Effect of Thermal Dehydration on Blood Lactate Accumulation During Incremental Exercise Under Different Environmental Conditions

Guo-chiang SHOU and Toshihiro ISHIKO

Laboratory for Exercise Physiology and Biomechanics, School of Physical Education, Chukyo University, Toyota, Aichi 470-03, Japan

Abstract

SHOU, G.C. and ISHIKO, T. Effect of Thermal Dehydration on Blood Lactate Accumulation During Incremental Exercise Under Different Environmental Conditions. Adv. Exerc. Sports Physiol., Vol.1, No.2, pp.1-7, 1995. The purpose of this study was to investigate the levels of blood lactate (HLa) during incremental exercise in both a hot and a thermoneutral environments after thermal dehydration. Oxygen consumption ($\dot{V}O_2$), pulmonary ventilation ($\dot{V}E$), HLa, heart rate (HR) and rectal temperature (Tr) were obtained during an incremental exercise test to exhaustion on a cycle ergometer for 12 unacclimated men under the following conditions: 1) under a thermoneutral condition without taking a sauna (N25℃). 2) under a thermoneutral condition after taking a sauna (D25℃). 3) under a hot dry environmental condition after taking a sauna (D40℃). The results were as follows: 1) HLa levels during incremental exercise were significantly higher in D40℃ than in D25℃ and N25℃ at the same intensity levels of the exercise, and were also significantly higher in D25℃ than in N25℃, although there were no significant differences in $\dot{V}O_2$ during the exercise among D40℃, D25℃, and N25℃. 2) $\dot{V}O_2$ max in N25℃ was significantly higher than that in D40℃ and D25℃, and $\dot{V}O_2$ max in D25℃ was significantly higher than that in D40℃. Exhaustion time was also higher in N25℃ than in D40℃ and D25℃. It is concluded that exercise under heat and dehydration stresses may increase blood lactate accumulation without a decrease of $\dot{V}O_2$ during submaximal exercise, and impair endurance performance. The increased blood lactate accumulation may be caused by the increased glycolysis in the working muscles, but cannot be attributed to augmented local hypoxia. The decreased removal of lactate by organs such as the liver may contribute to increased HLa accumulation.

Key words: dehydration, hot dry environment, maximal aerobic capacity, lactate, incremental exercise.

Introduction

When a man performs an incremental exercise under a hot environment, his internal temperature rises (19,20). Thermal stress may affect the rate of anaerobic metabolism, which alters the levels of blood lactate (HLa). Many studies have suggested that HLa levels were increased (11,12,19,23,24) but some studies reported them to be unchanged (14,20), or decreased (7) during exercise in a hot environment compared with a thermoneutral environment. On the other hand, England et al. (8) suggested that thermal dehydration resulted in significantly increased HLa levels, but opposite results were also reported (17,18). These experiments (8,17,18) were studies on metabolic reaction during exercise under a thermoneutral environment after thermal dehydration compared with metabolic reaction under the same environment without dehydration. From these reports, it is not possible to elucidate the effects of thermal dehydration on HLa during exercise in a hot environment. The effects of thermal dehydration on HLa during exercise in a hot environment are equivocal due to a lack of studies. Therefore, the purpose of our study was to compare HLa during incremental exercise in a hot environment after thermal dehydration with HLa during the same exercise in a thermoneutral environment with or without dehydration.

Address for correspondence: Guo-chiang SHOU
Laboratory for Exercise Physiology and Biomechanics, School of Physical Education, Chukyo University, Toyota, Aichi 470-03, Japan.

Materials and Methods

A. Subjects

The subjects of our study were 12 physically fit and healthy male students. The mean age (±SD) and physical characteristics of the students are presented in Table 1.

B. Measurements

The subjects wore sneakers, shorts and socks during the tests. They were asked to maintain a normal diet and to limit their physical activity for 48 h prior to testing. The use of alcoholic beverages was forbidden during the study period. They were considered to be unacclimated to heat, because the experiments were carried out from January to February in Japan. All subjects were fully informed of the procedures and risks before we obtained their informed consent to participate in this investigation. The tests were performed approximately at the same time of the day in a climate chamber. The subjects underwent incremental exercise testing under three conditions: (a) under a themoneutral condition: dry bulb temperature (Tdb) 25.0℃, wet bulb temperature (Twb) 14.6℃, relative humidity 30% without taking a sauna (N25℃), (b) under a thermoneutral condition

Table 1. Physical characteristics of the subjects.

