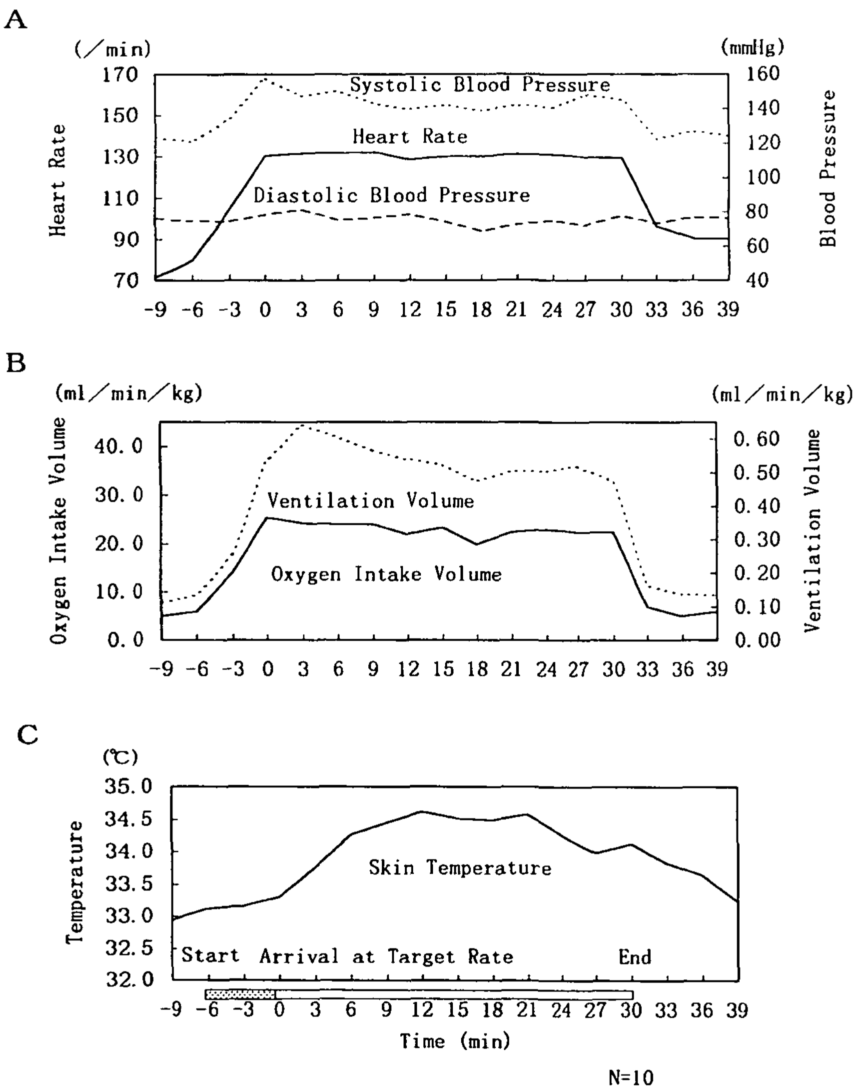

Figure 1 Heart rate, blood pressure and forehead skin temperature monitored every 3 min during exercise. Oxygen uptake ($\dot{V}O_2$) and pulmonary ventilation ($\dot{V}E$) were measured in 10 subjects.

change in the heart rate under exercise (mean: 130/s). The intensity of exercise was based on the percentage of the heart rate during maximal exercise (Boyer and Kasch, 1970). Exercise heart rate in beats per min = (maximum age-adjusted heart rate – resting heart rate) × 50% + resting heart rate. Maximum age-adjusted heart rate = 201.7–0.583 × age. The exercise period was 30 min.

Heart rate, blood pressure and skin temperature of the forehead were monitored every 3 min during exercise in all the subjects. Oxygen uptake ($\dot{V}O_2$) and pulmonary ventilation ($\dot{V}E$) were measured for ten subjects using an aeromonitor (Minato Medical Sience Co., Ltd, AE10).

As the control, the preference test was conducted after the subjects sat at rest for 30 min on the other day of exercise. On half of the subjects the exercise experiment was conducted first followed by the control experiment, and vice versa on the other half.

A comparison of the values for each solutions was conducted by a two-way ANOVA with repeated measures using the SPSS program. A *post hoc* test was performed using a paired *t*-test.

