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T. YANO, T. YUNOKI, R. MATSUURA, H. OGATA

EFFECT OF EXERCISE INTENSITY ON THE SLOW COMPONENT OF OXYGEN UPTAKE IN DECREMENTAL WORK LOAD EXERCISE

Exercise Physiology, Graduate School of Education, Hokkaido University, Kita-ku, Sapporo, Japan

The paper sought to determine the exercise intensity where the slow component of oxygen uptake ($\dot{V}o_2$) first appears in decremental work load exercise (DLE). Incremental work load exercise (ILE) was performed with an increment rate of 15 watts (W) per minute. In DLE, power outputs were decreased by 15 W per minute, from 120 (DLE_{120}), 160 (DLE_{160}), 200 (DLE_{200}) and 240 (DLE_{240}) W, respectively. The slopes of $\dot{V}o_2$ against the power output were obtained in the lower section from 0 to 50 W in all DLEs, and in the upper section from 80 to 120 W in DLE_{160} and from 100 to 150 W in DLE_{200} and DLE_{240}. The power output at exhaustion in ILE was 274 ± 20 W. The power output at the ventilatory threshold (VT) obtained in ILE was 167 ± 22 W. The initial power output in DLE_{160} was near the power output at VT. The slopes obtained in the upper sections were 11.4 ± 0.9 ml • min^{-1} • W^{-1} in DLE_{160}, 12.8 ± 0.8 ml • min^{-1} • W^{-1} in DLE_{200}, and 14.8 ± 1.1 ml • min^{-1} • W^{-1} in DLE_{240}. The slope obtained in DLE_{120} was 10.9 ± 0.6 ml • min^{-1}. There were no differences in slope between the upper and lower sections in DLE_{160} but there were significant differences in slopes between the upper and lower sections in DLE_{200} and DLE_{240}. Thus, the slow component, which could be observed as a steeper slope in DLE, began to increase when the initial power output in DLE was near to VT.

Key words: *oxygen uptake, decrement exercise, slow component, exercise intensity.*

INTRODUCTION

Oxygen uptake ($\dot{V}o_2$) rapidly increases (fast component) and reaches a steady state in constant work load exercise (CLE) below the ventilatory threshold (VT) (1, 2). The increasing rate in $\dot{V}o_2$ for power output (gain) is constant and 10 ml • min^{-1} • W^{-1} (1, 3). In CLE above VT, $\dot{V}o_2$ does not indicate a steady state in a few minute but a gradual increase (slow component) (1, 2, 4-8). Its final $\dot{V}o_2$ exceeds

the $\dot{V}o_2$ estimated by the gain obtained below VT. This higher gain is one of the characteristics of the slow component. Another characteristic is that the slow component is believed to have a time delay. Mathematical modeling has shown that the slow component begins 90-150 s after the onset of the transition (1, 2, 4-8). However, not all researchers agree with the concept of a delayed onset (9).

It has recently been shown that during incremental work load exercise (ILE) at high intensities of exercise $\dot{V}o_2$ increases non-linearly in relation to power output (10, 11, 12). Since a gain increases in the upper power output, its section can be called a slow component. In decremental work load exercise (DLE), $\dot{V}o_2$ has been reported to rapidly increase and then decrease linearly (13-15). The gain during the decrease section is higher in DLE starting from maximal power output than any other gains reported below VT in CLE, ILE and DLE (14). Therefore, this decrease section may be called the slow component.

Previous studies suggest that the decrease section observed in DLE is associated with lactic oxygen debt (13, 14, 16). If this is true, the decrease section should continue until the end of DLE since lactic oxygen debt in CLE continues for a long time (1, 5). If this section is related to the slow component, this section should appear only at a higher power output in DLE because the slow component appears in CLE above VT (1, 2, 4-8). However, this has not been examined.

