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EFFECT OF BLOOD LACTATE LEVEL ON OXYGEN UPTAKE AT THE OFFSET OF MIDDLE-INTENSITY EXERCISE

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Abstract. This study examines whether blood lactate level affects oxygen uptake at the offset of exercise (recovery ‡O_2) in middle–intensity exercise. Work rates in the exercise were constants at 60, 100, 140, 180 and 220 watts, respectively. Recovery ‡O_2 was approximated by a single or double exponential function to determine whether the kinetics of recovery ‡O_2 has only a fast phase or fast and slow phases. Blood lactate was determined at rest and at 3 min during recovery. One phase was observed below a blood lactate level of 3 mM (low-intensity exercise), one or two phases observed at a blood lactate level between 3 and 6 mM (middle-intensity exercise) and only two phases were observed above 6 mM (high-intensity exercise). Thus, exercise intensities were divided into three levels. ‡O_2 at 3 min during recovery was related to blood lactate at 3 min during recovery. The regression line obtained between them at 3 min during recovery ranged from the resting values of ‡O_2 and blood lactate to the highest value in high exercise intensity. We concluded that blood lactate affects recovery ‡O_2 even when it cannot be mathematically separated into two phases.
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Key words: Oxygen uptake-Blood lactate- Offset of exercise

Introduction

When exercise is performed, oxygen uptake (‡O_2) gradually increases and reaches steady state. Oxygen deficit produced before this steady state is repaid during recovery. This is called the oxygen debt. There are two phases of oxygen debt in high-intensity exercise: one is a fast phase in which ‡O_2 exponentially decreases with a half-time of 0.5 min, and the other is a slow phase in which ‡O_2

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exponentially decreases with a half-time of 15 min [8]. The slow phase of oxygen debt increases in accordance with the blood lactate rise that occurs above a given level of exercise intensity [7,8]. This slow phase is associated with the recovery of muscle glycogen [1,6].

Recent studies reported that only the fast phase was observed in heavy exercise judging from application of the approximation equation [10,11]. It was also confirmed that muscle glycogen cannot recover below a blood lactate level of 5 mM [9] and the slow phase is not increased when blood lactate level is elevated up to 5 mM by occlusion of legs during cycling exercise [13]. However, the time constant reported in this exercise intensity is somehow longer than the time constant in moderate exercise and than those separated as the fast phase in very heavy exercise [10]. Furthermore in heavy exercise, the time constant during recovery is around 0.5 min when the data are limited within 3 min but the time constant becomes longer for usage of data for 6 min [11]. Although it may be difficult to separate the oxygen debt into two phases, there should be an effect of lactate in heavy exercise on oxygen uptake at the offset of exercise (recovery ‡O_2). This also suggests that there may be a mechanism delaying recovery ‡O_2 except for the synthesis of muscle glycogen.

Exercise intensities are distinguished by a criterion of anaerobic threshold (AT). They are considered moderate below AT and heavy above AT. However, since blood lactate increases in constant-load exercise with intensity below AT, we must newly define exercise intensities in examining the effect of blood lactate on recovery ‡O_2. In the present study, therefore, we defined exercise intensities derived from blood lactate and separation of recovery ‡O_2, and examined whether blood lactate level affects recovery ‡O_2 in the exercise intensity where recovery ‡O_2 cannot be separated into two phases by exponential function.

Material and Methods

Eight healthy males participated in this study. The physical and aerobic performance characteristics of the subjects are shown in Table 1. After the objective and procedure of the experiment and the risks associated with the experiment were explained, written consent to participate in the study was obtained from each subject. This study was approved by the local ethics committee.

A bicycle ergometer in which the load can be adjusted by a computer (232C, Combi, Japan) was used. On the first day, each subject performed incremental-load exercise after a 5-min rest period to determine his peak ‡O_2 (peak ‡O_2). After

cycling at a work rate of zero watts for 4 min, the work rate was increased in ramp mode by 20 watts per min until the subject could no longer maintain a rotation rate of 60 rpm. On separate days, constant-load exercise tests were performed after rest periods of 5 min. Work rates were 60, 100, 140, 180 and 220 watts. Some subjects did not continue exercise at a high intensity for 6 min and did not always perform all set work rates. Only the subjects 4 could perform 220 watts for 6 min. Subject 1 could not continue the established duration at 140 and 180 watts. Subject 8 could not continue at 220 watts. This information is presented in Table 2. ‡O_2 was determined at rest, in exercise and during recovery for 10 min. Blood samples were taken at rest and at 3 min during recovery.