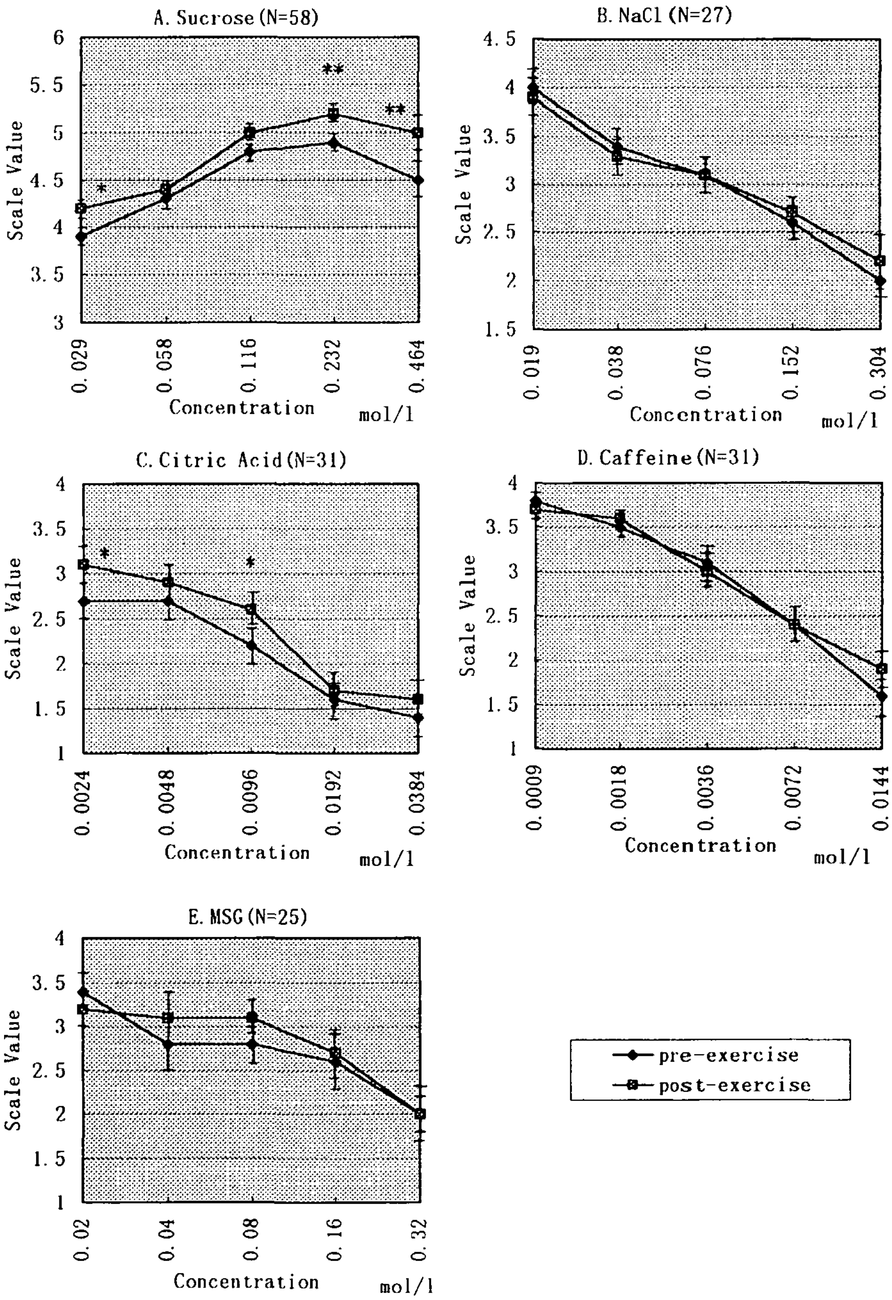

Figure 2 Comparisons of preferences for various taste solutions pre- and post-exercise. Asterisks indicate significant differences between pre- and post-exercise values. Vertical bars are expressed as mean ± SE. $^*P < 0.05$; $^{**}P < 0.01$.

Table 1 Absolute thresholds pre- and post-exercise for various taste solutions using the Probit method

	Sucrose (n = 27)	NaCl (n = 27)	Citric acid (n = 27)	Caffeine (n = 25)	MSG (n = 27)
Pre-exercise	0.0035 ± 0.0010	0.0017 ± 0.0009	0.00007 ± 0.00001	0.0012 ± 0.0002	0.0005 ± 0.0001
Post-exercise	0.0068 ± 0.0018	0.0017 ± 0.0006	0.00011 ± 0.00002	0.0009 ± 0.0002	0.0011 ± 0.0002

There were no differences in threshold between the pre- and post-exercise values. Values are expressed as mean ± SD. Units are mol/l.