The work mode of DLE is a good tool to test whether the slow component has a time delay for the following reason: If the slow component has no time delay, it can appear from the exercise intensity just above VT in DLE because the slow component begins from the point where blood lactate starts to increase in ILE (11, 12). However, if the slow component has time delay, it cannot always appear even if the initial power output is above VT. Because power output in DLE can be reduced below VT until the appearance timing of the slow component,

In the present study, therefore, we first examined whether the steep slope appears only at a higher power output in DLE. Then, we sought to identify the exercise intensity where the slow component first appears in DLE.

MATERIAL AND METHODS

Subject characteristics

Six healthy males participated in this study. Their physical and aerobic performance characteristics are presented in *Table 1.* After the objective, procedures, and 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.

Experimental protocol

A bicycle ergometer whose load can be adjusted by a computer (232C, Combi) was used. On the first day, each subject performed ILE after a 5-min rest period to determine his VT and peak value of $\dot{V}o_2$ ($\dot{V}o_2$peak). After the subject cycled at a power output of zero W for 4 min, the power output was increased in ramp mode by 15 watts (W) per min until the subject could no longer

Table 1. Subject characteristics and anaerobic capacity

Subjects	Age	Height	Weight	$\dot{V}o_2$peak	Work peak	VT-$\dot{V}o_2$	VT-power
(years)	(cm)	(kg)	(l • min^{-1})	(W)	(l • min^{-1})	(W)	
A	28	175	59.0	2.44	253	1.54	152
B	22	160	56.6	3.16	268	2.08	163
C	22	171	64.4	3.31	298	2.13	193
D	22	174	66.7	3.06	275	2.04	196
E	22	173	65.2	3.05	253	2.14	159
F	28	175	72.2	2.73	298	1.51	140
Mean	24.0	171.3	64.0	2.96	274	1.91	167
SD	3.1	5.8	5.6	0.32	20	0.3	23

maintain a pedaling rate of 60 rpm. On separate days, four DLE tests with different peak power outputs of 120 (DLE_{120}), 160 (DLE_{160}), 200 (DLE_{200}) and 240 W (DLE_{240}) were performed in random order. After the subject cycled at a power output of zero W for 4 min, the power output was suddenly increased to the peak value, and then the power output was reduced in ramp mode at a rate of 15 W^{-1} • min^{-1} until it reached zero W.

Measurements

O2 uptake and CO_2 output ($\dot{V}co_2$) were measured breath-by-breath using a respiratory gas analyzer (AE-280S Minato Medical Science). The flow volumes of inspiration and expiration were determined using a hot-wire respiratory flowmeter. The flow signals were electrically integrated for each breath and converted to ventilation per minute. The respiratory flowmeter was calibrated using a 2-liter syringe. The results of measurement with this instrument were linear with ventilation in the range of 0-600 l/min. The O_2 and CO_2 concentrations were analyzed using a zirconium sensor and infrared absorption analyzer, respectively. The $\dot{V}o_2$ and $\dot{V}co_2$ data were output every 15 seconds.

Determinations of the VT, slope and changing point of slope

The VT was determined by the V-slope method (17), using the data obtained in the ILE test. $\dot{V}o_2$ was plotted against $\dot{V}co_2$. Two regression lines were drawn- one at low exercise intensity and one at high exercise intensity. The intercept of the two regression lines was defined as the VT. The $\dot{V}o_2$peak was taken as the highest 15-s average achieved during the ILE test. The slopes between $\dot{V}o_2$ and the power output (slope) were determined below 50 W in all DLEs. The slope at the higher power output was determined from 80 to 120 W in DLE_{160} and from 100 to 150 W in DLE_{200} and DLE_{240}.

The changing point of the slope in $\dot{V}o_2$ during DLE_{240} and DLE_{200} was determined as follows: the regression line between $\dot{V}o_2$ and the power output was determined below 50 W and extrapolated into a higher power output. The difference between the measured $\dot{V}o_2$ and estimated $\dot{V}o_2$ was obtained. There were three sections for which the differences were plotted against the power outputs (see *Fig. 2*). These were the increasing section, the decreasing section and the flatter section. The point at which the decreasing section changed into the flatter section was defined as the changing point of the slope.