Table 1
Physical and exercise characteristics of the subjects

	Age (years)	Height (cm)	Weight (kg)	AT-work (watts)	AT-‡O_2 ($l \cdot min^{-1}$)	PeakWork (watts)	Peak‡O_2 ($l \cdot min^{-1}$)
Sub. 1	18	171	54	95	0.98	190	1.79
Sub. 2	19	172	59	115	1.22	220	1.96
Sub. 3	19	181	63	85	0.95	235	1.93
Sub. 4	21	176	68	125	1.32	250	2.25
Sub. 5	18	168	54	120	1.36	210	2.10
Sub. 6	18	166	55	105	1.06	200	1.94
Sub. 7	22	167	63	135	1.36	255	2.49
Sub. 8	18	185	65	110	1.20	210	2.15
Mean	19	173	60	111	1.18	221	2.08
SD	2	7	5	10	0.17	23	0.22

Peak work rate is the work rate at exhaustion in incremental-load exercise. AT is the anaerobic threshold

‡O_2 was measured breath-by-breath using a respiratory gas analyzer (AE-280S Minato Medical Science, Japan). The flow volumes of inspiration and expiration were determined using a hot-wire respiratory meter. The flow signals were integrated electrically for each breath and converted to ventilation per minute. The respiratory meter was calibrated using a 2-liter syringe. The results of measurements using this instrument were linear with ventilation in the range of

0-600 $l \cdot min^{-1}$. The O_2 and CO_2 concentrations were analyzed using a zirconium sensor and infrared absorption analyzer, respectively. The data of ‡O_2 was outputted every 15 seconds.

Table 2

Values of parameters obtained by Eqs. (1) and (2), and blood lactate (La) after exercise

	A_1 ($l \cdot min^{-1}$)	τ_1 (min)	A_2 ($l \cdot min^{-1}$)	τ_2 min)	r	La (mM)
Sub. 1						
60w	0.83	0.66			0.96	1.27
100w	1.27	0.70	0.17	1.3	0.99	4.98
140w(5min)	1.72	0.91	0.13	26.2	0.97	10.91
180w(2.15min)	1.42	0.72	0.48	1.9	0.99	10.40
Sub. 2						
60w	0.65	0.73			0.89	1.46
100w	1.40	0.53			0.96	2.68
140w	1.71	0.53	0.12	7.5	0.97	5.01
180w	2.03	0.43	0.48	1.5	0.99	10.25
Sub. 3						
60w	0.57	0.56			0.88	2.82
100w	1.08	0.52	0.09	2.3	0.95	3.21
140w	1.50	0.69	0.12	54.4	0.96	7.12
180w	1.42	0.66	0.33	15.0	0.99	13.05
Sub. 4						
60w	0.82	0.48			0.93	0.91
100w	1.00	0.57			0.94	2.39
140w	1.74	0.53			0.96	6.29
180w	1.71	0.75	0.05	25.6	0.98	6.18
220w	1.87	0.81	0.26	9.5	0.99	10.98
Sub. 5						
60w	0.53	0.49			0.89	1.22
100w	0.94	0.56			0.98	1.76
140w	1.55	0.65	0.03	11.9	0.98	3.31
180w	2.02	0.69	0.15	14.2	0.99	8.75
Sub. 6						
60w	0.72	0.48			0.95	1.80

100w	0.76	0.80			0.92	4.43
140w	1.28	0.67	0.12	26.6	0.98	10.51
Sub. 7						
60w	0.57	0.50			0.79	1.26
100w	1.30	0.59			0.97	1.37
140w	1.46	0.62	0.14	4.0	0.96	3.85
220w(4 min)	2.19	0.65	0.41	8.1	0.99	13.55
Sub. 8						
60w	0.65	0.98			0.90	0.92
100w	1.23	0.93			0.96	3.23
140w	1.85	0.93	0.05	23.9	0.97	8.50
180w	2.51	0.87	0.17	19.3	0.99	12.84

Time in parentheses shows the duration of exercise; The other durations are 6 min

The 25 μl blood samples taken from fingertips into capillary tubes were analyzed immediately after the sampling by Lactate analyzer (1500 Sport: YSI, USA). This analyzer was calibrated by the standard solution of lactate (5 mM) before each exercise test.