Results

Figure 1A shows the heart rate, and systolic and diastolic blood pressures (n = 10) taken every 3 min during exercise. The heart rate was 70/s before exercise, and then increase gradually up to 130/s. This latter heart rate level was maintained for 30 min during the exercise. The pre-exercise level was recovered after the exercise had ended. Systolic blood pressure was 123 mmHg before exercise and 139–158 mmHg during exercise, recovering to the original level after exercise. Diastolic blood pressure did not change during exercise. The other subjects showed almost the same results of the heart rate and blood pressure.

The ventilation volume ($\dot{V}E$) and oxygen intake volume ($\dot{V}O_2$) both increased during exercise (Figure 1B).

The skin temperature of the forehead rose gradually after the start of exercise to 34.5°C, at which point sweat appeared on the forehead, neck and arms, suggesting that the exercise in this experiment was hard.

Figure 2A shows the scale values of sucrose for pre- and post-exercise (n = 58). A two-way ANOVA with repeated measures (exercise × concentration) showed a significant effect of exercise [$F(1,57) = 20.61$, $P < 0.01$] and concentration [$F(4,228) = 8.45$, $P < 0.01$], but the exercise × concentration interaction was not significant [$F(4,228)$ = 1.73]. *Post hoc* analyses of these data using the t-test showed that the values for 0.029 ($T = 2.56$, $P < 0.05$), 0.232 (T = 2.89, $P < 0.01$) and 0.464 M ($T = 3.45$, $P < 0.01$) were significantly higher than those for pre-exercise.

For NaCl (n = 27, Figure 2B), the two-way ANOVA with repeated measures (exercise × concentration) showed no significant effect of exercise [$F(1,26) = 0.00$].

For citric acid (n = 31), the two-way ANOVA with repeated measures (exercise × concentration) showed a significant effect for exercise [$F(1,30) = 13.65$, $P < 0.01$]. *Post hoc* analyses of the data with the t-test showed that the post-exercise scale values for 0.0024 ($T = 2.36$, $P < 0.05$) and 0.0096 M ($T = 2.04$, $P < 0.05$) were higher than the pre-exercise values (Figure 2C).

Regarding caffeine (n = 31, Figure 2D), the exercise [$F(1,30) = 0.25$] was not significant.

For MSG (n = 25, Figure 2E), the two-way ANOVA with repeated measures (exercise × concentration) showed no significant effect of exercise [$F(1,24) = 0.56$].

In the control subjects who sat at rest for 30 min there was no difference in the scale values between pre- and post-exercise in all the tested taste solutions.

Table 1 shows the absolute threshold based on the probit method at pre- and post-exercise for the various taste solutions. For none of the taste solutions were there any differences in the pre- and post-exercise thresholds between the exercises and the controls.

Discussion

The preference scale values for sucrose and citric acid increased after exercise, whereas those for NaCl, caffeine and MSG were unchanged. In the control subjects, who sat at rest for 30 min, there were no differences in scale values pre- and post-exercise for all the taste solutions used. These findings indicate that the preference for sucrose (sweet) and citric acid (sour) increased after physical exercise, but the absolute thresholds of all the sapid solutions did not differ pre- and post-exercise. Physical exercise may not produce a significant change in taste threshold sensation, but a preference for sucrose and citric acid occurred after physical exercise.

Flavored water reduces voluntary dehydration in children who exercise intermittently (Wilk and Bar, 1996). Flavoring or cooling warm water enhances fluid intake in the treadmill exercise (Szlyk *et al.*, 1989). Infant acceptance of mother's breast milk after exercise decreased with the increase in lactic acid concentration (Wallace *et al.*, 1992). Children undertaking intermittent bouts of cycling preferred grape-flavored rather than unflavored water (Bar and Wilk, 1996). These changes may be caused by physiological changes in the body. Deficiency of calories could be induced by consumption of ATP or glucose. A feedback mechanism to the taste system may stimulate preference and consumption.

After a single bout of acute runnning, activity of citrate synthase was reduced in rat skeletal muscle (Frederick *et al.*, 1988), whereas training for several weeks increased the activity in the rat soleus muscle (Murakami *et al.*, 1994) but reduced it in the rat respiratory muscle (Green and Reichmann,1988). It was reported that athletes (swimmers) showed a lower preference for high sucrose and high fat (Crystal *et al.*, 1995). Hartung *et al.* (1980) reported that the daily diets of marathon runners and joggers had lower intakes of suger, jam, jelly and honey than those of inactive men. These findings suggest that beverages and food preferences just after acute exercise might differ from those after training for several weeks.

