| Title | Effects of Rate of Decrease in Power Output in Decrement-Load Exercise on Oxygen Uptake |
|-------|---------------------------------------------------------------------------------------|
| Author(s) | YANO, T.; YUNOKI, T.; MATSUURA, R.; ARIMITSU, T.; KIMURA, T. |
| Citation | Physiological Research, 56, 715-719 |
| Issue Date | 2007 |
| Doc URL | http://hdl.handle.net/2115/51985 |
| Type | article |
| File Information | DLE-Phys-Res.pdf |

Hokkaido University Collection of Scholarly and Academic Papers: HUSCAP
Effects of Rate of Decrease in Power Output in Decrement-Load Exercise on Oxygen Uptake

T. YANO, T. YUNOKI, R. MATSUURA, T. ARIMITSU, T. KIMURA

Laboratory of Exercise Physiology, Graduate School of Education, Hokkaido University, Sapporo, Japan

Received April 28, 2006
Accepted October 6, 2006
On-line available November 6, 2006

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 \(\cdot\) min\(^{-1}\): DLE\(_{10}\), DLE\(_{20}\) and DLE\(_{30}\), 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 DLE\(_{10}\), 9.9±0.7 for DLE\(_{20}\) and 10.2±1.0 ml \(\cdot\) min\(^{-1}\) \(\cdot\) watt\(^{-1}\) for DLE\(_{30}\).

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 DLE\(_{10}\) (189±116 ml \(\cdot\) min\(^{-1}\)) was significantly greater than those for DLE\(_{20}\) and for DLE\(_{30}\) (93±97 and 88±34 ml \(\cdot\) 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 DLE\(_{30}\) and smallest in DLE\(_{10}\). 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 DLE\(_{10}\), 413±136 for DLE\(_{20}\) and 483±187 ml \(\cdot\) min\(^{-1}\) for DLE\(_{30}\). 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...
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, Ozynener 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·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 · 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.
Oxygen uptake (V\(_{O_2}\)), carbon dioxide output (V\(_{CO_2}\)), and ventilation volume (V\(_E\)) 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 \(\cdot\) 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.

The Tukey-Kramer test was used to test for significance in difference among V\(_{O_2}\) levels in the three DLE tests and among peak values of ex-V\(_{O_2}\). The difference between 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 V\(_{O_2}\) kinetics in DLE20 and ILE. V\(_{O_2}\) exponentially increased and then decreased, and the rate of decrease was diminished at low power output. At the same power output, V\(_{O_2}\) in DLE was higher than that in ILE. V\(_{O_2}\) in ILE showed a delay in response to the power output.

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

Figure 3 shows values of ex-V\(_{O_2}\). Ex-V\(_{O_2}\) was greatest in DLE10 and lowest in DLE30. The average peak value for DLE10 (189\(\pm\)116 ml \(\cdot\) min\(^{-1}\)) was significantly greater than those for DLE20 and for DLE30 (93\(\pm\)97 and 88\(\pm\)34 ml \(\cdot\) min\(^{-1}\)). It appeared that there is no ex-V\(_{O_2}\) in DLE30. In DLE10, ex-V\(_{O_2}\) gradually increased and then decreased until around 50 watts.
Figure 4 shows the difference between $V_{O2}$ in ILE and that in DLE ($\Delta V_{O2}$). Since ex-$V_{O2}$ affects $\Delta V_{O2}$ above 50 watts and $V_{O2}$ at the onset of ILE is delayed, these periods are excluded in the figure. There were significant differences in $\Delta V_{O2}$ among the three DLE tests. At 30 watts, the levels of $\Delta V_{O2}$ were 283±152 for DLE10, 413±136 for DLE20 and 483±187 ml · min$^{-1}$ for DLE30.

**Discussion**

There were no differences in $V_{O2}$ at the onset of exercise among the three DLE tests. $V_{O2}$ exponentially increases toward the target level related to the power output. $V_{O2}$ in DLE is continuously modified towards the target level in response to decreased power output. As a result, $V_{O2}$ 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 $V_{O2}$ 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-$V_{O2}$.

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 $V_{O2}$ and power output (Henson et al. 1989). The difference between $\Delta V_{O2}$ in DLE10 and that in DLE30 at power output below 50 watts is derived from debt-$V_{O2}$. This difference does not include the oxygen deficit per min produced due to time delay of $V_{O2}$ in ILE. The value was around 200 ml/min. Slower response in DLE30 would be compensated by debt-$V_{O2}$.

