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Comparison of Oxygen Uptake at the Onset of Decrement-Load and Constant-Load Exercise

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

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

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Summary

The purpose of the present study was to examine whether the level of oxygen uptake ($\dot{V}o_2$) at the onset of decrement-load exercise (DLE) is lower than that at the onset of constant-load exercise (CLE), since power output, which is the target of $\dot{V}o_2$ response, is decreased in DLE. CLE and DLE were performed under the conditions of moderate and heavy exercise intensities. Before and after these main exercises, previous exercise and post exercise were performed at 20 watts. DEL was started at the same power output as that for CLE and power output was decreased at a rate of 15 watts per min. $\dot{V}o_2$ in moderate CLE increased at a fast rate and showed a steady state, while $\dot{V}o_2$ in moderate DLE increased and decreased linearly. $\dot{V}o_2$ at the increasing phase in DLE was at the same level as that in moderate CLE. $\dot{V}o_2$ immediately after moderate DLE was higher than that in the previous exercise by 98±77.5 ml/min. $\dot{V}o_2$ in heavy CLE increased rapidly at first and then slowly increased, while $\dot{V}o_2$ in heavy DLE increased rapidly, showing a temporal convexity change, and decreased linearly. $\dot{V}o_2$ at the increasing phase of heavy DLE was the same level as that in heavy CLE. $\dot{V}o_2$ immediately after heavy DLE was significantly higher than that in the previous exercise by 156±131.8 ml/min. Thus, despite the different modes of exercise, $\dot{V}o_2$ at the increasing phase in DLE was at the same level as that in CLE due to the effect of the oxygen debt expressed by the higher level of $\dot{V}o_2$ at the end of DLE than that in the previous exercise.

Key words
Heavy exercise • Moderate exercise • Oxygen debt • Oxygen uptake

Introduction

Whipp *et al.* (1992) reported the following interesting results regarding the kinetics of oxygen uptake ($\dot{V}o_2$) in decrement-load exercise (DLE). $\dot{V}o_2$ exponentially increased and linearly decreased till the end of the DLE. The level of $\dot{V}o_2$ during the phase of linear decrease was higher in DLE than in incremental-load exercise (ILE) at the same power output. These authors suggested that the higher level of $\dot{V}o_2$ is due to the repayment of oxygen debt during DLE. It was later confirmed that the oxygen debt in DLE exists at a late period of DLE (Horiuchi and Yano 1997, Yano *et al.* 2003b).

In response to an increase in exercise intensity, motor units (MUs) are recruited, although rate cording affects the degree of the recruitment of MUs. At the start of DLE, $\dot{V}o_2$ starts to be utilized in the recruited MUs.

Fax +420 241 062 164
E-mail: physres@biomed.cas.cz http://www.biomed.cas.cz/physiolres

Then some MUs are released from activity in response to a decrease of power output. The oxygen deficit produced in preceding work can be repaid by the released MUs (oxygen debt) but oxygen is still consumed by the other working MUs. If MUs are slightly released in DLE, the oxygen debt in released MUs can be revealed even at the onset of DLE. Under the condition of a slight release pattern, Yano *et al.* (2003a) simulated the kinetics of $\dot{V}o_2$ in DLE started from a power output below the ventilatory threshold (VT). It was quantitatively shown that the oxygen debt starts to increase soon after the onset of exercise and shows a steady state even when the oxygen deficit is produced at the onset of DLE. Yano *et al.* (2003b) also applied a mathematical equation including some items for $\dot{V}o_2$ measured in DLE below the VT. It was suggested that there is an item associated with oxygen debt and thereby early start of oxygen debt. However, the results of these studies only show the possibility of existence of oxygen debt in the early period of DLE.

$\dot{V}o_2$ at the onset of exercise increases toward the level related to power output. $\dot{V}o_2$ exponentially increases toward a steady state level in moderate and heavy constant-load exercise (CLE). The response speed for 2-3 min at the onset of exercise is fairly constant regardless of exercise intensity (Ozyener *et al.* 2001). In DLE, $\dot{V}o_2$ exponentially increases but is continuously modified toward the target level in response to the decrement of power output. As a result, the level of $\dot{V}o_2$ at the onset of DLE should continuously become lower than that in CLE when the initial power outputs in DLE and CLE are the same. However, if $\dot{V}o_2$ kinetics at the onset of DLE includes the oxygen debt, $\dot{V}o_2$ in DLE should be close to that in CLE.

