BIOLOGY OF EXERCISE
VOLUME 11.1, 2015

Exercise Intensity Differentially Impacts Sensitivity Thresholds to Specific Tastes

D.O.I: http:doi.org/10.4127/jbe.2015.0087

YASUTO NAKANISHI[1], YOSHIMITSU INOUE[2], TARO ITO[3], VINCENT NETHERY[4]

[1] *Department of Health Science, Osaka-Aoyama University, 2-11-1 Niina, Minoh, Osaka 562-8580, Japan*
[2] *Laboratory for Human Performance Research, Osaka International University, 6-21-57 Fujita-cho, Moriguchi, Osaka 570-8555, Japan*
[3] *Department of Health and Sports Science, Mukogawa Women's University, 6-46 Ikebirakicho, Nishinomiya, Hyogo 663-8558, Japan*
[4] *Department of Nutrition Exercise and Health Sciences, Central Washington, University 400 E. University Way, Ellensburg, WA*

ABSTRACT

The purpose of this study was to compare the impact of exercise intensity on sensitivity to four major tastes of sweet, sour, salty, and bitter. Ten subjects completed two separate 30-min cycling exercise bouts, one at low intensity (50% $\dot{V}O_2$max) and the other at high intensity (70% $\dot{V}O_2$max.). Sensitivity to the four tastes was assessed before and after each exercise bout, using taste discs. Comparative data were analyzed using paired t-tests and the relationships between work-related physiologic measures and taste sensitivities were calculated using Pearson Correlation. Significance was established at the 0.05 level of probability. Post-exercise sourness threshold was higher ($p \leq 0.05$) following the high intensity exercise compared to the low intensity exercise, sweetness threshold decreased following the higher intensity exercise ($p \leq 0.05$), while no differences were observed in threshold sensitivities for the other two tastes at either workload. The increased sensitivity to sweetness (decreased threshold) was strongly related to changes in blood glucose following both low ($r^2 = 0.62$; $p < 0.01$) and high ($r^2 = 0.50$; $p \leq 0.05$) intensity exercises. As well, changes observed in sourness threshold were directly related to the changes in core temperature ($r^2 = 0.49$; $p \leq 0.05$) but only for the low intensity exercise bout.

Key Words: *Four taste sensitivities, Blood sugar, Core temperature*

INTRODUCTION

A level of sensitivity towards basic taste is critical to appetite, health, the enjoyment of foods and beverages, and the maintenance of energy balance. However, sensitivity to taste can be impacted by a variety of factors including stress (10, 12, 13), illness and physical condition (14), exercise (12, 18, 19), and aging (5).

That taste sensitivity can be affected by mental and physical stress (12, 10, 13) has some logic because, like many other biologic functions, taste has the potential to be impacted by multiple factors. A rise in sensitivity to sweetness was previously observed after marathon running (18), however, the opposite response was reported after mountain hiking (18). In contrast, no change in sweetness sensitivity was reported after completion of a strenuous 8-day cross-country running camp where participants trained 20km/day (19). Marathon running elicited a rise in sourness sensitivity (18) and this same response was reported after seven consecutive days of 4hrs/day baseball training (12). Contributory factors to these varying observations might include the intensity, duration, total energy expended and rate of energy expenditure of the exercises, whether it is continuous or intermittent, the mode, and the environmental conditions. Field studies reporting the aforementioned outcomes are challenged to tightly control for many of these critical exercise factors, which makes it difficult to determine the degree to which specific exercise characteristics might impact taste sensitivity.

Sustained exercise that varies in intensity and duration induces a broad-range of well-established physiologic responses such as thermogenesis, fluid and electrolyte loss, alterations in pH, changes in circulating glucose, and fluctuations in hormone and other chemical mediators. However, while the aforementioned field observations suggest that exercise may alter taste sensitivities, the specific characterisitcs of the exercise setting that might differentially affect these sensitivities is not at all clear.

Therefore, the primary purpose of this study was to compare the impact of two exercise intensities (low and high) on sensitivity to the four major tastes of sweet, sour, salty, and bitter. We hypothesized that, if exercise does affect taste sensitivity, this effect would be more strongly associated with the physiologic strain and more pronounced responses of high intensity exercise.