	Age (years)	Height (cm)	Weight (kg)
Mean	19.7	172.8	65.2
SD	0.5	3.9	2.9

Values are means ± SD for 12 subjects.

after taking sauna (D25℃), (c) under a hot dry environmental condition: Tdb 40℃, Twb 25.3℃, relative humidity 30% after taking a sauna (D40℃). Air velocity in the climate chamber was kept constant at 0.3 m/s. The subjects were exposed to a sauna bath (Tdb 90℃) in the sitting position for 45 min or more until 1% reduction in body weight was attained.

Each subject sat quietly on an cycle ergometer for 15 min in the climate chamber, and thereafter his resting oxygen consumption ($\dot{V}O_2$), minute ventilation ($\dot{V}E$), heart rate (HR), HLa and rectal temperature (Tr) were measured. After attainment of this resting state incremental exercise was performed. Arterialized capillary blood samples for determination of HLa were taken not only at rest and during every minute of incremental exercise but also at the 3rd minute of recovery. Samples were taken from the earlobe. They were analyzed immediately with a lactate analyser (YSI Model 23A Yellow Springs Instrument Co. USA). Venous blood samples were obtained from a forearm vein before and after the experiment. Hematocrit (Hct) was determined by microcentrifugation and hemoglobin (Hb) was analyzed by the cyanmethemoglobin method. The incremental exercise tests were performed on a mechanically braked cycle ergometer (POWERMAX-V Combi Co., Japan). The subject pedaled at a work rate of 30 W (60rpm) and then the load was increased by 30 W every two minutes until the subject could not maintain it. Subjects performed three incremental cycle ergometer tests. Each experiment was scheduled one week apart. The tests were carried out in the order of D40℃, D25℃ and N25℃. During the experimental test each subject breathed through a low resistance valve and ventilation, oxygen consumption, carbondioxide production and respiratory exchange ratio (RER) were measured every minute with Oxcycon (Stress test system Oxycon- 4 MIJNHARDT Co., Netherland). Before every test the gas analyser was calibrated with standard gas mixtures. The changes in rectal temperature during exercise were measured with a rectal thermistor probe connected to a thermometer (Model VM 2-001 VINE Co., Japan). Heart rate was obtained from continuous ECG recording (Dyna Scope 880 FUKUDA Co., Japan). Before and after sauna and incremental exercise, the subject's weight was measured by a weighing indicator (AD-4323B A&D Co., Japan). Maximal $\dot{V}O_2$ ($\dot{V}O_2$ max) was defined as the point achieving three of the following four criteria: 1) leveling-off of the increase in $\dot{V}O_2$. 2) RER greater than 1.10, 3) HR greater than 180 beats/min, and 4) HLa greater than 8mmol/l.

C. Statistical analysis

The data were expressed as means ±SD and the differences in HLa, HR, and respiratory responses between the two environmental conditions were analyzed using the two-way analysis of variance for repeated measures. The statistical significance of the differences was estimated by Student's t-test on paired data. In all statistical analyses the level of significance was set at $p=0.05$.

Results

Table 2 summarizes selective values at exhaustion during the increamental exercise under the three experimental conditions. Figures 1-5 show the comparison of mean values for Tr, HR, $\dot{V}O_2$, $\dot{V}E$ and HLa in 12 subjects during the incremental exercise at N25℃, D25℃ and D40℃. Tr was increased throughout two experimental conditions (D40℃ and D25℃) (Fig. 1). The mean Tr at the rest period was almost the same for D40℃ and D25℃. During incremental exercise in D40℃, Tr was consistently higher ($p < 0.05$) compared with that in D25℃ (Fig. 1). HR was increased during incremental exercise in D40℃, D25℃ and N25℃, and the difference was significant between these three conditions ($p < 0.05$) (Fig. 2). $\dot{V}O_2$ and $\dot{V}E$ were increased in a linear fashion under three experimental conditions but no significant difference was demonstrated (Fig. 3-4). Note that not only was $\dot{V}O_2$ max in N25℃ higher compared with that in D25℃ and D40℃ ($P < 0.05$), but also $\dot{V}O_2$ max in D25℃ was higher than that in D40℃ ($P < 0.05$) (Table. 2). $\dot{V}E$ max in D40℃ was also significantly lower than that in D25℃ and N25℃ ($P<0.05$), and $\dot{V}E$ max in D25℃ was also significantly lower

Table 2. Cardiorespiratory and blood lactate values at exhaustion.