Thus, it is possible to determine whether the oxygen debt exists in $\dot{V}o_2$ at the onset of DLE by comparing the $\dot{V}o_2$ kinetics in DLE and CLE. The purpose of the present study, therefore, was to determine whether the level of $\dot{V}o_2$ at the onset of DLE is lower than that in CLE.

Methods

Eight healthy males participated in this study. The 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.

Table 1. Characteristics of the subjects

	Age (yrs)	**Weight (kg)**	**Height (cm)**	**$\dot{V}o_2$-VT (l/min)**	**$\dot{V}o_2$ peak (l/min)**
Sub. 1	24	67	174	1,05	2,1
Sub. 2	22	69	190	1,61	2,94
Sub. 3	21	54	168	1,32	2,15
Sub. 4	24	52	173	1,19	1,97
Sub. 5	24	70	174	1,67	2,53
Sub. 6	27	63	174	2,06	3,19
Sub. 7	25	74	181	2,3	3,55
Sub. 8	20	52	168	1,2	2,35
Mean	23,4	62,6	175,3	1,55	2,60
SD	2,3	8,8	7,2	0,45	0,57

A cycle ergometer in which the power output could be adjusted by a computer (232C, Combi, Tokyo) was used. On the first day, each subject performed an ILE test after a 5-min rest period to determine his peak oxygen uptake ($\dot{V}o_2$peak). After cycling at 20 watts for 4 min, the power output was increased by 30 watts per minute until the subject could no longer maintain a rotation speed of 60 rpm. Two CLE tests were performed on separate days. After cycling at 20 watts for 4 min (previous exercise), the power output was increased suddenly to a level corresponding to 90 % of the power output at the VT, maintained for 6 min (main exercise), and reduced to 20 watts. This power output was continued at 20 watts (post exercise). The other CLE test was performed in the same manner, but the power output of the main exercise was increased to a level of VT + ($\dot{V}o_2$peak – VT)/3. Two DLE tests were also performed. Before and after DLE, previous and post exercises at 20 watts were carried out. The main exercise was started from the same power output as that of CLEs. It was then reduced by a rate of 15 watts/min until it reached 20 watts. Tests were performed in a random order within a period of 2 weeks.

$\dot{V}o_2$, carbon dioxide output ($\dot{V}co_2$) and ventilation volume ($\dot{V}E$) were measured breath-by-breath using a respiratory gas analyzer (AE-280S Minato Medical Science, Tokyo). The ventilation volumes of inspiration and expiration were determined using hot-wire respiratory flowmeter. The flow volume signals were integrated electrically for each breath and converted to ventilation volume per minute. The respiratory flowmeter was calibrated using a 2-liter syringe. Ventilation volume can be linearly measured over a range of 0-600 l/min by this instrument. Oxygen and carbon dioxide concentrations were analyzed using a zirconium sensor and infrared absorption analyzer, respectively. $\dot{V}o_2$ was measured in breath-by-breath every 15 s in order to enable direct comparison between $\dot{V}o_2$ in DLE and CLE.

The ventilatory threshold was determined by the V-slope method (Beaver *et al.* 1986). $\dot{V}o_2$ was plotted against $\dot{V}co_2$. Two straight lines were drawn on the data plot in the lower and higher sections, respectively. The intersection of the two straight lines was defined as the point of VT.

Significant differences were tested by Student's paired t-test for comparison between $\dot{V}o_2$ in the previous exercise and the starting value of the post exercise. Student's paired t-test was also used for the comparison between $\dot{V}o_2$ in CLE and DLE. The differences in $\dot{V}o_2$ between CLE and DLE tests ($\Delta\dot{V}o_2$) in the previous exercise at 20 watts and in the main exercise were obtained. A repeated ANOVA was used to show significant differences in $\Delta\dot{V}o_2$, and Fisher's PLSD test was used to determine the level of significance which was set at $p<0.05$. The results are expressed as means and standard deviations (SD).

