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Effects of Rate of Decrease in Power Output in Decrement-Load Exercise on Oxygen Uptake

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Summary

The purpose of this study was to examine how oxygen uptake ($\dot{V}o_2$) in decrement-load exercise (DLE) is affected by changing rate of decrease in power output. DLE was performed at three different rates of decrease in power output (10, 20 and 30 watts • min^{-1}: DLE10, DLE20 and DLE30, respectively) from power output corresponding to 90 % of peak $\dot{V}o_2$. $\dot{V}o_2$ exponentially increased and then decreased, and the rate of its decrease was reduced at low power output. The values of $\dot{V}o_2$ in the three DLE tests were not different for the first 2 min despite the difference in power output. The relationship between $\dot{V}o_2$ and power output below 50 watts was obtained as a slope to estimate excessive $\dot{V}o_2$ (ex-$\dot{V}o_2$) above 50 watts. The slopes were 10.0±0.9 for DLE10, 9.9±0.7 for DLE20 and 10.2±1.0 ml • min^{-1} • watt^{-1} for DLE30. The difference between $\dot{V}o_2$ estimated from the slope and measured $\dot{V}o_2$ was defined as ex-$\dot{V}o_2$. The peak value of ex-$\dot{V}o_2$ for DLE10 (189±116 ml • min^{-1}) was significantly greater than those for DLE20 and for DLE30 (93±97 and 88±34 ml • min^{-1}). The difference between $\dot{V}o_2$ in DLE and that in incremental-load exercise (ILE) below 50 watts ($\Delta\dot{V}o_2$) was greater in DLE30 and smallest in DLE10. There were significant differences in $\Delta\dot{V}o_2$ among the three DLE tests. The values of $\Delta\dot{V}o_2$ at 30 watts were 283±152 for DLE10, 413±136 for DLE20 and 483±187 ml • min^{-1} for DLE30. Thus, a faster rate of decrease in power output resulted in no change of $\dot{V}o_2$ at the onset of DLE, smaller ex-$\dot{V}o_2$ and greater $\Delta\dot{V}o_2$. These results suggest that $\dot{V}o_2$ is disposed in parallel in each motor unit released from power output or recruited in DLE.

Key words
Decrement-load exercise • Rate of decrease in power output • Oxygen uptake • Oxygen debt

Introduction

It has been shown by electromyography that in isometric contraction, motor units (MUs) are progressively recruited in response to an increase in exercise intensity, although the rate cording affects the degree of recruitment of MUs (De Duka *et al.* 1982). It has also been shown by examining the change of glycogen density in muscle fibers during dynamic exercises of various intensity that there is a progressive increase in the number of active muscle fibers with increasing intensity (Vøllestat and Blom 1985). When exercise intensity is reduced after a sudden increase, MUs are first recruited and then some of the MUs are released from being involved. Oxygen is utilized in the working MUs and oxygen deficit produced in the preceding work is repaid

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in the released MUs (oxygen debt). Under the condition of such hierarchical release of MUs, Yano *et al.* (2003) simulated the kinetics of oxygen uptake ($\dot{V}O_2$) in decrement-load exercise (DLE) starting from a power output below the ventilatory threshold (VT). The simulation quantitatively showed that the oxygen debt starts to increase soon after the start of exercise and shows a stable state even when an oxygen deficit is produced at the onset of DLE.

The existence of an oxygen debt in the early period has been examined by comparing $\dot{V}O_2$ at the onset of DLE with that at the onset of constant-load exercise (CLE) (Yano *et al.* 2007). The results showed that $\dot{V}O_2$ at the onset of DLE was on the same level as that in CLE despite the progressive decrease of power output in DLE. It was suggested that since the oxygen debt per min (debt-$\dot{V}O_2$) was added to $\dot{V}O_2$ at the onset of DLE, effect of the decrease in power output on $\dot{V}O_2$ was compensated. The existence of the oxygen debt at a later period of DLE has been examined by comparing of $\dot{V}O_2$ in DLE with that in incremental-load exercise (ILE) (Whipp *et al.* 1992, Horiuchi and Yano 1997, Yano *et al.* 2003). The results showed that $\dot{V}O_2$ in ILE was lower than that in DLE at the same power output, suggesting that the difference between $\dot{V}O_2$ in DLE and that in ILE is derived from the oxygen deficit due to a delay in response of $\dot{V}O_2$ in ILE and oxygen debt in DLE. However, Yano *et al.* (2004) have suggested that excessive $\dot{V}O_2$ (ex-$\dot{V}O_2$) exists in DLE starting from high exercise intensity and continues until power output is low. Therefore, the difference between $\dot{V}O_2$ in DLE and that in ILE need not be associated with the oxygen debt only.