		$\dot{V}O_{2max}$ (ml/min/kg)	$\dot{V}O_{2max}$ (l/min)	$\dot{V}E_{max}$ (l/min)	RER ($\dot{V}CO_2/\dot{V}O_2$)	HR_{max} (beats/min)	HLa_{max} (mM/l)	Exhaustion time (min)
N25℃	Mean	53.0[a,b]	3.44[a,b]	121.9[a,b]	1.18[a,b]	187.1	8.21[a,b]	19.07[a,b]
	SD	2.7	0.33	12.8	0.13	8.0	0.28	1.50
D25℃	Mean	50.6[c]	3.24[c]	100.4[c]	1.06	187.6	8.80[c]	17.29
	SD	2.8	0.27	13.0	0.07	9.9	0.33	1.30
D40℃	Mean	47.9	3.08	94.4	1.08	187.7	9.25	16.71
	SD	2.7	0.27	10.4	0.07	8.2	0.26	0.30

Values are means ± SD for 12 subjects. (a: significant difference between N25℃ and D25℃, b:significant difference between N25℃ and D40℃, c: singnificant difference between N25℃ and D40℃;$p<0.05$)

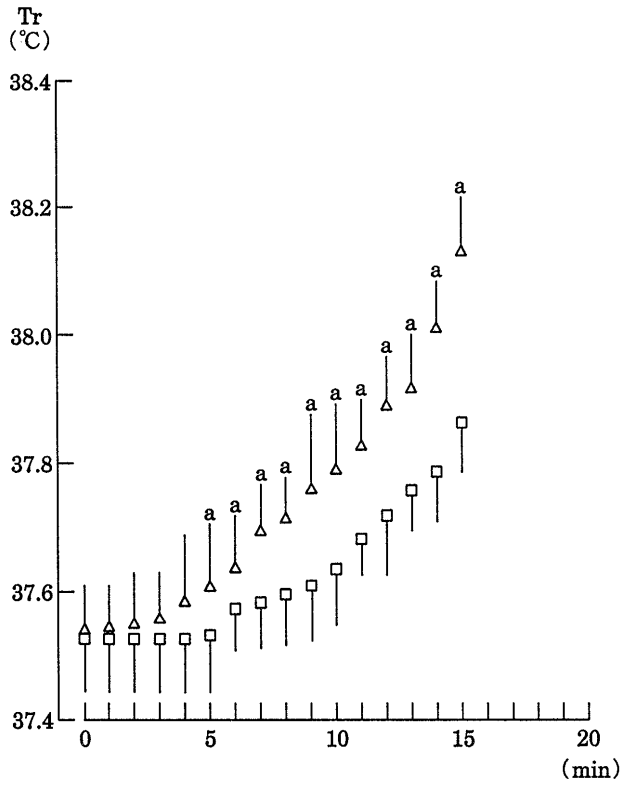

Fig. 1. Comparison of mean values for Tr in 12 subjects during incremental exercise in D40℃ (△), D25℃ (□).
(a: significant difference between △ and □; $p<0.05$)