Results

Figure 1 shows examples of $\dot{V}o_2$ kinetics in constant-load and decrement-load exercise, previous exercise at 20 watts and at rest. $\dot{V}o_2$ showed a steady state after a rapid increase in moderate CLE and showed a gradual increase after a rapid increase in heavy CLE. $\dot{V}o_2$ in moderate DLE showed a rapid increase (increasing phase) and a linear decrease. In heavy DLE, $\dot{V}o_2$ showed a rapid increase and returned to a gradual increase (increasing phase). Then $\dot{V}o_2$ decreased linearly after a gradual decrease (decreasing phase). There were no differences in $\dot{V}o_2$ between CLE and DLE at the previous exercise and at rest. There were no differences between $\dot{V}o_2$ in CLE and that in DLE until 1.75 min after the onset of exercise, in the case of moderate exercise intensity and until 3 min after the onset of exercise in the case of heavy intensity exercise.

Figure 2 shows the difference between $\dot{V}o_2$ in CLE and that in DLE ($\Delta\dot{V}o_2$). Time zero is the starting point of DLE and CLE. In moderate DLE, there were no significant differences in the first minute of the main exercise compared to the values in the previous exercise. In heavy DLE, there were no significant differences in values for the first two minutes of the main exercise compared to those in the previous exercise. Peak values of $\dot{V}o_2$ in DLE were observed at 1.53±0.28 min in moderate DLE and at 2.19±0.46 min in heavy DLE. Hence, significant differences in $\Delta\dot{V}o_2$ were derived from $\dot{V}o_2$ at the decreasing phase in DLE.

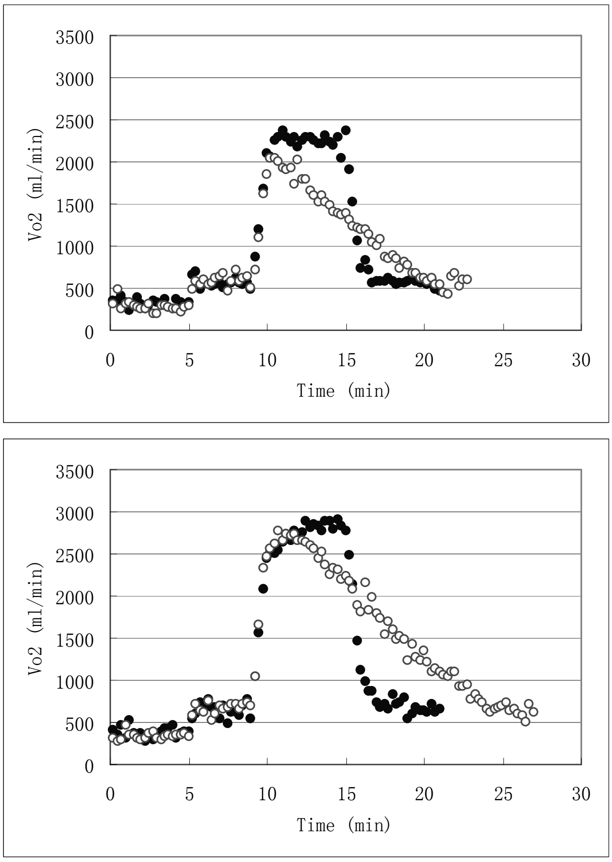

Fig. 1. A typical example of oxygen uptake ($\dot{V}o_2$) kinetics in constant-load and decrement-load exercises (CLE: closed circles, DLE: open circles). After a 5-min resting state, previous exercises were performed for 4 min and the main exercises were started. CLE was continued from 9 min to 15 min and then became post exercise. $\dot{V}o_2$ at post exercise after DLE is not shown. The upper panel shows $\dot{V}o_2$ kinetics in moderate exercise, and the lower panel shows $\dot{V}o_2$ kinetics in heavy exercise.

Figure 3 shows $\dot{V}o_2$ at the previous exercise and at the starting point of post exercise at 20 watts in DLE. In moderate DLE, $\dot{V}o_2$ significantly increased from 539±58 to 639±54 ml/min. In heavy DLE, $\dot{V}o_2$ significantly increased from 551±110 to 702±79 ml/min. The differences in $\dot{V}o_2$ before and immediately after DLE were 98±77.5 ml/min in moderate DLE and 156±131.8 ml/min in heavy DLE. These differences between moderate and heavy DLEs were not significant.