MATERIAL AND METHODS

Subjects

Ten healthy, but untrained male university students served as subjects. Biographical data for these subjects are presented in Table 1. All subjects were nonsmokers. Before participating, the subjects were informed of all experimental pro-

cedures, the possible risks, and their voluntary withdrawal from the procedures at any time. Formal consent was obtained, all procedures conformed to the Declaration of Helsinki, and the protocol approved by the Ethical Committee of Osaka Aoyama University. Subjects avoided strenuous exercise and consumption of alcoholic beverages for at least 24hrs, and did not consume any food or caffeine for at least 3 hours prior to undertaking each test procedure.

Table 1. *Biographical data for subjects*

Age (yrs)	19.6±5.4
Height (cm)	171.7±5.6
Weight (kg)	68.1±13.6
Body fat (%)	20.9±5.5
$\dot{V}O_2$max (l/min)	2.88±0.43
$\dot{V}O_2$max (ml/kg/min)	43.4±7.5
HRmax (bpm)	198.6±5.1
Blood lactate for incremental aerobic test (mmol/ℓ)	13.9±3.7
Workload for 50% Ex. (W)	91.1±19.6
Workload for 70% Ex. (W)	139.6±26.4
Data are represented as mean ± SD	

Methods and procedures

1. Exercise Load Determination

In order to determne the exercise loads for each test, the participants completed an incremental aerobic test to volitional exhaustion on a computer controlled bicycle ergometer (75XL II, Combi Wellness Co. Ltd, Tokyo, Japan). The seat height was adjusted, post height marked and recorded for each subject. Subjects were then connected to an automated respiratory gas analyzing system (VE-310, Minato Med Sci Co., Osaka, Japan) where the respiratory measures of ventilation, expired oxygen fraction, and expired carbon dioxide fraction were obtained at 15 second intervals. From these data, the metabolic measures of oxygen consumption, carbon dioxide production, and respiratory exchange ratio (RER) were calculated. Heart rate (HR) was monitored continuously throughout the progressive

test using a Polar Vantage XL Heart Rate Monitor (Polar Electro Inc., NY, USA) and recorded at 15-second intervals.

Subjects first rested on the cycle ergometer for four minutes while instrumentation was connected and checked, and then completed a 4-min warm up (20W). All subjects then performed a ramped exercise test (20W/min) until volitional fatigue. The highest 15-sec value for oxygen consumption represented $\dot{V}O_2$max and the existence of at least three of the following five criteria were used to determine if maximum was reached, 1) levelling of $\dot{V}O_2$ with increasing exercise intensity, 2) attainment of age-predicted HR_{max} ± 10 bpm, 3) a RER > 1.1, 4) a blood lactate value ≥ 10 mmol/ℓ, and 5) Rating of Perceived Exertion (RPE) ≥ 19. All subjects satisfied at least three of these criteria. Blood lactate was determined from a 0.3 μL sample drawn from the fingertip 30 seconds after finishing the test and this sample was analyzed for concentration using the Lactate Pro Blood Lactate II Analyzer (Kyoto Daiichi Kagaku Co., Japan). RPE for breathing and for legs were reported from Borg's 6-20 Scale with values for legs recorded at the end of each two-minute workload stage and at the end of the test.

The low and high workloads for each subject were determined by regression analysis from the relationship between $\dot{V}O_2$ and workload. The low workload was determined by the power output associated with 50% of $\dot{V}O_2$max minus a 1-minute increment workload value (20W) and the high workload was determined by the power output associated with 70% of $\dot{V}O_2$max also minus 20W.

The order of exercise intensity for the taste tests were randomly assigned and at least 48hrs separated each test session. In both the high and the low intensity tests, the subjects rested for 5 minutes on the cycle ergometer prior to beginning the workload. During this time, monitoring devices were secured and any necessary adjustments made to the ergometer. Each test session required the subject to pedal for 30 minutes (60 rpm) at the prescribed load. Room temperature and humidity were kept constant throughout the testing at 25±1°C and 50±5%, respectively.

2. Taste sensitivity test

Sensitivity for sweet, salt, sour and bitter tastes were measured before and after each exercise with the subjects seated in a comfortable chair. Pre-exercise taste sensitivity was conducted after a 30-minute rest and acclimatization period in the testing facility. Post-exercise taste sensitivity was conducted 10 minutes after completion of the exercise bout. Taste discs (Sanwa Kagaku Kenkyusho Co.Ltd.) were used to determine the four taste thresholds. A filter paper soaked in the specific taste solution, was placed for three seconds on the right or left anterior two-thirds of the tongue, 2cm from the tip, and the subject was asked to identify the specific taste.