Statistical analysis

Significant differences between mean values were examined by Student's paired t-test. ANOVA was used to test for a significant difference among the four

DLEs for analyzing the slopes obtained at low power output. The level of significance was set at $P<0.05$. The results are expressed as the mean and standard deviations (SD).

RESULTS

The mean power output at the VT was 167 ± 22 W. The initial power output in DLE_{120} was all below the power outputs at the VT. In DLE_{160}, the initial power output was lower in two subjects and higher in the other two subjects than the power output at the VT. The mean power output at exhaustion in ILE was 274 ± 20 W. DLE_{240} corresponded to 88 ± 5.6% of the power output at exhaustion in ILE.

The average values of $\dot{V}o_2$ are shown in comparison with DLE_{120} in *Figure 1*. Note that time passes from right to left in the figure on the work axis. $\dot{V}o_2$ rapidly increased and linearly decreased until zero W in DLE_{120}. In DLE_{200} and DLE_{240}, a convex change and transient steady state were observed between the rapid increase and the decrease phases. There were two slopes in the decreasing phase in DLE_{200} and DLE_{240}. There was no significant difference between the $\dot{V}o_2$ obtained in DLE_{120} and in the other DLEs in the range showing a straight decrease in DLE_{120} (below 80 W).

A regression line was obtained between the power output and $\dot{V}o_2$ below 50 W in each DLE. The differences between the $\dot{V}o_2$ estimated by the slope and the $\dot{V}o_2$ measured ($\Delta\dot{V}o_2$) are shown in *Figure 2*. There was no positive value above zero level in DLE_{120} and DLE_{160}. $\Delta\dot{V}o_2$ showed zero levels until 100 W in DLE_{120} and 130 W in DLE_{160}. Positive values were observed from 80 to 170 W in DLE_{200} and 80 to 200 W in DLE_{240}.

Slopes were obtained at the higher power output in DLE_{160}, DLE_{200}, and DLE_{240}. The average values are shown in *Table 2*. There were significant differences in DLE_{200} and DLE_{240} between the slopes obtained at the high power output and at the low power output. There were no significant differences in the slopes obtained below 50 W.

Figure 3 shows the relationship between the slope and the relative power output. The relative power output was calculated by dividing the initial power output in DLE by the end power output in ILE. The slopes in the figure were values obtained below 50 W in DLE_{120} and values obtained at the higher power output in any other DLEs. The slope increased above around 60% of the relative power output. As this relative power output is close to the power output at the VT, the slopes are plotted against the work difference from the power output at the VT. The power outputs at the VT were lower in two subjects and higher in two subjects than the initial power output in DLE_{160}. In the two subjects showing a low VT, the slopes in DLE_{160} were close to the slope obtained in DLE_{120}.