It has been suggested that ex-$\dot{V}O_2$ observed in DLE is equivalent to the slow component of $\dot{V}O_2$ (Yano *et al.* 2004) observed as a gradual increase after rapid increase in heavy constant-load exercise (CLE) (Barstow and Mole 1991, Ozyener *et al.* 2001). However, ex-$\dot{V}O_2$ does not show a gradual increase but a convexity (Yano *et al.* 2004) In order to explain the phenomenon in DLE, we put forward a hypothesis that the slow component consists of a sub-slow component in the MUs (sub-slow-$\dot{V}O_2$). Sub-slow-$\dot{V}O_2$ is small in the early period, resulting in smaller summation. In the later period, the amount of working MUs is small, although sub-slow-$\dot{V}O_2$ becomes greater. This results in smaller summation. Then, since the optimal condition could be in the intermediate period, the peak value of ex-$\dot{V}O_2$ may appear during this period.

Thus, it is hypothesized that sub-$\dot{V}O_2$ kinetics exist in each MU and that $\dot{V}O_2$ includes sub-slow-$\dot{V}O_2$ in working MUs and sub-debt-$\dot{V}O_2$ in recovering MUs. In order to examine this hypothesis, the effects of the rate of decreased power output in DLE on ex-$\dot{V}O_2$ and debt-$\dot{V}O_2$ were investigated in the present study because of the following predictions: 1) the summation of sub-debt-$\dot{V}O_2$, which is equivalent to debt-$\dot{V}O_2$, will become greater when a larger number of MUs is released in DLE by a fast rate of decrease in power output, 2) the summation of sub-slow-$\dot{V}O_2$, which is equivalent to ex-$\dot{V}O_2$, will become greater when the majority of working MUs operate during a longer period at a slower rate of decrease in power output, and 3) $\dot{V}O_2$ at the onset of DLE will be the same in the three DLE tests despite the different power output at a given time since debt-$\dot{V}O_2$ affects the $\dot{V}O_2$ kinetics.

The purpose of the present study was, therefore, to examine how $\dot{V}O_2$ in DLE is affected by the changing rate of decrease in the power output.

Methods

Characteristics of subjects

Six healthy males who do not regularly train participated in this study. Their mean age, height, weight, and peak oxygen uptake were 26.0±1.9 years, 170±5.3 cm, 62.9±4.3 kg, and 2.69±0.14 $l \cdot min^{-1}$, respectively. After the objective, the procedure of the experiment and the risks associated with the experiment had been explained, the written consent to participate in the study was obtained from each subject.

Experimental protocol

A cycle ergometer in which the power output can be adjusted by a built-in computer (232C, Combi, Tokyo) was used. On the first day, each subject carried out an ILE test after a 5-min rest period to determine his peak oxygen uptake (peak $\dot{V}O_2$). After cycling with zero watts for 4 min, the power output was increased by 15 watts per minute until the subject could no longer maintain a rotation speed of 50 rpm. On separate days, three DLE tests were performed at three different rates of decrease in power output. After cycling with zero watts for 4 min, the power output was increased suddenly to the level corresponding to 90 % of peak $\dot{V}O_2$, and then the power output was reduced at a rate of 10, 20 or 30 watts $\cdot$ min^{-1} until it reached zero watts. Tests using these rates of decrease were performed in a random order within a period of two weeks.

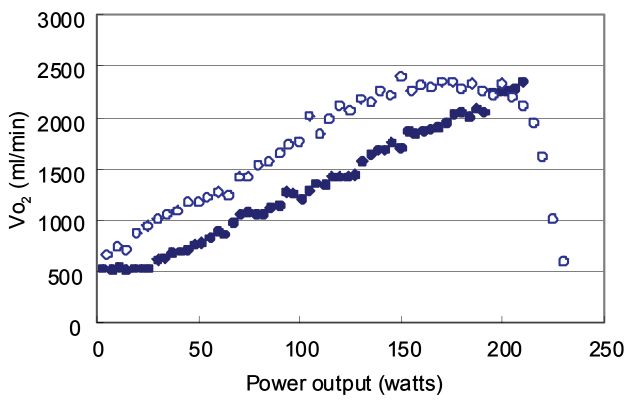

Fig. 1. Changes in oxygen uptake in a typical subject during decrement-load exercise with rate of decrease at 20 watts · min^{-1} (○) and during incremental-load exercise (●).

