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Effect of Prolonged Exercise on Pulmonary Gas Exchange during Decremental-Load Exercise.

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Abstract

HORIUCHI, M. and YANO, T. Effect of Prolonged Exercise on Pulmonary Gas Exchange during Decremental-Load Exercise. Adv. Exerc. Physiol., Vol.3, No.1 pp.23-28, 1997. The effects of prolonged exercise on pulmonary gas exchange during decremental-load exercise were investigated. Eight healthy male subjects participated in two experiments. In the first experiment, maximal incremental-load exercise (ILE) was used to determine the maximal work rate and peak oxygen uptake (peak VO₂). In the second experiment, subjects exercised for one hour following a first decremental-load exercise (DLE1) starting from the maximal work rate determined by the first experiment and then again following a second decremental-load exercise (DLE2). VO₂ measured every ten minutes during the prolonged exercise, was around 50% of the peak value at 10 min, increasing to around 60% at 60 min. Total VO₂, the sum of VO₂ uptake (V̇O₂) from the start to the end of the exercise, was significantly lower during DLE2 than DLE1. Total CO₂, the sum of CO₂ output (V̇CO₂) was significantly lower during DLE2 than DLE1. Although V̇CO₂ tended to be lower during DLE2 than DLE1 at almost all work rates, this difference was only significant at high work rates. The results for VO₂ and V̇CO₂ suggested a smaller increase in lactate during exercise. Furthermore, we consider this exercise a useful tool because the kinetics of other pulmonary gas exchanges are involved (6).

Although there have been many studies on the biochemistry and circulation of pulmonary gas exchange during prolonged exercise (1, 4, 9), few have examined the kinetics of pulmonary gas exchange (10, 11). This is because pulmonary gas exchange changes more in the early stage of prolonged steady state exercise than in the later stage. Prolonged decremental-load exercise can provide new insights into pulmonary gas exchange. However if the duration of the decrease in the work rate is too long, distinguishable changes in the pulmonary gas exchange become vague.

To avoid this, in the present study, decremental-load exercises were carried out before and after prolonged exercise, and the kinetics of pulmonary gas exchange between the two compared.

Methods

1. Subjects

The subjects included eight healthy male college students, three undergraduates and five post-graduates. All the subjects were untrained, but familiar with the ergometer in our laboratory. Consent was obtained after explaining the purpose of the experiment, the procedure, and possible risks. The physical characteristics of each subject are shown in Table 1.

2. Loaded experiments

Exercise was performed using a bicycle ergometer (Combi) at 50 rpm. In the first experiment, incremental-load exercise (ILE) was carried out to determine the maximal work rate and peak oxygen uptake (peak VO₂). In the second experiment, each subject performed prolonged exercise for one hour following the first decremental-load exercise (DLE1) and then again following the second decremental-load exercise (DLE2).
In the first experiment, each subject exercised on the ergometer for four minutes at 0 watt after five-minutes rest. This was followed by incremental-load exercise of 15 watts/min until exhaustion.

One week later, the second experiment was carried out. Each subject exercised on the ergometer for four minutes at 0 watt after five-minutes rest. This was followed by a decremental-load exercise of 15 watts/min from the maximal work rate determined by the first experiment. Then, after a sitting rest of twenty minutes, subjects performed prolonged exercise for one hour at a work rate of 50% of the peak VO₂ obtained from the first experiment. The subjects were again rested, this time for thirty minutes, and after O₂ uptake and heart rate had recovered to resting levels, performed DLE2 (the same procedure as for DLE1). In total, the second experiment took 155 - 163 min. (Table 1 and Fig. 1).

3. Measurements

Expired gas was analyzed during rest and exercise in a mixing chamber with a capacity of six liters. The volume of expired gas was measured with a respiratory flow meter (Minato Medical Science: RF-H). O₂ and CO₂ fractions were measured with an expired gas monitor (NEC-Sanei: 1H-21A). These

Table 1 Physical characteristics and aerobic work capacity of the subjects

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Peak VO₂ (ℓ/min)</th>
<th>Work max (watts)</th>
<th>Time in incremental and decremental-load exercise (min)</th>
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<tr>
<td>K.F</td>
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<td>62.4</td>
<td>2.49</td>
<td>260</td>
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<tr>
<td>T.H</td>
<td>26</td>
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<td>69.0</td>
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</tr>
<tr>
<td>M.H</td>
<td>29</td>
<td>174.0</td>
<td>68.0</td>
<td>3.51</td>
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<td>20.00</td>
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<tr>
<td>N.M</td>
<td>26</td>
<td>168.2</td>
<td>63.5</td>
<td>2.62</td>
<td>240</td>
<td>16.00</td>
</tr>
<tr>
<td>S.O</td>
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<td>64.6</td>
<td>2.60</td>
<td>245</td>
<td>16.33</td>
</tr>
<tr>
<td>T.Y</td>
<td>25</td>
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<td>59.5</td>
<td>2.50</td>
<td>240</td>
<td>16.00</td>
</tr>
<tr>
<td>K.N</td>
<td>25</td>
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<td>61.5</td>
<td>2.86</td>
<td>260</td>
<td>17.33</td>
</tr>
<tr>
<td>S.M</td>
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<td>65.9</td>
<td>2.31</td>
<td>240</td>
<td>16.00</td>
</tr>
<tr>
<td>mean</td>
<td>± 2.1</td>
<td>± 5.9</td>
<td>± 3.2</td>
<td>± 0.39</td>
<td>± 21</td>
<td>± 1.39</td>
</tr>
</tbody>
</table>