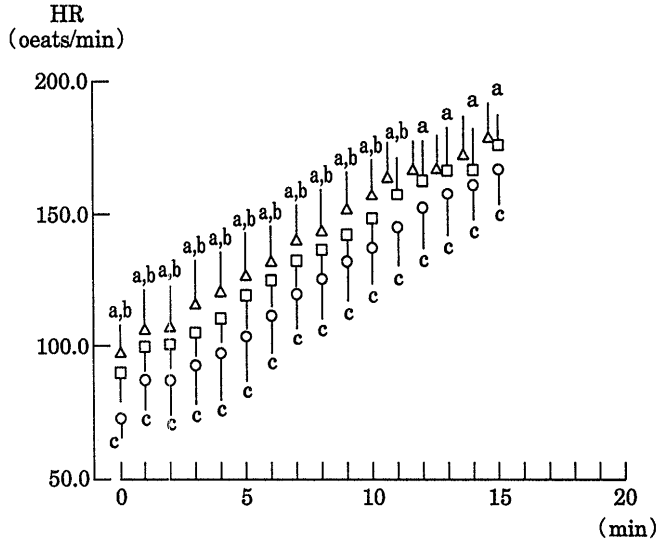

Fig. 2. Comparison of mean values for HR in 12 subjects during incremental exercise in D40℃ (△), D25℃ (□) and N25℃ (○).
(a: significant difference between △ and □, b: significant difference between △ and ○, c: significant difference between □ and ○; $p<0.05$)

than that in N25℃ ($P<0.05$) (Table. 2). Mean time to exhaustion in D40℃ was 16.71 ± 0.30 min while that in D25℃ was 17.29 ± 1.30 min, but the difference was not significant. The mean time to exhaustion under two dry conditions was significantly shorter compared with that under N25℃ (19.07 ± 1.50 min) ($P<0.05$, Table. 2). HLa levels were significantly higher at each measurement period under D40℃ compared with those under two other thermoneutral conditions (N25℃ and D25℃) ($P<0.05$), and HLa in D25℃ was also higher compared with that in N25℃ ($P<0.05$) (Fig. 5). Before thermal dehydration, no significant changes were found in Hb or Hct at the end of the rest period under two conditions (D25℃ and D40℃). After incremental exercise in D40℃, Hb and Hct were significantly increased compared with

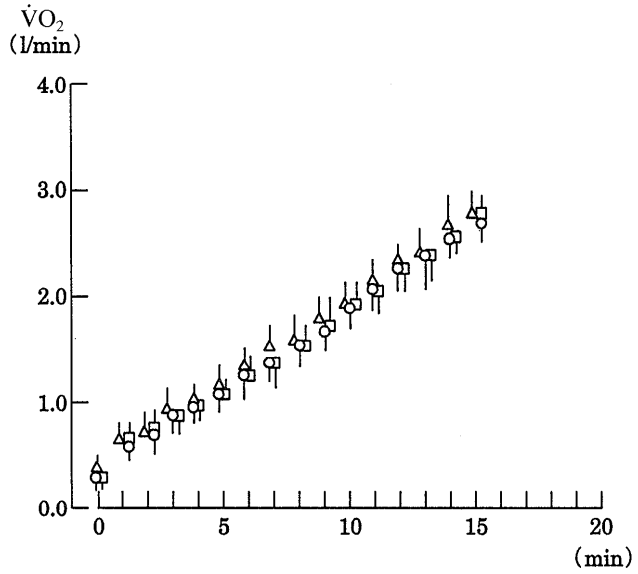

Fig. 3. Comparison of mean values for $\dot{V}O_2$ in 12 subjects during incremental exercise in D40℃ (△), D25℃ (□) and N25℃ (○).

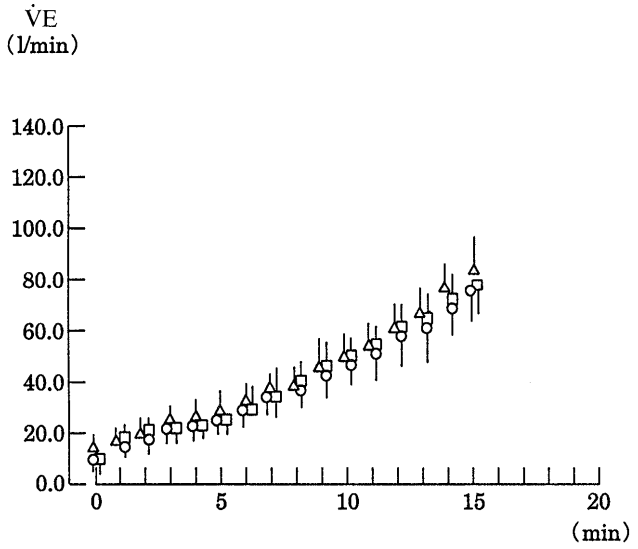

Fig. 4. Comparison of mean values for $\dot{V}E$ in 12 subjects during incremental exercise in D40℃ (△), D25℃ (□) and N25℃ (○).