$\ddagger O_2$ for 15 s during a 10-min recovery period (recovery $\ddagger O_2$) was approximated by the following equation (Model 1):

$$\ddagger O_2 = A_1 * \exp(-t/\tau_1) + A_2 * \exp(-t/\tau_2) + \ddagger O_2 \text{rest.} \quad (1)$$

where A is amplitude of the system, τ is time constant of the system, $\ddagger O_2$ rest is $\ddagger O_2$ at rest and t is time. If A_2 and τ_2 were minus or extreme values, the following equation was used (Model 2):

$$\ddagger O_2 = A_1 * \exp(-t/\tau_1) + \ddagger O_2 \text{rest} \quad (2)$$

In order to detect the effect of blood lactate on recovery $\ddagger O_2$, the values at 3 and 9 min during recovery were chosen in the present study. However, data for 15 s may include error. Therefore, four data of $\ddagger O_2$ around 3 and 9 min during recovery were averaged, respectively.

The strength of the relation between dependent and independent variables was expressed by a single correlation coefficient of Pearson. Student's t-test (paired samples) was used to test for significance in differences between variables. The

level of significance was set at $P<0.05$. Results are expressed as means and standard deviations (SD).

Results

The mean $\ddagger O_2$ at rest was 237±41.3 $ml \cdot min^{-1}$. The mean blood lactate level at rest was 0.95±0.16 mM. As shown in Table 2, 60 watts were below AT in two subjects. 60 and 100 watts were below AT in six subjects. Although blood lactate levels after 60 watts in two subjects were close to resting levels, in the others the blood lactate clearly increased from resting level.

We used Eqs. (1) and (2). In this case, the separation of recovery $\ddagger O_2$ started from a blood lactate level of 3-6 mM (Table 2). Fig. 1 shows the relation between blood lactate level and the difference in recovery $\ddagger O_2$ at 3 and 9 min ($\Delta \ddagger O_2$). There was significant relation between them ($r=0.76$, $P<0.01$). When $\Delta \ddagger O_2$ became higher by 50 $ml \cdot min^{-1}$, it was possible to obtain the separation by the approximation equation. It was possible to separate recovery $\ddagger O_2$ into two phases when blood lactate level was more than 6 mM and impossible when the level was less than 3 mM. There were both types when blood lactate level was between 3 and 6 mM.

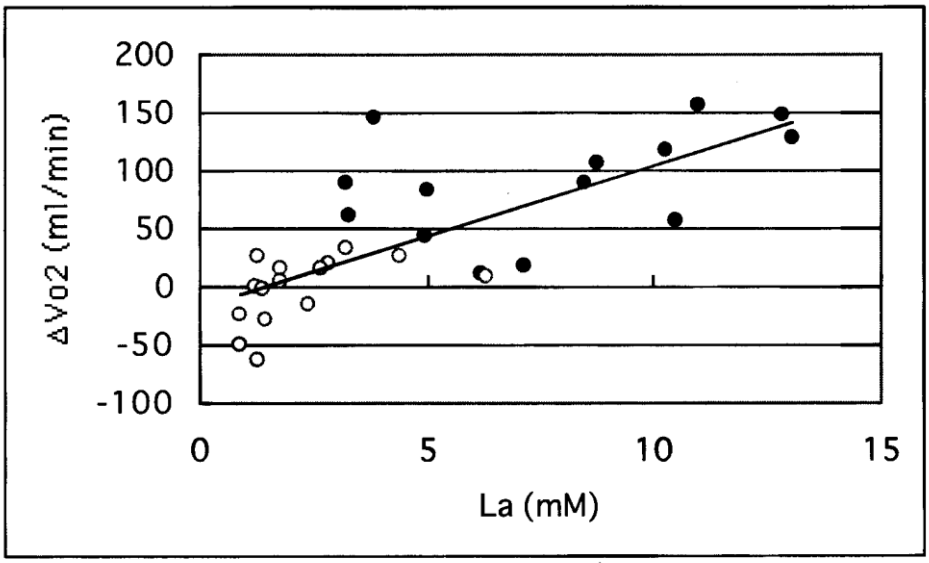

Fig. 1
The blood lactate level at 3 min during recovery plotted against the difference between oxygen uptakes at 3 and 9 min during recovery; Closed circles show the separation by approximation equation into double exponential; Open circles show no separation