First experiment

Exhaustion

ILE

Rest: 5min
VO₂
5min
4min

Second experiment

Maximal work rate

Work rate of 50% peak VO₂

DLE 1

Prolonged exercise

20min
80min
30min
4min

DLE 2

Rest: 5min
VO₂
5min
4min

Fig. 1 Protocol of the experiment.
values were transmitted through an AD converter into a personal computer (NEC: PC 9801m), allowing continuous measurement of O₂ uptake (V̇O₂), CO₂ output (V̇CO₂), respiratory gas exchange ratio (RER) and ventilation (V̇E) every 20 seconds during ILE and DLE. During the one hour of prolonged exercise, expired gas was also analyzed every 20 seconds at 9–10, 19–20, 29–30, 39–40, 49–50, and 59–60 min. The expired gas monitor was checked by known gases before and after the experiments.

Heart rate (HR) was measured by a heart rate monitor (Cannon: Vantage XL) during experiments.

4. Statistics and management of values

The paired Student's t-test was used and differences at levels of 5%, 1%, and 0.1% were considered significant. Total volumes of V̇O₂ and V̇CO₂ from the beginning to the end of the exercise (not including the first four minutes at a work rate of 0 watt) were expressed as total VO₂ and total VCO₂. The relationship between VO₂ and work rate was approximated by a single regression line.

Results

Work rate at exhaustion in ILE ranged from 240 to 300 watts and performance time in ILE and DLE from 16 to 20 min. (Table 1). V̇O₂ measured every ten minutes during prolonged exercise was around 50% of peak V̇O₂ at 10 min, increasing to around 60% at 60 min. RER significantly decreased from 0.88±0.09 (mean±SD) at 10 min to 0.80±0.06 at 60 min in the prolonged exercise.

Levels of VO₂ corresponding to the work rate in the incremental and the two decremental exercises of one representative subject are shown in Fig. 2 (the time course in decremental-load exercise proceeds from right to left while that in ILE proceeds from left to right). VO₂ in ILE linearly increased except during of the beginning and end of the exercise.

In decremental-load exercise, VO₂ increased rapidly, reaching a peak within 1–2 minutes, then plateaued and later decreased. VO₂ corresponding to the work rate minus the increasing and plateau phase during decremental-load exercise was approximated by a single regression line. Its slope (ΔVO₂/ΔW) was 9.34±0.70 l/min/watts in ILE. The ΔVO₂/ΔW was 10.54±0.81 l/min/watts in DLE1 and 10.08±1.03 l/min/watts in DLE2. The ΔVO₂/ΔW in DLE1 and DLE2 were significantly higher than that in ILE (p<0.05). VO₂ tended to be lower in DLE2 than in DLE1, but the difference was not significant. Total VO₂, the sum of VO₂ from the beginning to the end of exercise, was 24.9±5.9 l in ILE. Total VO₂ was decreased in DLE2 compared to DLE1 in six subjects and almost the same in two subjects. Total VO₂ values in DLE1 and DLE2 were 29.4±4.6 l and 28.1±5.0 l, respectively. Total VO₂ values were significantly higher in DLE1 and DLE2 than ILE (p<0.05), and lower in DLE2 than DLE1 (p<0.05).

VCO₂ in decremental-load exercise increased rapidly, reaching a peak within 2–3 minutes, and then decreased (Fig. 3: the subject is the same as in Fig. 2). As VCO₂ appeared to be lower in DLE2 than in DLE1, the VCO₂ values were compared at all work rates. It was found that VCO₂ was significantly lower in DLE2 than DLE1 from 105 to 230 watts with exceptions for 140, 145, and 225 watts (p<0.05, p<0.01 and p<0.001, respectively). Total VCO₂, the sum of VCO₂ from the beginning to the end of DLE1 and DLE2, was 29.9±2.7 l and 26.9±3.0 l, respectively. Total VCO₂ was significantly lower in DLE2 than DLE1 (p<0.01).

V̇E in decremental-load exercise increased rapidly within a few minutes of exercise, reached a peak at 3–5 minutes, and then decreased (Fig. 4: the subject is the same as in Fig. 2). The V̇E level in DLE2 in six subjects was higher than that in DLE1 for the first three minutes of exercise, but the level decreased after 3 min. In two subjects, V̇E was higher in DLE1 than DLE2. No significant differences were found between DLE1 and DLE2.