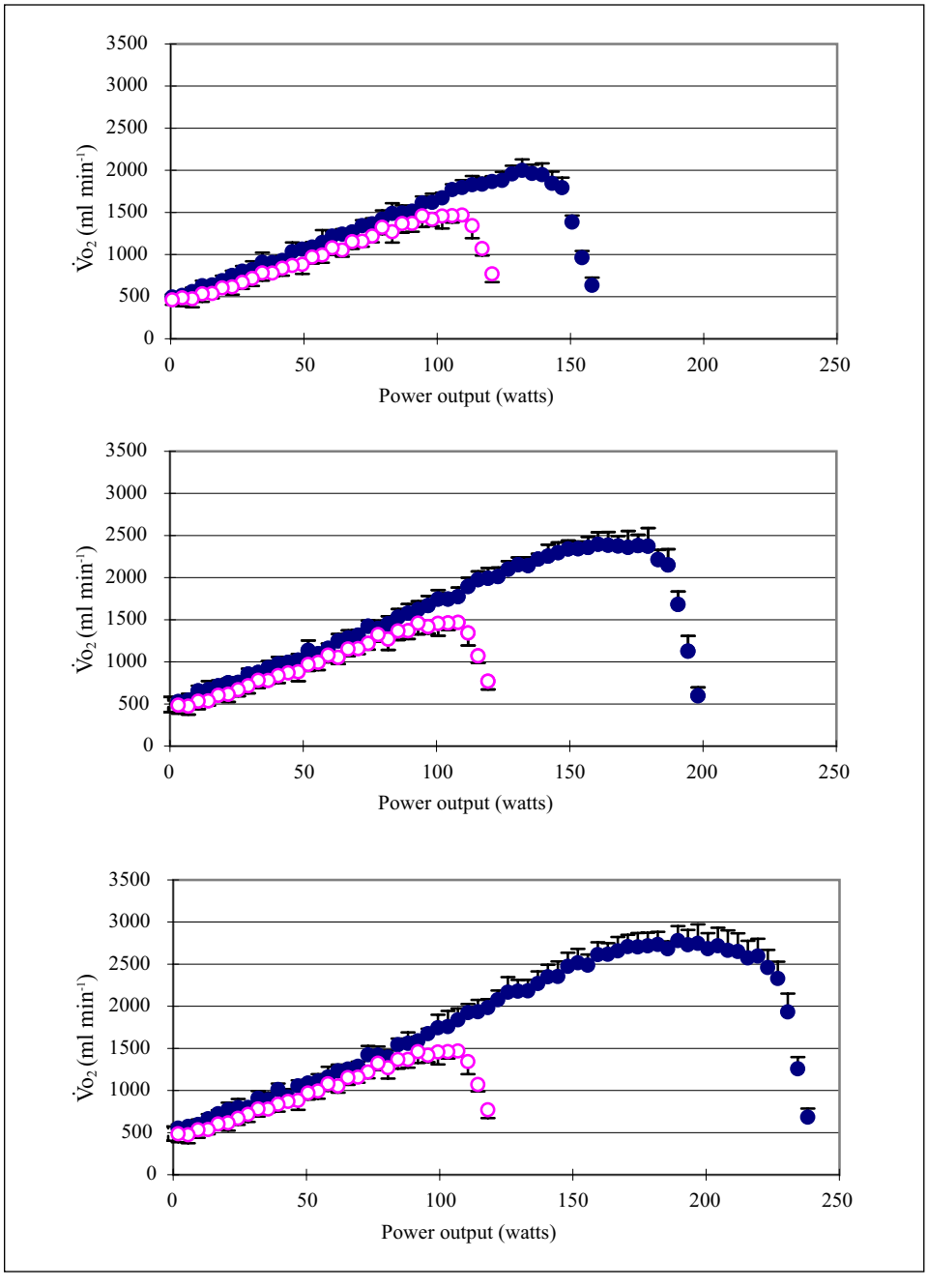

Fig. 1. Comparison of oxygen uptake ($\dot{V}o_2$) in decremental work load exercise (DLE) starting from 120 W (○) with the other DLEs (●). $\dot{V}o_2$ kinetics in DLE starting from 160 W are shown in the upper panel. $\dot{V}o_2$ kinetics in DLE starting from 200 W are shown in the middle panel. $\dot{V}o_2$ kinetics in DLE starting from 240 W are shown in the lower panel.