Five levels of reagent concentration were used for each taste and these were presented in an ascending order of concentration (see Table 2). Subjects rinsed

with distilled water before receiving each test disc. The numeral (1-5) associated with the reagent concentration for sensitivity to each disc concentration was recorded to determine the threshold for each taste solution (3) and that number was used for data analysis.

Table 2. *The concentration of each taste solution*

Tastes	**Reporting number associated with each solution concentration**				
	1	**2**	**3**	**4**	**5**
Sweetness (Sucrose - g/dℓ)	0.3	2.5	10	20	80
Saltiness (Sodium Chloride- g/dℓ)	0.3	1.25	5	10	20
Sourness (Tartaric Acid- g/dℓ)	0.02	0.2	2	4	8
Bitterness (Citric Quinine Chloride-g/dℓ)	0.001	0.02	0.1	0.5	4

3. Physiologic Variables Measured

Oral temperature (T_{or}) to indicate changes in core temperature was measured sub-lingually at rest and at 5-minute intervals during exercise using an Omuron clinical thermometer (MC-612). T_{or} was also measured after each taste sensitivity test. Blood glucose was measured before and after each exercise bout using Glutest Neo Super (Sanwa Kagaku Kenkyusho Co.Ltd.) and blood lactate was measured 30 seconds after finishing each exercise bout. Sweat loss was estimated as the fluid volume that corresponded to the difference between pre-exercise and post-exercise nude weight.

Data Analyses

Data were analyzed using paired t-tests to compare pre-test values for each variable between each exercise test, to compare post-test values for each variable between each exercise test, to assess the significance of change between pre-exercise and post-exercise measures within each exercise test, and to assess whether the magnitude of change was greater for one exercise intensity compared

to the other intensity. Pearson correlation coefficients determined the direction and magnitude of the relationships between the changes in sensitivities to each specific taste and the changes in physiologic responses. While $p \leq 0.05$ represents a typically accepted level of probability for analyses, specific "p" values are reported for observations that approach this traditional level. Relevant data are reported as means ± standard deviations (SD) unless otherwise indicated.

RESULTS

The physiological responses to the low and high intensity exercise bouts are presented in Table 3. Total quantity of sweat, post-exercise core temperature, post-exercise blood lactate concentration, and the change in core temperature for the high intensity exercise were all higher ($p \leq 0.05$) compared to the low intensity exercise.

Table 3. *Physiological responses to low and high exercise bouts*

	Exercise Intensity		
	50% $\dot{V}O_2$max	70% $\dot{V}O_2$max	Differences
Total Sweat Quantity (ℓ)	0.38±0.18*	0.57±0.13*	0.22
Pre-Ex. Core Temp. (˚C)	36.77±0.18	36.76±0.21	0.01
Pre-Ex. Core Temp. (˚C)	37.39±0.34*	37.72±0.61*	0.33
Δ Core Temp. (˚C)	0.62±0.3*	0.96±0.59*	0.34
Pre-Ex. Blood Glucose (mg/dℓ)	87.6±13.6	92±10.1	4.4
Post-Ex. Blood Glucose (mg/dℓ)	82.9±11.3	95.5±21.3	12.6
Blood lactate (mmol/ℓ)	6.0±2.9*	10.7±4.6*	4.7
Results are represented as mean ± SD			
** Significant difference (p<0.05) between the two exercises.*			

The thresholds for each taste discrimination test prior to and following each exercise tests are presented in Table 4. Pre-exercise thresholds were the same for each taste for both exercise bouts, however a higher threshold (reduced sensitivity) for sourness followed the high intensity exercise (3.4 ± 0.7) compared to the threshold following the low intensity bout (2.6 ± 1.1) ($p<0.01$) (Figure 1). As well, the sourness threshold tended to decrease (pre = 3.1 ± 1.1; post = 2.6 ±

1.1) (p=0.09) following the low intensity exercise bout. Also, while neither exercise bout affected thresholds for saltiness and bitterness, the sweetness threshold decreased following the high intensity exercise (pre = 3.2 ± 0.9; post = 2.6 ± 0.7) (p≤0.05) and tended to decrease (pre = 3.6 ± 1.2; post = 2.8 ± 1.5) following the lower intensity exercise bout (p=0.08).