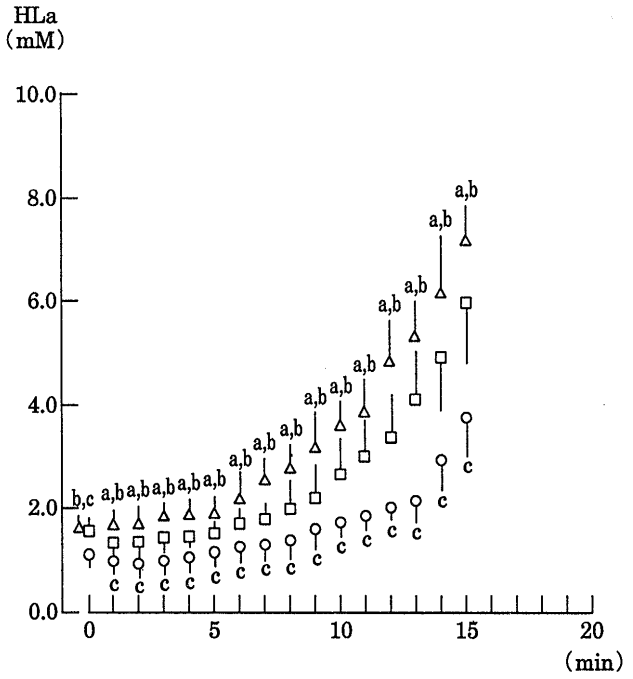

Fig. 5. Comparison of mean values for HLa in 12 subjects during incremental exercise in D40℃ (△), D25℃ (□) and N25℃ (○).
(a: significant difference between △ and □, b: significant difference between △ and ○, c: significant difference between □ and ○; $p<0.05$)

those in D25℃ ($P<0.05$) (Fig. 6, Fig. 7). The mean loss of body weight during incremental exercise was 0.59%, 1.77%, and 2.07% in N25, D25℃ and D40℃ (Table. 3), respectively.

Discussion

The main objective of this study was to compare the change of HLa during incremental exercise in a hot environment after thermal dehydration with that during the same exercise in a thermoneutral environment after dehydration. To the best of our knowledge, this is the first study comparing HLa between

Table 3. Average values of body weight loss during bicycle exercise under three experimental conditions.

	N25℃	D25℃	D40℃
Body weight (kg)	(pre) 65.04±5.33	(pre) 65.01±4.97	(pre) 65.32±5.37
	(post) 64.73±5.31	(post) 63.86±4.89	(post) 63.97±5.16
Weight loss (kg)	0.31±0.01[a,b]	1.15±0.08[c]	1.35±0.21
Weight loss (%)	0.59	1.77	2.07

Values are means ± SD for 12 subjects. (a: significant difference between N25℃ and D25℃, b:significant difference between N25℃ and D40℃, c: singnificant difference between N25℃ and D40℃;$p<0.05$)

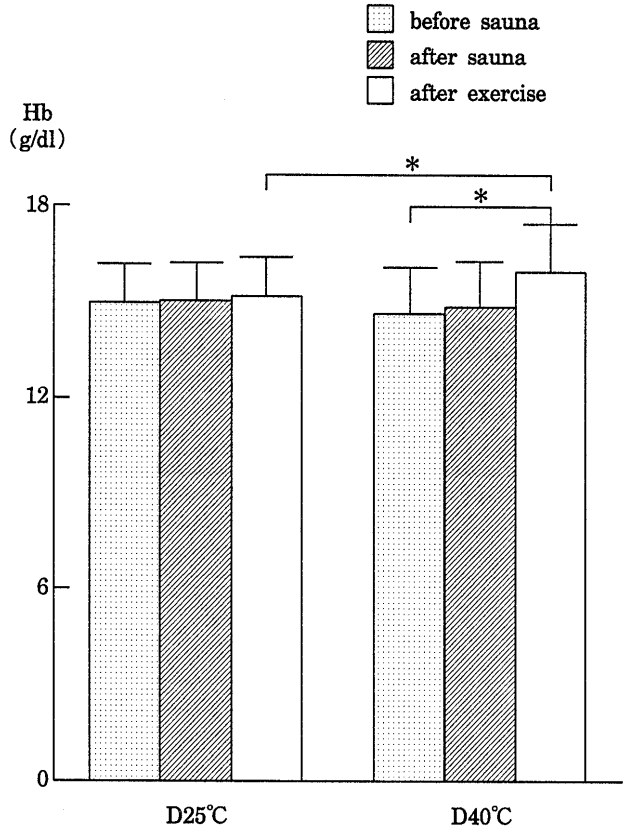

Fig. 6. Comparison of mean values for Hb in 12 subjects during incremental exercise in D25℃ and D40℃ (* $p<0.05$).