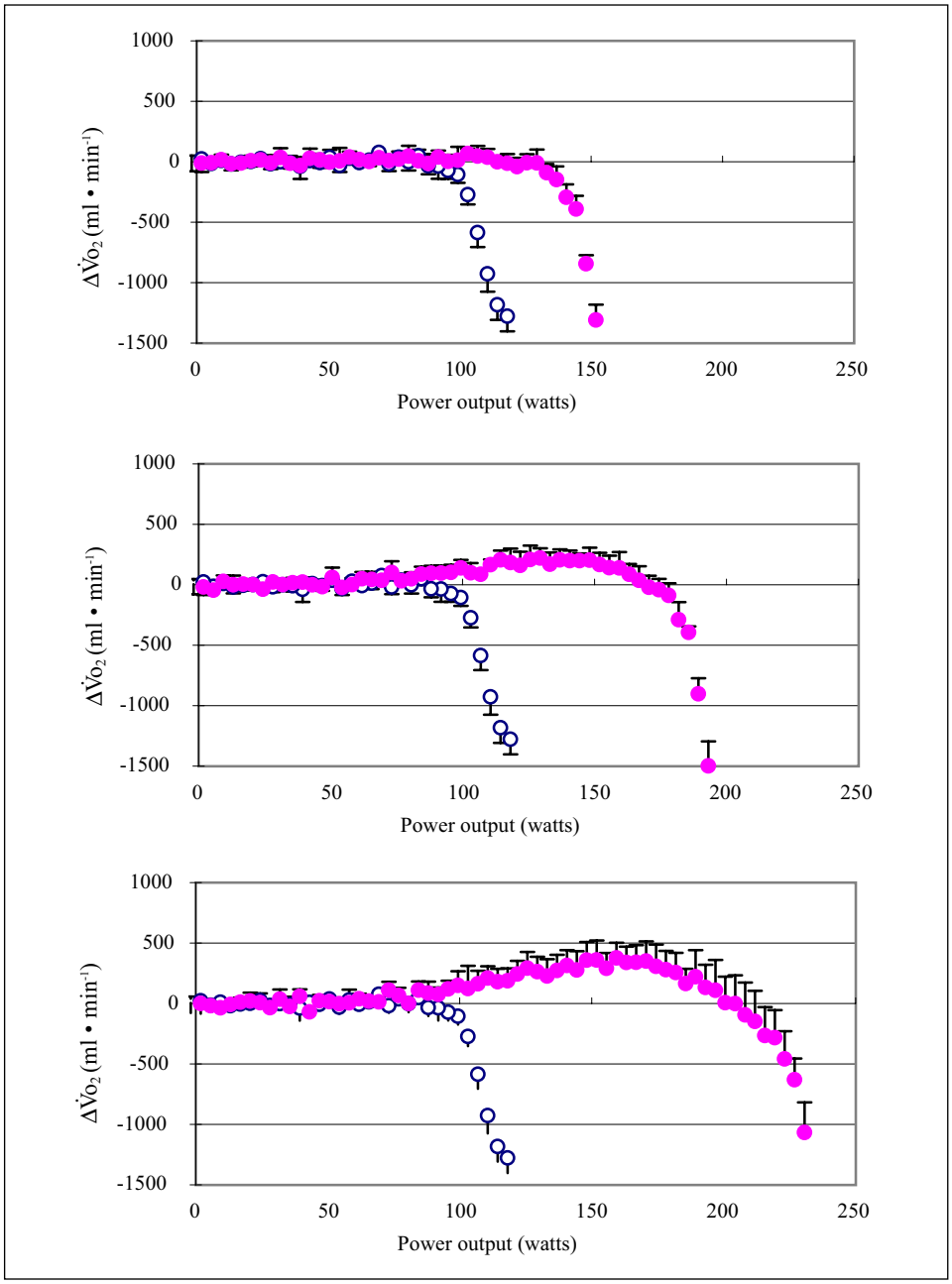

Fig. 2. Comparison of the difference between oxygen uptakes ($\dot{V}o_2$) measured and estimated from the power output-$\dot{V}o_2$ relation obtained below 50 W ($\Delta\dot{V}o_2$) in decremental work load exercise (DLE) starting from 120 W (○) with the other DLEs (●). $\Delta\dot{V}o_2$ in DLE starting from 160 W is shown in the upper panel. $\Delta\dot{V}o_2$ in DLE starting from 200 W is shown in the middle panel. $\Delta\dot{V}o_2$ in DLE staring from 240 W is shown in the lower panel.

Table 2. Slope of oxygen uptake versus power output in decremental work load exercise (DLE).