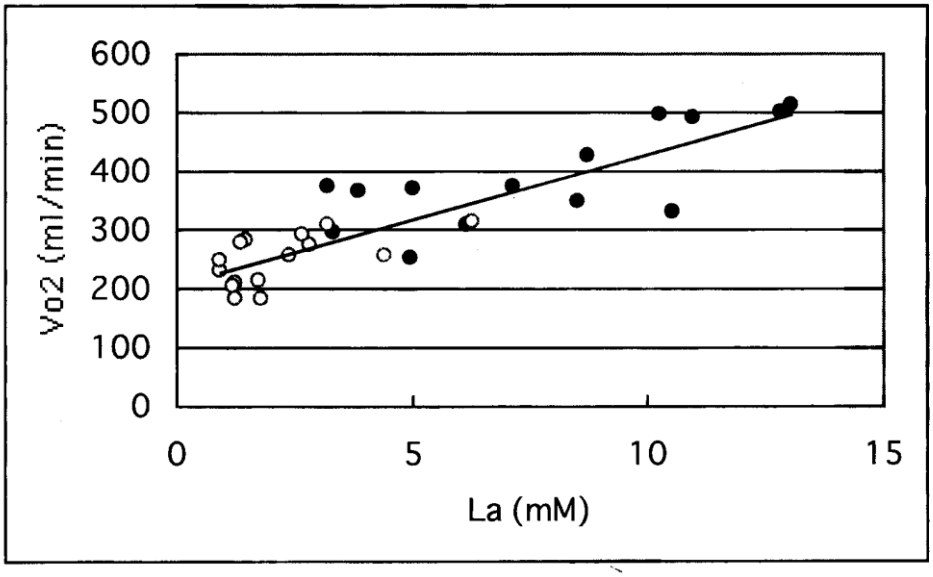

Fig. 2
Relation between blood lactate (La) and oxygen uptake (‡O_2) at 3 min after the start of recovery; Closed circles show the separation by approximation equation into double exponential; Open circles show no separation

Fig. 2 shows the relation between ‡O_2 at 3 min during recovery and blood lactate at 3 min during recovery. There was significant relation between blood lactate and ‡O_2 at 3 min during recovery ($r=0.87$, $P<0.01$). The regression line started from around the resting values of blood lactate and ‡O_2.

Discussion

Exercise intensities can be distinguished from the separation of recovery ‡O_2. These are low exercise intensity less than 3 mM of blood lactate, middle exercise intensity between 3 and 6 mM and high exercise intensity more than 6 mM. Through all exercise intensities, recovery ‡O_2 at 3 min related to blood lactate level at 3 min during recovery.

In recent studies, exercises with the same exercise intensity were repeated to yield second-by-second values of ‡O_2. The second-by-second data were used for analysis. In the present study, values of ‡O_2 for 15 s were used for approximation

since it has been reported that the time constant of the slow component showed wide variance [2,3,4] and its time constant obtained in repeated exercises differed each time [10]. However, this method in the present study limits the data number and consequently the number of parameters used for approximation equation is limited. Therefore, we did not include the parameter of time delay in the present approximation equation. This might affect the separation of recovery ‡O_2.

Some investigators reported that recovery ‡O_2 cannot be separated into two phases [10] and others reported separation into two phases in the exercise intensity of slightly above AT [2,3,4]. In the present study, both cases were observed. These studies suggest that statistical separation is insufficiently to detect the effect of blood lactate on recovery ‡O_2 in this exercise domain.

A fast phase of recovery ‡O_2 can be recovered within 2 or 3 min. Therefore, ‡O_2 at 3 min during recovery can be one of the criteria whether blood lactate level affects recovery ‡O_2. In the present study, we found the effect of blood lactate on ‡O_2 at 3 min during recovery in middle-intensity exercise within 3 min. This might affect recovery ‡O_2.

Phosphocreatine (PCr) might be a mediating factor between lactate and ‡O_2 during recovery. PCr is the main factor in the fast phase of oxygen debt. PCr is resynthesized during recovery and is then equilibrated to phosphate and creatine. However, if this equilibration level is affected by pH [5], PCr does not recover to the resting level due to the production of lactate during exercise.

Conclusions

We distinguished exercise intensities by separation of recovery ‡O_2. As a result, three exercise intensities were distinguished. In the defined middle exercise intensity, mathematical method of separating recovery ‡O_2 was insufficiently sensitive to detect the effect of blood lactate but ‡O_2 at 3 min during recovery showed the effect of lactate in middle-intensity exercise as well as in high-intensity exercise.

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