Table 4. *Taste thresholds before and after low and high intensity exercise*

	Pre-Ex.		Post-Ex.	
	50% $\dot{V}O_2$max	70% $\dot{V}O_2$max	50% $\dot{V}O_2$max	70% $\dot{V}O_2$max
Sweetness threshold	3.6±1.2	3.2±0.9	2.8±1.5	2.6±0.7
Saltiness threshold	3.4±1.4	2.8±1.2	2.8±1.5	2.4±1.1
Sourness threshold	3.1±1.1	3.2±0.8	2.6±1.1*	3.4±0.7*
Bitterness threshold	2.9±1.1	3.2±0.9	2.7±1.2	3.1±1.0
Results are represented as mean ± SD				
** Significant difference (p<0.05) in post-Ex. between the two exercises*				

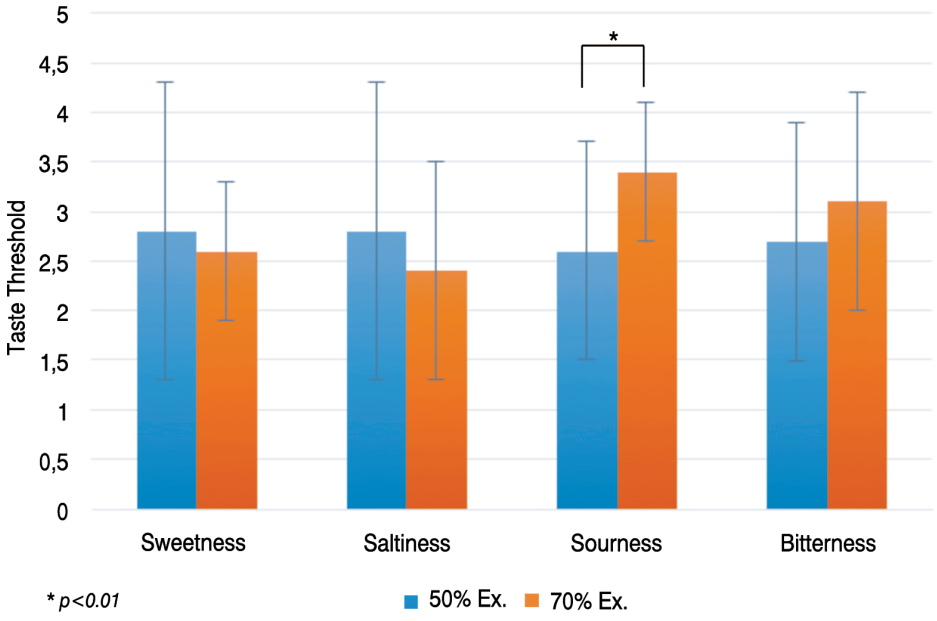

Fig 1. *Post-exercise threshold for each taste.*

When physiologic responses were correlated to taste sensitivities, moderately strong inverse relationships were observed between the change in threshold for sweetness (increased sensitivity) and the change in blood glucose (decreased concentration) for both low intensity exercise ($r^2=0.62$; $p<0.01$) and high intensity exercise ($r^2=0.50$; $p\leq0.05$). Also, a moderately strong positive correlation was observed between the change in threshold for sourness and the change in oral temperature ($r^2 = 0.49$; $p \leq 0.05$) but only for the 50% exercise intensity bout.

DISCUSSION

This study assessed the influence of two different exercise intensities on sensitivity to four major tastes of sweet, sour, salty, and bitter. Exercise intensity was categorized as low (50% $\dot{V}O_2$max) and high (70% $\dot{V}O_2$max).

Two direct effects of exercise on taste were observed. Firstly, a substantially lower detection existed for sourness (higher threshold) following the high intensity exercise compared to the post-exercise threshold of the low intensity exercise. And secondly, an increased sensitivity to sweetness (lower threshold) was observed but only following the high intensity exercise.

However, even though the 50% intensity exercise did not indicate statistically significant change in sensitivities to sourness or sweetness, sourness sensitivity tended to decrease ($p=0.09$) and sweetness sensitivity tended to increase ($p=0.08$) following this lower intensity exercise bout.

As expected, the intensity of exercise directly impacts core temperature with a greater rise (0.96˚C) following the heavier exercise bout compared to lighter exercise (0.62˚C). Internal temperature is a direct indicator of physiologic stress – especially under controlled ambient conditions, and the 55% greater increase in core temperature accompanied by the 50% greater sweat loss (570ml vs 380ml) of the high intensity exercise may have inititated release of biologic mediators to regulate temperature and fluid balance. Biologic mediators of stress have previously been suggested as modulators of taste perception (15). As well, salivary volume and constituency can also change taste sensitivity by altering the chemical interaction with specific elements of foods, resulting in an alterion in taste responses (16). Quantity of saliva decreases when exercise exceeds 60% of maximum (20,11) and saliva buffering capacity is elevated following heavy exercise (13). Although we did not measure salivary volume or pH, the reduced sensitivity to sourness (tartaric acid) following the high intensity exercise may be related to lower salivary secretion and/or changes in saliva chemistry.