		Mean	SD
		(ml • min^{-1} • watt^{-1})	
DLE_{240}	Low	10.7	0.5
	High	14.8*	1.1
DLE_{200}	Low	10.9	0.8
	High	12.8*	0.8
DLE_{160}	Low	11.7	0.5
	High	11.4	0.9
DLE_{120}	Low	10.9	0.6
	High	-	-

*: Significant difference between slopes obtained at the low and high power outputs
Slopes were obtained at low power output (Low) and high power output (High) in DLE.

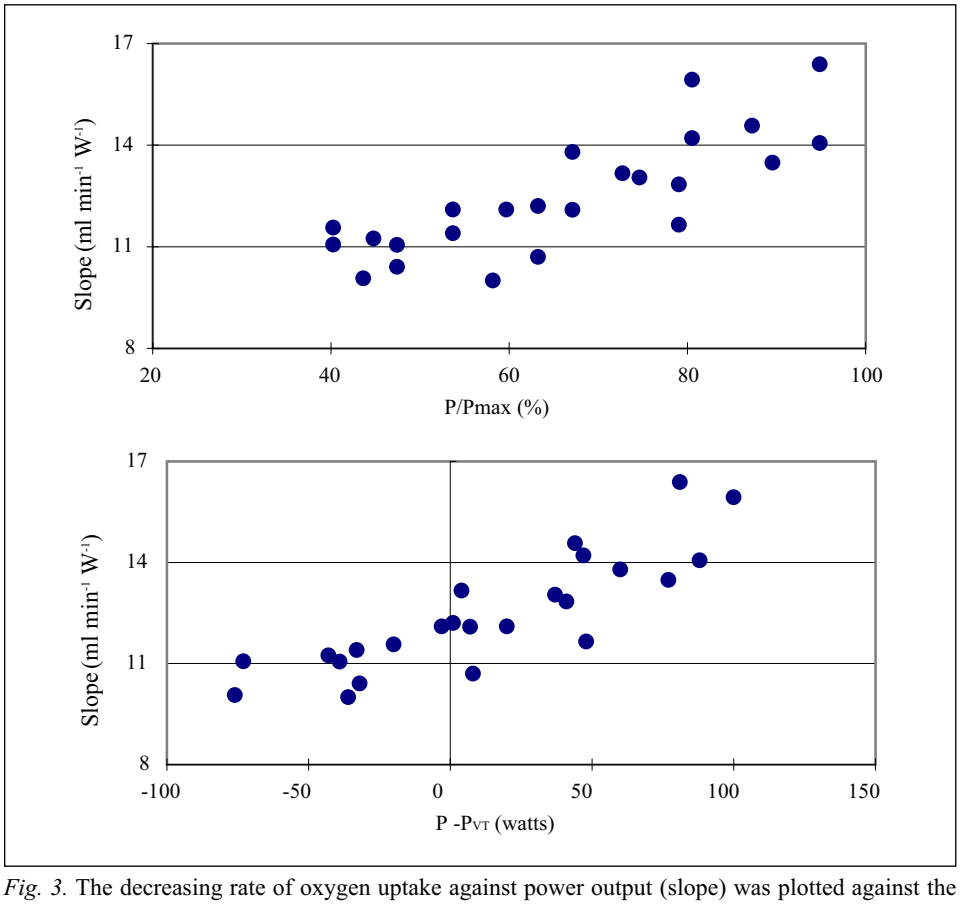

Fig. 3. The decreasing rate of oxygen uptake against power output (slope) was plotted against the relative power output (P). The upper panel shows the relationship between the slope and the relative power output (P/Pmax). The lower panel shows the relationship between the slope and the difference in the power output from the power output at the ventilatory threshold (PAT).