Discussion

$\dot{V}o_2$ responds toward the steady-state level in response to the power output in moderate and heavy

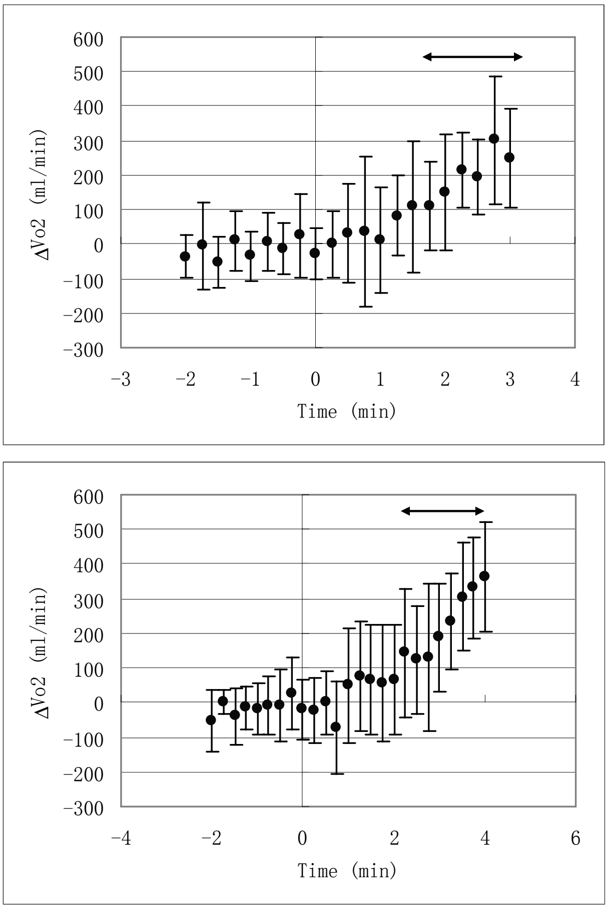

Fig. 2. Difference between oxygen uptake in constant-load exercise and that in decrement-load exercise ($\Delta\dot{V}o_2$). Time zero indicates the starting point of constant-load and decrement-load exercise (CLE and DLE). $\Delta\dot{V}o_2$ before this point is the value in previous exercise before CLE and DLE. The upper panel shows $\Delta\dot{V}o_2$ in moderate exercise, and the lower panel shows $\Delta\dot{V}o_2$ in heavy exercise. The arrow shows a significant difference from the previous exercise.

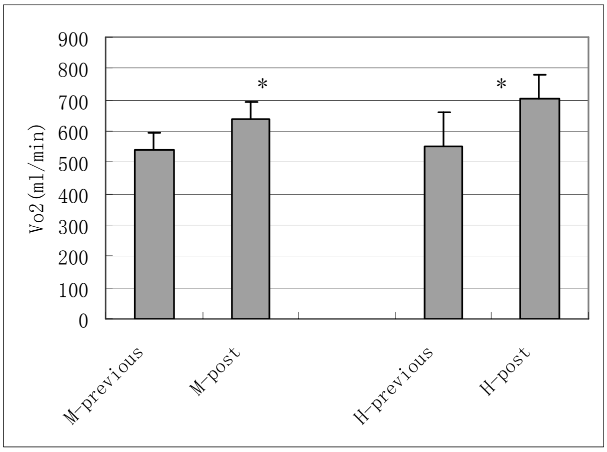

Fig. 3. The right side of the graph shows oxygen uptake ($\dot{V}o_2$) in previous exercise before heavy decrement-load exercise (DLE) and in post exercise immediately after heavy DLE (H-previous and H-post). The left side of the graph shows $\dot{V}o_2$ in previous exercise before moderate DLE and in post exercise immediately after moderate DLE (M-previous and M-post).

CLE, although there is an additional increase (slow component) after the fast increasing phase in heavy exercise (Ozyener *et al.* 2001). If the power output is decreased such as in DLE, the response of $\dot{V}o_2$ should continuously be modified in response to the decreased rate in power output. This should result in a lower level of $\dot{V}o_2$ in DLE than that in CLE. Nevertheless, the level of $\dot{V}o_2$ at the increasing phase of DLE was the same as that in CLE in the present study. This finding might be related to the following factors.