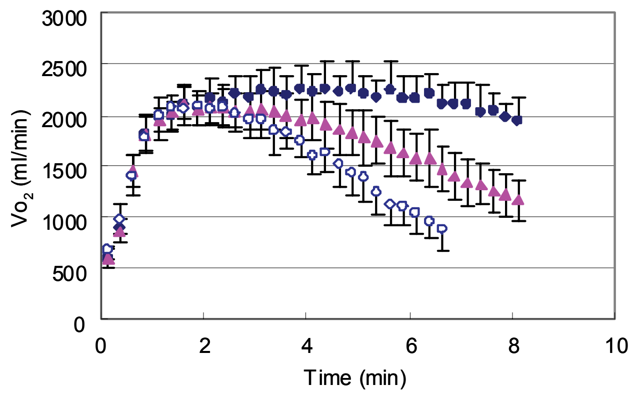

Fig. 2. Changes in oxygen uptake at the onset of decrement-load exercise with rates of decrease at 10 (●), 20 (▲), and 30 (○) watts · min^{-1}.

Measurements

Oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), and ventilation volume (VE) were measured breath-by-breath using a respiratory gas analyzer (AE-280S Minato Medical Science). The ventilation volumes of inspiration and expiration were determined using a hotwire respiratory flow meter. The flow volume signals were integrated electrically for each breath and converted to ventilation volume per minute. The respiratory flow meter was calibrated using a 2-liter syringe. This instrument can linearly measure the ventilation volume in a range of 0 to 600 l · min^{-1}. Oxygen and carbon dioxide concentrations were analyzed with a zirconium sensor and infrared absorption analyzer, respectively. The data of each parameter were evaluated every 15 s. This output makes it possible to compare the results of each time interval and for each power output.

Determinations

The slope was obtained from the relationship between $\dot{V}O_2$ and power output below 50 watts in DLE tests according to method of Yano *et al.* (2004). The slope was extrapolated to the power output above 50 watts to give an estimate of $\dot{V}O_2$ from power output. The difference between estimated $\dot{V}O_2$ and measured $\dot{V}O_2$ was defined as ex-$\dot{V}O_2$.

The difference between $\dot{V}O_2$ in DLE and that in ILE ($\Delta\dot{V}O_2$) was obtained at the same power output from 50 watts to 15 watts. This range was determined in order to avoid the effect of ex-$\dot{V}O_2$ and the delayed response in $\dot{V}O_2$ in ILE.

Statistical analysis

The level of significance was set at $p<0.05$. The results are expressed as means and standard deviations. The Tukey-Kramer test was used to test for significance in difference among $\dot{V}O_2$ levels in the three DLE tests and among peak values of ex-$\dot{V}O_2$. The difference between $\dot{V}O_2$ in DLE and that in ILE was tested among the three DLE tests by the Tukey-Kramer test.

Results

Figure 1 shows a typical example of $\dot{V}O_2$ kinetics in DLE20 and ILE. $\dot{V}O_2$ exponentially increased and then decreased, and the rate of decrease was diminished at low power output. At the same power output, $\dot{V}O_2$ in DLE was higher than that in ILE. $\dot{V}O_2$ in ILE showed a delay in response to the power output.

Figure 2 shows the initial $\dot{V}O_2$ responses in the three DLE tests. The levels of $\dot{V}O_2$ in the three DLE tests were the same for the first 2 min. After 2 min, $\dot{V}O_2$ in DLE10 was significantly different from that in DLE20 and DLE30. $\dot{V}O_2$ in DLE20 was significantly different from that in DLE30 after 3.5 min. In DLE30, after a rapid increase, $\dot{V}O_2$ showed a decrease until the low power output. In DLE10, $\dot{V}O_2$ showed a transient phase after a rapid increase and then decreased. The relationship between $\dot{V}O_2$ and power output was obtained. The slopes were 10.0±0.85 for DLE10, 9.9±0.73 for DLE20 and 10.2±0.99 ml · min^{-1} · watt^{-1} for DLE30. There were no significant differences among the three tests.

Figure 3 shows values of ex-$\dot{V}O_2$. Ex-$\dot{V}O_2$ was greatest in DLE10 and lowest in DLE30. The average peak value for DLE10 (189±116 ml · min^{-1}) was significantly greater than those for DLE20 and for DLE30 (93±97 and 88±34 ml · min^{-1}). It appeared that there is no ex-$\dot{V}O_2$ in DLE30. In DLE10, ex-$\dot{V}O_2$ gradually increased and then decreased until around 50 watts.