A slope to estimate ex-$V_{O2}$ was obtained from the relationship between $V_{O2}$ and power output below 50 watts. The slope is equivalent to gain, which is the ratio of power output and $V_{O2}$. 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 $\text{VO}_2$ or ex-$\text{VO}_2$, 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-$\text{VO}_2$.

Ex-$\text{VO}_2$ was greatest in DLE10 out of the three DLE tests. As mentioned in the Introduction, sub-slow-$\text{VO}_2$, 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-$\text{VO}_2$ is greater due to a gradual increase in ex-$\text{VO}_2$. This results in smaller summation. Therefore, greatest ex-$\text{VO}_2$ 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-$\text{VO}_2$, could be small. Furthermore, it should be pointed out that ex-$\text{VO}_2$ does not exist at a lower output. This means that sub-slow-$\text{VO}_2$ 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-$\text{VO}_2$ in these muscle fibers.

There were differences among $\Delta\text{VO}_2$ obtained in the three DLE tests from 50 to 15 watts. $\Delta\text{VO}_2$ includes not only debt-$\text{VO}_2$ in DLE but also oxygen deficit per min (def-$\text{VO}_2$) in ILE. As mentioned above, the differences among $\Delta\text{VO}_2$ in the three DLE tests are derived from debt-$\text{VO}_2$. The fastest rate of decrease in power output resulted in the greatest debt-$\text{VO}_2$ and vice versa. The greatest debt-$\text{VO}_2$ 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 $\text{VO}_2$ at the onset of DLE, in greater debt-$\text{VO}_2$ and in smaller ex-$\text{VO}_2$. These results suggest that $\text{VO}_2$ is disposed to change in parallel in each motor unit released from the power output or recruited in DLE.

References

BARSTOW TJ, MOLE PA: Linear and nonlinear characteristics of oxygen uptake kinetics during heavy exercise. J Appl Physiol 71: 2099-2106, 1991.

DE DUCA CJ, LEFEVER RS, MCCUE MP, XENAKIS AP: Behavior of human motor units in different muscles during linearly varying contractions. J Physiol Lond 329: 113-128, 1982.

HENSON LC, POOLE DC, WHIPP BJ: Fitness as a determinant of oxygen uptake response to constant-load exercise. Eur J Appl Physiol 59: 21-28, 1989.

HORIUCHI M, YANO T: Effect of prolonged exercise on pulmonary gas exchange during decremental-load exercise. Adv Exerc Sports Physiol 3: 23-28, 1997.

OZYENER F, ROSSITER HB, WARD SA, WHIPP BJ: Influence of exercise intensity on the on- and off-transient kinetics of pulmonary oxygen uptake in humans. J Physiol Lond 533: 891-902, 2001.

VOLLESTAT NK, BLOM PCS: Effect of varying exercise intensity on glycogen depletion in human muscle fibers. Acta Physiol Scand 125: 357-405, 1985.

WHIPP BJ, WARD SA, PATERSON DA: Dynamic asymmetries of ventilation and pulmonary gas exchange during on- and off-transients of heavy exercise in humans. In: Control of Breathing and Its Modeling Perspective, HONDA Y, MIYAMOTO Y, KONNO K, WIDDICOMBE JG (eds), Plenum Press, New York, 1992, pp 237-243.

YANO T, YUNOKI T, OGATA H: Relationship in simulation between oxygen deficit and oxygen uptake in decrement-load exercise starting from low exercise intensity. J Physiol Anthropol 22: 1-5, 2003.

YANO T, YUNOKI T, MATSUURA R, OGATA H: Effect of exercise intensity on the slow component of oxygen uptake in decremental work load exercise. J Physiol Pharmacol 55: 315-324, 2004.

YANO T, OGATA H, MATSUURA R: Comparison of oxygen uptake at the onset of decrement-load and constant-load exercise. Physiol Res 56: 169-174, 2007.

Corresponding author

T. Yano, Laboratory of Exercise Physiology, Graduate School of Education, Hokkaido University, Nishi-7, Kita-11, Kita-ku, Sapporo 060-0811, Japan. Fax: 011-706-5090. E-mail: yano@edu.hokudai.ac.jp