V̇E/VCO₂ in decremental-load exercise decreased rapidly within the first 1–2 minutes of exercise and then increased (Fig. 5: the subject is the same as in Fig. 2). Although V̇E/VCO₂ during the decrease and increase phases appeared to be higher
in DLE2 than DLE1, significant differences were only found from 185 to 235 watts with an exception for 200 watts (p<0.05 and p<0.01).

Discussion
In the present study, subjects exercised for one hour following the first decremental-load exercise and then again following the second decremental-load exercise. The kinetics of pulmonary gas exchange were compared between DLE1 and DLE2. It was found that total VCO₂, the sum of VCO₂ from the beginning to the end of exercise, decreased from DLE1 to DLE2. This could be due to a decrease in VCO₂ at a higher work rate. While total VO₂ significantly decreased from DLE1 to DLE2, VO₂ did not differ at any work rate. This suggests that prolonged exercise affects VO₂ at the overall work rate, but not at any specific work rate. Moreover, \( \frac{V_{E}}{V_{CO₂}} \) in DLE2 increased at higher work rates.

Lactate was thought to increase from the beginning of decremental-load exercise, since in the present study this exercise was performed at the maximal work rate determined by the ILE. It has been reported that when high-intensity, prolonged exercises were repeated several times, the peak blood lactate level decreased during exercise at higher work rates (1). This increase in lactate is partly buffered by a rightward shift of the bicarbonate system, \( H^+ + HCO₃^- \rightleftharpoons H₂O + CO₂ \) (8). Elimination of the shifted CO₂ by lung ventilation, results in an excessive expiration of CO₂. Yano et al. (21) observed excess CO₂ expiration associated with an increase in the blood lactate level during incremental-load exercise at a high work rate. This indicates that lactate kinetics can be estimated from CO₂ kinetics. Therefore, in the present study, it is suggested that the increase in the lactate level at higher work rates is lower during DLE2 than DLE1.

The lactate concentration in the blood is regulated by a balance between production and oxidation of lactates (15). We next discuss the lactic oxidation based on the kinetics of VO₂.

Whipp et al. (18) reported that the changing rate of VO₂ corresponding to the work rate \( \frac{\Delta VO₂}{\Delta W} \) was higher in decremental than incremental-load exercise, as was VO₂ at the same work rate. Horiuchi et al. (6) confirmed that VO₂ was significantly higher.
in decremental than incremental-load exercise, as was the total VO₂ obtained by summing VO₂ during exercise. It was suggested that total VO₂ is higher in decremental-load exercise due to the repayment of the O₂ deficit produced at the early phase.

The respiratory quotient (RQ) is known to generally decrease during prolonged exercise(4). This is due to not an increase of VCO₂ but an increase in ATPO₂ because O₂ is needed more for the production of ATP in fatty turnover than in carbohydrate turnover(5). However, as the increase in the lactate level observed at higher work rates restrains fatty mobilization(13), the effect of the fatty metabolism may be less on O₂ uptake during DLE2.

The kinetics of VO₂ and VCO₂ suggest that the lactate level is lower in DLE2 than in DLE1 at higher work rates, and therefore, the repayment of the O₂ deficit would decrease in DLE2.

Thus, the increase of the CO₂ derived from the energy metabolism and buffer of lactic acid during exercise must be expired by an increase of pulmonary ventilation. The relationship between VCO₂ and VSCO₂ should be discussed.

VSCO₂/VCO₂ has been reported to be higher under conditions of depleted muscle glycogen due to diet control and exercise than under normal conditions(5, 7). In the present study, the muscle glycogen might have been depleted immediately before DLE2 by the lactate production during DLE1 because the subjects started from the maximal work rate determined by ILE. Since decremental-load exercise and prolonged exercise were performed aerobically, these exercises would also have affected the value of muscle glycogen. The results of previous studies(5, 7), therefore, suggest that the increase in VSCO₂/VCO₂ in the present study is related to the depletion of muscle glycogen.

A depletion of muscle glycogen is known to lead to a lower blood lactate level during exercise(5, 7, 14). Generally, a change in the lactate level affects pulmonary ventilation, and excess CO₂ is expected to be expired by hyperventilation(16). Thus the decrease of CO₂ in the present study may have been accompanied by a decrease in hyperventilation. However, this was not confirmed by the present results. Therefore, other factors must relate to the output of excess CO₂, as Whipp et al.(17) and Casaburi et al.(3) have already suggested.

Nakamura et al. (12) suggested that the bicarbonate system in venous blood affects the output of excess CO₂. That is, in this buffer, HCO₃⁻ shifts to CO₂ and the fractions of CO₂ increase. The difference in CO₂ fractions between pulmonary and venous blood increases and may result in excess CO₂ being expired. However, the kinetics of mixed venous CO₂ pressure are reported to be unaffected by an increase in the lactate level in both incremental-load and constant-load exercise (19, 20).

In conclusion, after prolonged exercise, pulmonary gas exchange kinetics during decremental-load exercise changed as follows; total O₂ uptake and CO₂ output decreased, the ventilatory equivalent for CO₂ at a higher work rate increased. The mechanism by which excess CO₂ is removed without increasing pulmonary ventilation remains to be elucidated.

References
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