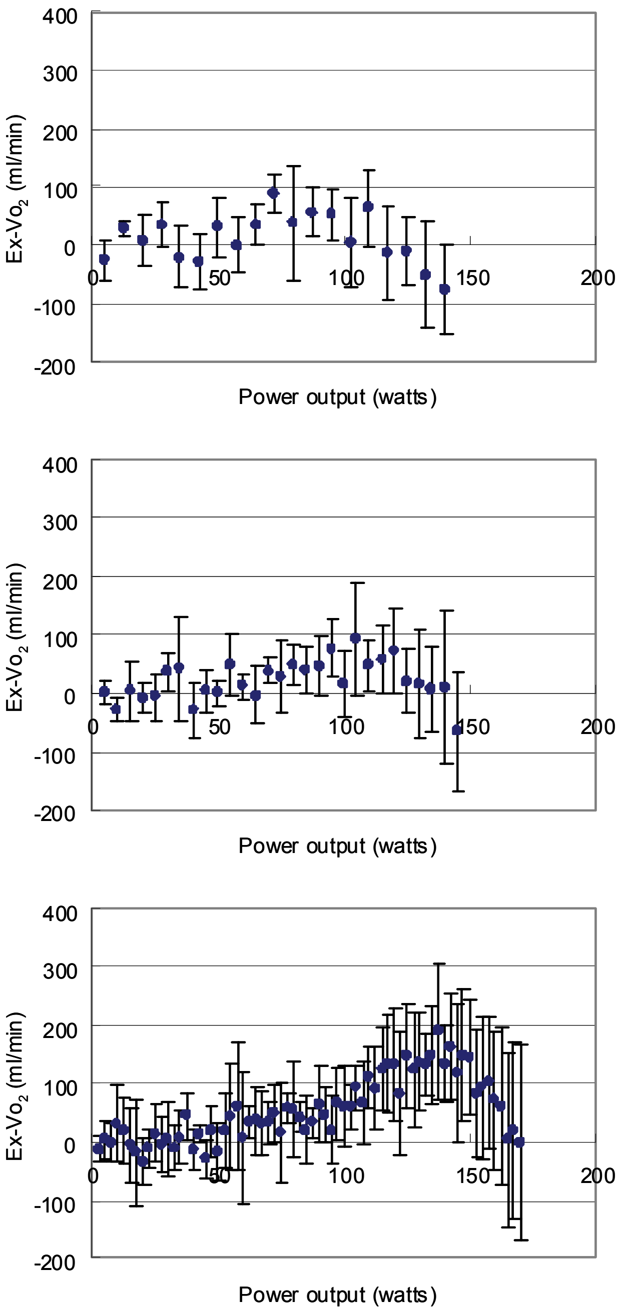

Fig. 3. Excess oxygen uptake during decrement-load exercise with rates of decrease at 10 (lower panel), 20 (middle panel), and 30 (upper panel) watts · min^{-1}.

Figure 4 shows the difference between $\dot{V}O_2$ in ILE and that in DLE ($\Delta\dot{V}O_2$). Since ex-$\dot{V}O_2$ affects $\Delta\dot{V}O_2$ above 50 watts and $\dot{V}O_2$ at the onset of ILE is delayed, these periods are excluded in the figure. There were significant differences in $\Delta\dot{V}O_2$ among the three DLE tests. At 30 watts, the levels of $\Delta\dot{V}O_2$ were 283±152 for DLE10, 413±136 for DLE20 and 483±187 ml · min^{-1} for DLE30.

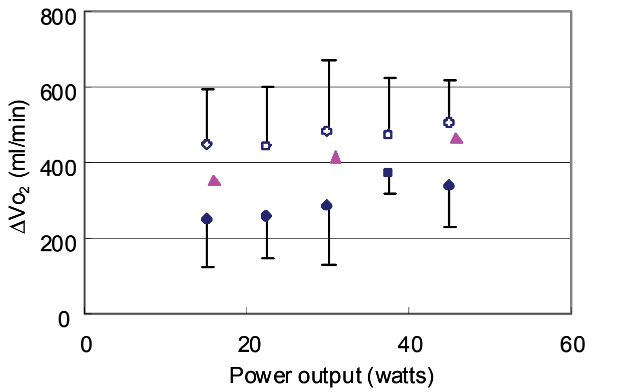

Fig. 4. Differences between oxygen uptake in decrement-load exercise (DLE) and that in incremental-load exercise (ILE). ●: DLE with 10 watts · min^{-1}. ▲: DLE with 20 watts · min^{-1}. ○: DLE with 30 watts · min^{-1}.