The first factor concerned is early lactate (Cerretelli *et al.* 1979). At the onset of CLE, the response speed of $\dot{V}o_2$ is associated with the degree of increase in blood lactate. A fast response of $\dot{V}o_2$ results in a reduction of blood lactate. Therefore, if the blood lactate level in DLE is lower than that in CLE, the response of $\dot{V}o_2$ in DLE can be faster. However, recent studies have shown that the response at the onset of CLE does not change (Barstow and Mole 1991, Burnley *et al.* 2000, Ozyener *et al.* 2001, Scheuermann *et al.* 2001) or decreases (Paterson and Whipp 1991, Engelen *et al.* 1996) from moderate exercise intensity to heavy exercise intensity, although blood lactate level is higher in heavy CLE than since in moderate CLE, the response of $\dot{V}o_2$ must be reduced according to the early lactate theory. Therefore, the effect of early lactate remains unclear. Furthermore, the present study indicated that the level of $\dot{V}o_2$ at the onset of moderate DLE was the same as that in moderate CLE. This suggests that the same level of $\dot{V}o_2$ in moderate exercise observed in the present study is not due to the difference in blood lactate level, although this result in moderate exercises is not direct evidence proving that early lactate does not cause the same kinetics of $\dot{V}o_2$ in heavy DLE and heavy CLE.

The second factor concerns repayment of the oxygen debt. The value per minute of oxygen debt can be observed at a low power output, since it has been reported that the level of $\dot{V}o_2$ in DLE is higher than that in ILE at the same power output (Whipp *et al.* 1992, Horiuchi and Yano 1997, Yano *et al.* 2003b). This difference includes the oxygen debt per minute produced in DLE and oxygen deficit in ILE due to the time delay of $\dot{V}o_2$. In the present study, in order to eliminate the effect of oxygen deficit in ILE, the difference between $\dot{V}o_2$ in the previous exercise and that in the post exercise immediately after DLE was obtained. The value of $\dot{V}o_2$ immediately after DLE could become greater than that in the previous exercise as oxygen debt per minute. The oxygen debt per minute in DLE was approximately 100-150 ml/min.

The power output was reduced by 15 watts per minute in DLE in the present study. Therefore, power output one minute after starting DLE became lower than that in CLE by 15 watts. This power output corresponds to 150 ml/min in $\dot{V}o_2$ if the reported gain (10 ml/min/watt), which is the ratio of power output and $\dot{V}o_2$, is accepted (Henson *et al.* 1989). If the oxygen debt per minute is not included in $\dot{V}o_2$, $\dot{V}o_2$ in DLE will be lower by 150 ml/min one minute after DLE. However, the present results showed the same levels of $\dot{V}o_2$ in DLE and CLE. Therefore, it is thought that this gap is compensated by the oxygen debt.

There was no significant difference between the oxygen debt per min in moderate DLE and that in heavy DLE. In severe CLE, there are two phases in oxygen debt (Astrand *et al.* 1986). One is traditionally called lactic oxygen debt, which is observed for a long time, and the other is alactic oxygen debt, which is observed for a short period. However, in recent studies (Paterson and Whipp 1991, Ozyener *et al.* 2001,), only one short phase was seen in moderate and heavy CLE. Therefore, oxygen debt in moderate and heavy DLE has one phase, and consequently oxygen debt per min can be the same.

The increasing phase in $\dot{V}o_2$ was longer in heavy exercise. This may be due to the additional increase, i.e. due to the slow component of $\dot{V}o_2$. It is well known that there is a slow component of $\dot{V}o_2$ in heavy CLE, but it was not clear whether the slow component exists in heavy DLE. Recently, $\dot{V}o_2$ kinetics in DLE with various exercise intensities has been examined (Yano *et al.* 2004), and it has been shown that there is one decreasing phase after the increasing phase in moderate DLE but that there are two decreasing phases in DLE with high intensity exercise. The first decreasing phase is steeper than the second decreasing phase. It is suggested that this steeper decreasing phase is derived from the slow component produced in hierarchical muscle recruitment. Therefore, since the slow component appeared not only in CLE but also in DLE, this additional increase must compensate for the difference in $\dot{V}o_2$ between DLE and CLE.

It can thus be concluded that the level of $\dot{V}o_2$ at the increasing phase of DLE is the same as that in CLE due to the effect of the oxygen debt in DLE.

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Corresponding author

T. Yano, Department of Exercise Physiology, Graduate School of Education, Hokkaido University, Kita-ku, Sapporo, Japan. E-mail: yano@edu.hokudai.ac.jp