In the NaCl, caffeine and MSG tests preferences after exercise did not change from those before exercise. The composition of the drink did not affect perceptual responses to drinking while euhydrated children exercised in the heat (Meyer *et al.*, 1995). The Na appetite after a 7 h depletion of H_2O and Na^+ was produced by intermittent exercise at 35°C (Takamata, 1994). Possibly long and/or intense exercise may lead to changes in the preference for NaCl, caffeine and MSG; i.e., both the quantity and quality of exercise is important for determining food taste preferences.

Acknowledgement

This work was supported in part by a grant from the Ministry of Education, Science, Sports and Culture of Japan (No. 07610095).

References

Bar, O.O. and **Wilk, B.** (1996) *Water and electrolyte replenishment in the exercising child*. Int. J. Sport. Nutr., 6, 93–99.

Boyer, J.L. and **Kasch, F.W.** (1970) *Exercise therapy in hypertensive men*. J. Am. Med. Assoc., 211, 1668–1671.

Crystal, S, Frye, C.A and **Knarek, R.B.** (1995) *Taste preferences and sensory perceptions in female varsity swimmers*. Appetite, 24, 25–36.

Finney, D.J. (1971) Probit Analysis, 3rd edn. University Press, London.

Frederick, L.L.J., Stratman, W. and **Lardy, H.A.** (1988) *Enzymatic down regulation with exercise in rat skeletal muscle*. Arch. Biochem. Biophys., 263, 137–149.

Green, H.J. and **Reichmann, H.** (1988) *Differential response of enzyme activities in rat diaphragm and intercostal muscle to exercise training*. J. Neurol. Sci., 84, 157–165.

Hartung, G.H., Foreyt, J.P. and **Michel, R.E.** (1980) *Relation of diet to high-density-lipoprotein cholesterol in middled-aged marathon runners, joggers, and inactive men*. N. Engl. J. Med., 302, 357–361.

Horio, T. and **Kawamura, Y.** (1995) *Effect of physical exercise on preference of taste solutions*. Chem. Senses, 20, 3.

Horio, T. and **Kawamura, Y.** (1997) *Effect of physical exercise on preference of taste solutions*. Chem. Senses, 22, 354.

Meyer, F., Bar, O.O. and **Wilk, B.** (1995) *Children's perceptual responses to ingesting drinks of different compositions during and following exercise in the heat*. Int. J. Sport Nutr., 5, 13–24.

Mori, M., Kawada, T., Ono, T. and **Torii, K.** (1991) *Taste preference and protein nutrition and l-amino acid homeostasis in male Sprague–Dawley rats*. Physiol. Behav., 49, 987–995.

Murakami, T., Shimomura, Y., Fujitsuka, N., Nakai, N., Sugiyama, S., Ozawa, T., Sokabe, M., Horai, S., Tokuyama, K. and **Suzuki, M.** (1994) *Enzymatic and genetic adaptation of soleus muscle mitochondria to physical training in rats*. Am. J. Physiol., 267, E388–395.

Nakagawa, M., Mizuma, K. and **Inui, T.** (1996) *Changes in taste perception following mental or physical states*. Chem. Senses, 21, 195–200.

Richter, C.P. (1936) *Increased salt appetite in adrenalectomized rats*. Am. J. Physiol., 115, 155–161.

Szlyk, P.C., Sils, I.V., Francesconi, R.P., Hubbard, R.W. and **Armstrong, L.E.** (1989) *Effects of water temperature and flavoring on voluntary dehydration in men*. Physiol. Behav., 45, 639–647.

Takamata, A., Mack, G.W., Gillen, C.M. and **Nadel, E.R.** (1994) *Sodium appetite, thirst, and body fluid regulation in humans during rehydration without sodium replacement*. Am. J. Physiol., 266, R1493–502.

Vazquez, M., Pearson, P.B. and **Beauchamp, G.K.** (1982) *Flavor preferences in malnourished Mexican infants*. Physiol. Behav., 28, 513–519.

Wakkace, J.P., Inbar, G. and **Ernsthausen, K.** (1992) *Infant acceptance of post exercise breast milk*. Pediatrics, 89, 1245–1247.

Wilk, B. and **Bar, O.O.** (1996) *Effect of drink flavor and NaCl on voluntary drinking and hydration in boys exercising in the heat*. J. Appl. Physiol., 80, 1112–1117.

Accepted May 6, 1998