Moderately strong, inverse relationships were observed between blood glucose changes and sweetness sensitivity changes for both exercise intensities. Individual data on blood glucose-sweetness sensitivity changes provides some interesting

observations. Five of the six subjects who exhibited decreases in blood glucose after the low intensity exercise and all three who exhibited decreases after the high intensity exercise, reported a higher sensitivity to sweetness (Table 5). Moreover, when we analyzed (paired t-test) the pre-post change in sweetness sensitivity only for these nine data units independent of exercise intensity, the post-exercise threshold for sweetness was significantly lower ($p<0.0001$). Sensitivity to sweetness is believed to be related to organism energy demands (12) and a decrease in circulating glucose may link to the glucostatic theory of hunger and feeding regulation (6). However, while the observed relationships are both moderately high and statistically significant, and suggest that blood glucose might be a factor in the alteration of sweetness sensitivity, this interpretation is tempered by the void in causation of descritive relationships and the inter-individual variability observed in plasma glucose responses to exercise, even among those who exhibited decreases.

Table 5. *Sweetness threshold and circulating glucose data for all subjects whose circulating glucose decreased with exercises*

Subject	Exercise Intensity	Pre-Ex. ST	Post-Ex. ST	ΔST	Pre-Ex. BG	Post-Ex. BG	ΔBG
a	50%	4	2	-2	101	95	-6
b	50%	3	1	-2	95	89	-6
c	50%	5	3	-2	86	76	-10
d	50%	5	3	-2	98	75	-23
e	50%	2	2	0	77	66	-11
f	50%	3	1	-2	99	84	-15
g	70%	4	2	-2	89	64	-25
e	70%	3	2	-1	101	78	-23
f	70%	3	2	-1	76	65	-11

ST = sweetness threshold; ΔST = change in sweetness threshold

BG = blood glucose (mg/100ml); ΔBG = change in blood glucose

Exercise has variable effects on substrate activity depending on nutritional state, level of fitness, and intensity of the exercise. In light to moderate exercise in

a post-absorptive state, lipid is typically an important metabolic substrate for oxidative rephosphorylation and the demand for glucose is rather moderate. As well, the active myocyte facilitates plasma glucose uptake into the cell in the absence of other cell-transport mediators (typically insulin). Furthermore, the glycogenolytic activator adrenaline is quite low at this level of physical work and little stimulus is present to mobilize glycogen from hepatocytes (7).

In contrast, higher intensity exercise may result in some elevation of circulating glucose from hepatic glycogenolysis, a process that is mediated by the release of acute stress responders such as epinephrine (2, 17, 9). Although we did not measure circulating epinephrine, we assume that the inter-individual stress epinephrine responses were varied and this would lead to some variation in circulating plasma glucose levels.

Total sweat loss was significant for each exercise session with 380ml secreted during the low intensity exercise and 570ml during the high intensity exercise. However and a little surprisingly, there was no change in threshold to saltiness either between intensities or within each exercise level. This observation differs somewhat from previous studies that indicated a decreased saltiness threshold (increased sensitivity) after exercise (4, 1) that was purportedly related to exercise induced sweating. Sodium and chloride ions predominate in sweat and levels of these ions could be reduced during endurance tasks (8). However, volume of sweat loss for these previous observations (4, 1) was substantially larger (~1000ml) than for the current study and we assume that sodium and chloride concentration disruption at the intensity-duration-environmental conditions of the present exercise generated sudorfic responses that were insufficiently large to alter the threshold for salt detection.

As for the lack of any impact of exercise on bitterness threshold, we speculate that, because bitterness sensitivity is directed at avoiding potentially harmful substances, the sensitivity towards such substances would logically be maintained regardless of exercising state.

CONCLUSIONS

In conclusions, high intensity exercise brought about an increase in sensitivity to sweetness when pre-post levels were compared and a decrease in sensitivity to sourness when the high intensity post-exercise level was compared with that of the low-intensity post-exercise level. Sweetness sensitivity was highly related to the changes in circulating glucose regardless of exercise intensity. However, neither level of exercise affected either the bitter or salty taste thresholds. These outcomes provide additional insight into the impact of exercise on basic taste functions and this information may be useful for flavoring of food and sports related nutrition products directed to the exercising population.

ACHKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number 24570261.