DISCUSSION

Yano et al., (18) simulated the kinetics of $\dot{V}o_2$ in DLE from a power output below AT. In this simulation, the power output in DLE was separated into several steps. The steps were regarded as constant-load exercise (CLEs) (see *Fig. 1* in reference 18). $\dot{V}o_2$ kinetics was assumed to change exponentially at the onset and offset of CLEs. $\dot{V}o_2$ at the onset of CLEs simultaneously increases in all steps, and becomes step-by-step recovery phases corresponding to the decrement in the power output. The sum of the $\dot{V}o_2$ at the onset of CLEs at a given time corresponds to $\dot{V}o_2$ excluding the oxygen debt in DLE (net $\dot{V}o_2$). The sum of $\dot{V}o_2$ at the offset of CLEs at a given time corresponds to $\dot{V}o_2$ related oxygen debt (debt $\dot{V}o_2$). The total of net and debt $\dot{V}o_2$ is equivalent to $\dot{V}o_2$ actually observed in DLE. If this simulation were made for a higher exercise intensity, two factors would be considered. One would be lactic oxygen debt. The other would be the slow increase after fast increase in $\dot{V}o_2$ (slow component), which is observed at the onset of CLE with heavy exercise intensity (1, 2, 4, 6).

There were no significant differences in $\dot{V}o_2$ among DLE_{120} and any other DLEs below 50 W. In DLE_{120}, lactic oxygen debt is not expected since this initial power output was conducted below VT. Therefore, the $\dot{V}o_2$ during the linear section in DLE_{120} is critical for examining whether there is lactic oxygen debt in another DLE. If there is a lactic oxygen debt in DLE, $\dot{V}o_2$ should be higher than that in DLE_{120}. It has been reported that $\dot{V}o_2$ during recovery is mono-exponential or no difference was observed between approximations by mono- and two exponential functions in heavy CLE (1, 5). Therefore, we expected that lactic oxygen debt would be negligible in DLE_{160} and DLE_{200} but that $\dot{V}o_2$ kinetics in DLE_{240} would have both a slow component and a lactic oxygen debt. This is because both are observed during recovery in very heavy and severe CLE (1). Initial power output was very high in DLE_{240}. However, as the power output was decreased in DLE, the exercise intensity of DLE_{240} might not have corresponded with a very heavy CLE. Thus, we failed to show the lactic oxygen debt in all the DLEs.

The slopes of $\dot{V}o_2$ to power output were 11 ml • min^{-1} • W^{-1} in DLEs below 50 W. This value is close to that reported in CLE below the VT (3), in ILE with an increasing rate of 15 W (10), and in DLE starting from low exercise intensity (15). These slopes were used to estimate $\dot{V}o_2$ at the upper power output and the differences between the measured and estimated $\dot{V}o_2$ were obtained. The obtained values showed positive. As lactic oxygen debt would not exist in DLEs established in the present study, these positive values derive from the other factor. As mentioned in the simulation, the factor would be a slow component.

The steeper slope was observed when the initial power output was just above VT. This suggests that the slow component has essentially no time delay. If it had time delay, the start of the steeper slope could not have materialized in DLE starting from the exercise intensity of VT because the power output in DLE can

be reduced below VT until the appearance timing of the slow component, even if the initial power output is above VT.

The steeper slope observed in the upper power output continued below VT. This indicates that the slow component continues below VT if it once started. It has been hypothesized that the slow component is related to the recruitment of the muscle fibers with low mechanical efficiency (type II fibers). Barstow et al., (4) demonstrated that magnitude of slow component was positively correlated the percentage of type II fibers. However, Zoladz et al., (12) suggests that the slow component found in ILE with cycling is not related to the patter of motor unit recruitment in any simple way because no systemic effect on the magnitude or onset of the slow component was not found in relation to pedaling rate. A recent study using surface electromyographic techniques, suggests that the increased O_2 cost is coupled with a progressive increase in ATP requirements of the already recruited motor units rather than to changes in the recruitment pattern of slow versus fats-twitch motor units (8). Thus, the characteristics of hysteresis found in the present study may be related to increase of O_2 cost in recruited motor units.

Thus, we concluded that the steeper slope is associated with the slow component. It is likely that the slow component has essentially no time delay.

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Author's address: T. Yano, Exercise Physiology, Graduate School of Education, Hokkaido University, Kita-ku, Sapporo, Japan. Tel: 011-706-5090, fax: 011-552-1347.
E-mail: yano@edu.hokudai.ac.jp