Discussion

There were no differences in $\dot{V}O_2$ at the onset of exercise among the three DLE tests. $\dot{V}O_2$ exponentially increases toward the target level related to the power output. $\dot{V}O_2$ in DLE is continuously modified towards the target level in response to decreased power output. As a result, $\dot{V}O_2$ at the onset of DLE30 should have gradually become lower than that in DLE10. However, the results showed the same levels during the first 2 min. Yano *et al.* (2007) reported that values of $\dot{V}O_2$ kinetics at the onset of DLE were the same as those at the onset of CLE. The periods during which the levels were the same were 1 min in moderate exercise and 2 min in heavy exercise. They suggested that the longer period in heavy exercise is probably due to ex-$\dot{V}O_2$.

The difference between power output in DLE10 and in DLE30 becomes 20 watts at 1 min. This corresponds to 200 ml/min according to the reported gain, which is the ratio of $\dot{V}O_2$ and power output (Henson *et al.* 1989). The difference between $\Delta\dot{V}O_2$ in DLE10 and that in DLE30 at power output below 50 watts is derived from debt-$\dot{V}O_2$. This difference does not include the oxygen deficit per min produced due to time delay of $\dot{V}O_2$ in ILE. The value was around 200 ml/min. Slower response in DLE30 would be compensated by debt-$\dot{V}O_2$.

A slope to estimate ex-$\dot{V}O_2$ was obtained from the relationship between $\dot{V}O_2$ and power output below 50 watts. The slope is equivalent to gain, which is the ratio of power output and $\dot{V}O_2$. It has been reported that the gain in CLE is around 10 ml · min^{-1} · watt^{-1} in the case of moderate exercise, but it increases in the case of heavy or very heavy exercise due to the slow component of $\dot{V}o_2$ or ex-$\dot{V}o_2$, which is an additional increase after a rapid increase at the onset of exercise (Henson *et al.* 1989, Barstow and Mole 1991, Ozyener *et al.* 2001). The obtained slope is close to that reported for moderate CLE. Therefore, the slope would not include ex-$\dot{V}o_2$.

Ex-$\dot{V}o_2$ was greatest in DLE10 out of the three DLE tests. As mentioned in the Introduction, sub-slow-$\dot{V}o_2$, which is the sub-slow component in each MU, is quantitatively small in the early period, resulting in smaller summation. In the later period, the amount of working MUs is small, although sub-ex-$\dot{V}o_2$ is greater due to a gradual increase in ex-$\dot{V}o_2$. This results in smaller summation. Therefore, greatest ex-$\dot{V}o_2$ can be observed in the middle of DLE. However, in the case of a fast rate of decrease in power output, the duration from the start to the end in the sub-slow component becomes short. Since the sub-slow component gradually increases, its summation, i.e. ex-$\dot{V}o_2$, could be small. Furthermore, it should be pointed out that ex-$\dot{V}o_2$ does not exist at a lower output. This means that sub-slow-$\dot{V}o_2$ does not exist in MUs that work at a lower output. At lower output, type I muscle fibers are recruited (Vollestat and Blom 1985). Therefore, it is suggested that there is no sub-slow-$\dot{V}o_2$ in these muscle fibers.

There were differences among $\Delta\dot{V}o_2$ obtained in the three DLE tests from 50 to 15 watts. $\Delta\dot{V}o_2$ includes not only debt-$\dot{V}o_2$ in DLE but also oxygen deficit per min (def-$\dot{V}o_2$) in ILE. As mentioned above, the differences among $\Delta\dot{V}o_2$ in the three DLE tests are derived from debt-$\dot{V}o_2$. The fastest rate of decrease in power output resulted in the greatest debt-$\dot{V}o_2$ and *vice versa*. The greatest debt-$\dot{V}o_2$ would be derived from the large amount of hierarchical release of MUs.

Thus, a faster rate of decrease in power output results in no change in $\dot{V}o_2$ at the onset of DLE, in greater debt-$\dot{V}o_2$ and in smaller ex-$\dot{V}o_2$. These results suggest that $\dot{V}o_2$ is disposed to change in parallel in each motor unit released from the power output or recruited in DLE.

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