REFERENCES

1. Asami N: The study of taste chages before and after exercise (In Japanese), Rep Jpn Coka Cola science fund in 2007, 2008.
2. Coggan AR, Raguso CA, Williams BD, Sidossis LS, Gastaldelli A; Glucose kinetics during high-intensity exercise in endurance-trained and untrained humans, J Appl Physiol., 78, 1203-1207, 1995.
3. Esumi Y: Relationship between the Taste Perception, the Dietary Habits and the Food Preference. B Shimane Women's College, Vol. 38, pp. 63-71, 2000.
4. Fujiwara A, Iwaihara Y, Sugiyama K: The influence of sweat quantity and urine pH change during basketball practice on taste threshold (In Japanese), Jpn Society of Phys Fit and Sports Med, Vol. 61, No. 6, pp. 665, 2012.
5. Glanville EV, Kaplan AR, Fisher R; Age, sex, and taste sensitivity: J. Geront, Vol. 19, pp.474-478, 1964.
6. Guyton C; Textbook of Medical Physiology, pp.779, W. B. Saunders Company, 1991.
7. Jenkins AB, Furler SM, Chisholm DJ, Kraegen EW; Regulation of hepatic glucose output during exercise by circulating glucose and insulin in humans, Am J Physiol., 250, R411-417, 1986.
8. Kenney LK, Wilmore JH, Costill DL: Physiology of Sports and Exercise(5th Edition). pp.382-384, Human Kinetics, Illinois, 2012.
9. Kjaer M, Farrell PA, Christensen NJ, Galbo H; Increased epinephrine response and inaccurate glucoregulation in exercising athletes, J Appl Physiol., 61, 1693-1700, 1986.
10. Mizuma K, Nanba K, Nakagawa T: The Study of Relationship between Moods and Taste Sensitivities (In Japanese), JPN Assoc for the Stud of Taste & Smell, Vol. 1, No. 3, pp. 340-343, 1994.
11. Morishita A, Yamada M, Yamaoka M, et al.: The influence of exercise intensity on appetite (In Japanese), Jpn Society of Phys Fit and Sports Med, Vol. 58, No. 6, pp. 853, 2009.
12. Motooka Y, Asami N: The Influence of Physical Activity on Taste Thresholds (In Japanese, English abstract), Jpn Society of Exercise Sport Physiol., Vol.17, No.2, pp. 59-66, 2010.
13. Nakagawa M, Mizuno K, Inui T: Changes in taste perception following mental or physical stress, Chem Senses, Vol. 21, pp. 195-200, 1996.

14. Narukawa M, Ue H, Morita K, and et al.: Change in Taste Sensitivity to Sucrose due to Physical Fatigue. Food Sci. Technol. Res. Vol. 5, No.2, pp. 195-198, 2009.
15. Roper SD; Taste buds as peripheral chemosensory processors, Semin Cell & Dev Biol, Vol. 24(1), pp. 71-79, 2013.
16. Sasano T, Satoh-Kuriwada S, Shoji N, Sekine-Hayakawa Y: Application of umami taste stimulation to remedy hypogeusia based on reflex salivation, Biol & Pharm B, Vol. 33, No.11, pp. 1791-1795, 2010.
17. Sigal RJ, Fisher S, Halter JB, Vranic M, Marliss EB; The role of catecholamines in glucoregulation in intense exercise as defined by the islet cell clamp technique, Diabetes, 45, 148-156, 1996.
18. Uemura M, Narikawa M, Morita K, Ue H, Matsumura Y, Hayashi Y: The effects of Physical Stress on Gustatory Sensation (In Japanese), Jpn Society of Exercise Sport Physiol., Vol. 15, No. 3, pp. 309-312, 2008.
19. Uemura M, Ue H, Kuga S, Isaka T, Matsumura Y, Hayashi Y: The effects of physical stress from athletic training camp on gustatory Sensation (In Japanese), JPN Assoc for the Stud of Taste & Smell, Vol. 16, No. 3, pp.4 59-462, 2009.
20. Zhu B, Takahashi M, Taito S et al.: Changes in salivary secretory immunoglobulin A levels during moderate exercise (In Japanese, English abstract), Journal of Hiroshima U Health Educ, Vol. 10, No. 1, pp. 20-25, 2011.

Address for correspondence:

Nakanishi Y (PhD)
Osaka-Aoyama University, 2-11-1 Niina,
Minoh 562-8580, Japan
Fax: +81-78-922-6811
e-mail: y-nakanishi@osaka-aoyama.ac.jp