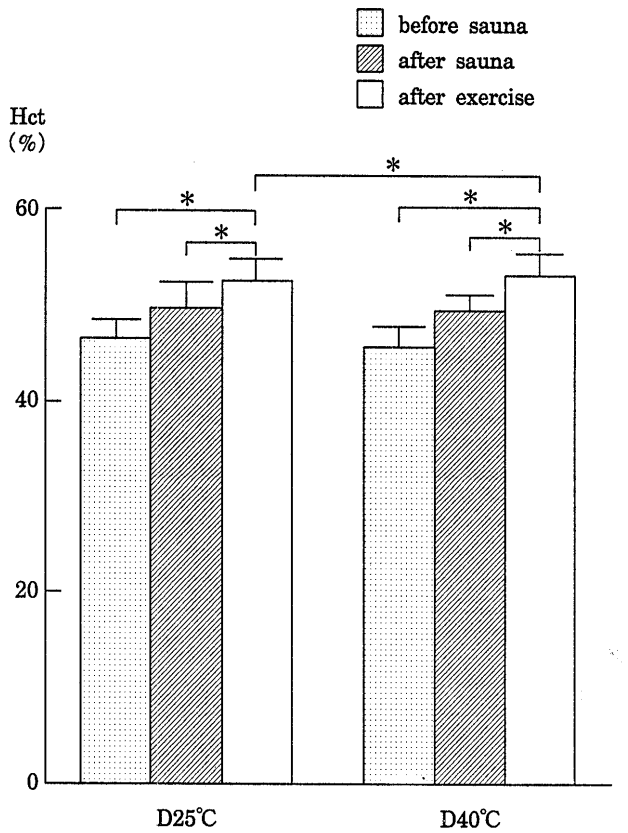

Fig. 7. Comparison of mean values for Hct in 12 subjects during incremental exercise in D25℃ and D40℃ (* $p<0.05$).

hot and thermoneutral conditions during incremental exercise after dehydration. To date, most reseachers have measured HLa during exercise in a thermoneutral environment after thermal dehydration to compare HLa without dehydration (8,17,18), or HLa under a hot environment without thermal dehydration to compare HLa under a thermoneutral condition (19,20).

In our findings, HLa levels during incremental exercise in D40℃ were significantly higher compared with those during the same exercise in D25℃ and N25℃. HLa levels in D25℃ were also higher than those in N25℃. England et al. (8) observed an increase in HLa during exercise in a thermoneutral environment following thermal dehydration. However, Saltin et al. (17) observed a decrease in HLa during exercise under thermal dehydration. Our results showing that HLa was higher under thermal dehydration disagreed with the work by Saltin et al., whose study adopted a different method: a thermal load (sauna) without exercise, hard work under a thermoneutral condition (17-20℃) or mild work under a hot environment (36-38.5℃). Exercise in a hot environment after thermal dehydration in our experiment showed a much greater effect on HLa accumulation than a thermal load without exercise or exercise without a thermal load (17).

It is a well-known fact that HLa represents the balance between the amount of HLa released from the muscles into the blood and the amount of HLa removed from the blood. Fink (9) reported that during exercise in heat HLa was significantly higher than that in a thermoneutral environment, and he explained that elevated HLa was due to a reduced blood flow to active muscles in favour of increased skin blood flow, which resulted in local hypoxia and elevated HLa. However, this could not have been the case in the present study, because $\dot{V}O_2$ did not differ significantly, while HLa was higher significantly in the hot environment after thermal dehydration compared with those in the thermoneutral environment. These results in D40℃ are similar to the change in a hot environment without thermal dehydration observed in our previous investigation (19). Rowell et al. (16) observed that femoral venous HLa was increased but that $\dot{V}O_2$ of the quadriceps muscles was unchanged during graded progressive exercise under hypoxemia (breathing 10-11% O_2) compared with normoxemia. Connett et al. (5) observed that O_2 tension in muscle tissue was not related to lactate efflux

from the muscles during twitch contractions of red muscles in dogs. In fact many investigators believe that factors other than muscle hypoxia are important and reponsible for the increase in HLa (1,3,6). One explanation might be that the thermal dehydration and hot environment in our study resulted in a greater circulatory stress and probably increased physical discomfort compared with the same exercise under normal conditions. These stresses would elicit the involvement of the sympathoadrenal system. It had been found that increased rates of glucose and lactate turnovers in exercise indicate a greater dependence on glycogenolysis and glycolysis due to increased levels of epinephrine (10). Epinephrine is known to act through β-adrenergic receptors to stimulate muscle glycogenolysis (4,21) and to be associated with an increased rate of glycogen breakdown during exercise, which results in an increased HLa during exercise (13,22). It has been argued that the rise in plasma epinephrine levels during incremental exercise is the primary factor influencing HLa because the level of epinephrine was very highly correlated to the rate of lactate turnover ($r=0.97$) (10).

Another possible explanation might be a decreased rate of HLa removal by the liver due to decreased hepatic blood flow (14,15). In our previous study (19) we observed that HLa levels during incremental exercise in a hot dry environment were significantly elevated compared with that during the same exercise load under the thermoneutral environment. These results agreed with England's results showing that HLa was higher after thermal dehydration in the thermoneutral environment (8) and would suggest that HLa is much higher after thermal dehydration in the hot dry environment. These findings might be explained partly by the reduced hepatic blood flow.

In the present study, $\dot{V}O_2$ max was affected by the three experimental conditions and it was significantly lower in D40℃ compared with both in D25℃ and N25℃ (Table. 2). In contrast, other studies have reported that $\dot{V}O_2$ max was not significantly reduced during exercise in a thermoneutral environment after thermal dehydration (2,18). Buskirk et al. (2) reported that, during exercise after thermal dehydration, the average $\dot{V}O_2$ max of subjects ($N=13$) was decreased by 210ml/min after the 1st dehydration and by 220ml/min after the 2nd dehydration, but that the reduction was not significant. Their results would be due to the fact that their subjects were acclimated. Acclimation to heat was accomplished by the performance of daily bouts of work in the heat and they remained in the hot room for 2.5 hours every morning for one week, and some of them took part in a training program. In the present study, obervation of reduced $\dot{V}O_2$ max during bicycle exercise in a hot dry environment after thermal dehydration for comparison during same exercise in a thermoneutral environment was contradictory to the findings of our previous study (19). But thermal dehydration was absent in the method used previously, which in the present study significantly affected $\dot{V}O_2$ max. The significant change in $\dot{V}O_2$ max in the present study could be explained by the fact that the thermal dehydration reduced the time to exhaution during incremental exercise in D40℃ and D25℃ (Table. 2). During incremental exercise in D40℃ and D25℃, HR and HLa were significantly higher than those in N25℃. This would increase circulatory stress and probably physical discomfort, both of which might reduce the performance time. Psychological factors may account for the diminished performance after thermal dehydration (17).

In conclusion, the major finding of our study was that HLa was higher, $\dot{V}O_2$ was unchanged and $\dot{V}O_2$ max was lower during incremental exercise in a hot environment after thermal dehydration compared with the same exercise in a thermoneutral environment. This can be explained as follows: hard exercise under hot environment after thermal dehydration elevated epinephrine secretion which increased HLa from the muscles via β-adrenergic receptors without a concomitant increase in $\dot{V}O_2$. The decreased rate of HLa removal from the liver might contribute to HLa elevation. Physical disconfort due to high HR and high HLa would affect performance time and $\dot{V}O_2$ max.

References

1) Barbee R W, Stainsby W N, Chirtel S J (1983) Dynamics of O_2, CO_2, lactate, and acid exchange during contractions and recovery. J Appl Physiol: Respirat Environ Exercise Physiol 54: 1687-1692.
2) Buskirk E R, Iampietro P F, and Bass D E (1958) Work performance after dehydration: effects of physical conditioning and heat acclimatization. J Appl Physiol 12(2): 189-194.
3) Carlson L A and Pernow B (1961) Studies on the peripheral circulation and metabolism in man. I. Oxygen utilization and lactate-pyruvate formation in the legs at rest during exercise in healthy subjects. Acta Physiol Scand 52: 323-342.
4) Chastiotis D, Sahlin K, and Hultman E (1983) Regulation of glycogenolysis in human muscle in response to epinephrine infusion. J Appl Physiol 54: 45-50.
5) Connett R J, Gayeski T E J, Honig C R (1986) Lectate efflux is unrelated to intracellular PO_2 in a working red skeletal muscle in situ. J Appl Physiol 61: 402-408.
6) Costill D L, Branam L, Eddy D, and Fink W (1974) Alterations in red cell volume following exercise and dehydration. J Appl Physiol 37: 912-916.
7) DeLanne R, Barnes J R, Brouha L, Massat F (1959) Changes in acid-base balance and blood gases during muscular activity and recovery. J Appl Physiol 14: 328-332.
8) England P, Powers S, Dodd S, Callender T, and Brooks E (1984) The effect of acute thermal dehydration on blood lactate accumulation during incremental exercise. J Sports Sci 2: 105-111.

9) Fink W J. Costill D L, VanHandel P J (1975) Leg muscle metabolism during exercise in the heat and cold. Eur J Appl Physiol 34: 183-190.
10. Gregg S G, Mazzeo R S, Budinger T F, Brooks G A (1989) Acute anemia increases lactate production and dcreases clearance during exercise. J Appl Physiol 67: 756-764.
11) MacDougall J D, Reddan W G, Layton C R, and Dempsey J A (1974) Effects of metabolic hyperthermia on performance during heavy prolonged exercise. J Appl Physiol 36: 538-544.
12) Powers S K, Howley E T, and Cox R (1985) Blood lactate consentrations during submaximal work under differing environmental conditions. J Sports Med 25: 84-89.
13) Powers S K, Howley E T, and Cox R (1982) A differential catecholamine response during prolonged exercise and passive heating. Med Sci Sports Exerc 14: 435-439.
14) Rowell L B, Blackmon J R, Martin R H, Mazzarella J A, Bruce R A (1965) Hepatic clearance of indocyanine green in man under thermal and exercise stresses. J Appl Physiol 20: 384-394.
15) Rowell L B, Bregelmann G L, Blackmon J R, Twiss R D, Kusumi F (1968) Splanchnic blood flow and metabolism in heat-stressed man. J Appl Physiol 24: 475-484.
16) Rowell L B, Saltin B, Kiens B, Christensen N J (1986) Is peak quadriceps blood flow in humans even higher during exercise with hypoxemia? Am J Physiol 251: H1038-H1044.
17) Saltin B (1964) Aerobic and anaerobic work capacity after dehydration. J Appl Physiol 19: 1114-1118.
18) Saltin B (1964) Circulatory response to submaximal and maximal exercise after thermal dehydration. J Appl Physiol 19: 1125-1132.
19) Shou G C, and Ishiko T (1994) The effect of different environmental conditions on blood lactate accumulation, LT and OBLA during incremental exercise. Jpn J Phys Fitness Sports Med. 43: 58-65.
20) Smolander J, Kolari P, Korhonen O, and Ilmarinen R (1986) Aerobic and anaerobic responses to incremental exercise in a thermoneutral and a hot dry environment. Acta Physiol Scand 128: 15-21.
21) Stainsby W N, Sumners C, and Eitzman P D (1987) Effects of adrenergic agonists and antagonists on muscle O_2 uptake and lactate metabolism. J Appl Physiol 62(5): 1845-1851.
22) Stainsby W N, Sumners C, and Eitzman P D (1985) Effects of catecholamines on lactic acid output during progressive working contractions. J Appl Physiol 59(6): 1809-1814.
23) Williams C G, Bredell G A G, Wyndham C H, Strydom N B, Morrison J F, Peter J, Fleming P W, and Ward J S (1962) Circulatory and metabolic reactions to work in heat. J Appl Physiol 17: 625-638.
24) Yaspelkis III B B, Scroop G C, Wilmore K M and Ivy J L (1993) Carbohydrate metabolism during exercise in hot and thermoneutral environments. Int J Sports Med 14: 13-19.

Received 13 December 1993; accepted 9 November 1994