Accumulated O₂ Deficit during Intense Exercise and Muscle Characteristics of Elite Athletes

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Abstract

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The accumulated O₂ deficit (the difference between the estimated energy demand and the actual O₂ uptake) was determined during intense exhaustive exercise (2–7 min) in elite athletes, and its relationship with muscle buffer capacity, muscle enzymes and muscle morphology was examined. Five oarsmen, fifteen soccer players, and fourteen distance runners ran, and three sprint cyclists cycled intensely to exhaustion (2–7 min). The oarsmen also performed exhaustive rowing. Blood lactate was measured immediately after several submaximal exercise bouts. A muscle biopsy was taken at rest from m. gastrocnemius of the soccer players and runners, and from m. vastus lateralis of the cyclists. The accumulated O₂ deficit for the oarsmen, soccer players and runners during treadmill running was 47.3 (range: 29.6–62.4), 49.5 (34.3–73.7) and 51.9 (26.5–85.5) ml O₂ equivalents (“O₂-Eq.” kg⁻¹ b.w., respectively, and it was 56.5 (47.5–73.2) ml “O₂-Eq.” kg⁻¹ for the cyclists during cycling. The O₂ deficit was not related to blood lactate during submaximal exercise, muscle enzyme activity (citrate synthase, 3-hydroxyacyl-CoA-dehydrogenase, lactate dehydrogenase), number of muscle capillaries, %ST fibres or muscle buffer capacity. The accumulated O₂ deficit was 36% higher (p < 0.05) during rowing compared to running. The present data suggest that the anaerobic energy production during intense exercise is related to the muscle mass involved. However, it appears that the anaerobic energy turnover is not determined by muscle fibre type distribution, muscle buffer capacity or muscle endurance capacity.

Key words

O₂ deficit, anaerobic energy production, muscle mass, muscle buffer capacity, muscle enzymes, muscle capillaries, intense exercise

Introduction

Anaerobic energy production, consisting of creatine phosphate (CP) and adenosine triphosphate (ATP) breakdown and glycolytic activity with formation of lactate, is essential in many sports. Therefore, it is important to obtain information about the anaerobic capacity of athletes in such sports. Since Krogh and Lindhard (20) introduced the concept of O₂ deficit, determined as the difference between energy demand and actual O₂ uptake during exercise, it has been used frequently as an expression of the anaerobic energy yield (14, 15, 18, 21). In a recent study, Medbø et al. (26) systematically investigated the O₂ deficit method, and proposed that if the exercise time was between 2 and 16 min, the O₂ deficit during exhaustive exercise represented the anaerobic capacity. Its validity is supported by the finding of a close relationship between the O₂ deficit and the anaerobic energy production during intense exhaustive exercise for a single muscle group (4).

Since the study by Medbø et al. (26) a modified procedure has been used to determine the accumulated O₂ deficit for trained and untrained subjects (25, 27, 33). However, the number of data on top class athletes is small, and it is unclear how the O₂ deficit is associated with muscle variables, such as muscle buffer capacity and fibre type distribution, which might be related to the anaerobic energy production (28, 35). With endurance training the muscle oxidative potential, number of capillaries and lactate turnover are elevated (9, 10, 13, 24, 32). These changes may affect lactate production, and it has been suggested that the muscle respiratory capacity influences the rate of fatigue development during intense exercise (8, 16). However, it is uncertain how the oxidative potential of the muscles is linked to the anaerobic energy production during exhaustive exercise.

The aim of the present study was to evaluate the O₂ deficit of top class athletes in different sports when performing various types of whole body exhaustive exercise. It was further assessed whether or not the accumulated O₂ deficit was related to muscle characteristics which have been associated with anaerobic energy production or endurance capacity.

Methods

Subjects

Thirty-seven male athletes of national and international calibre (distance runners [n = 14], soccer players [n = 15], oarsmen [n = 5], and sprint cyclists [n = 3]) were studied during their competitive season. The physical and athletic characteristics of these men are presented in Table 1. The subjects were fully informed of any risks and discomfort associated with

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Table 1 Physical and athletic characteristics of the subjects.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Weight kg</th>
<th>Height cm</th>
<th>VO_{2max} ml·min^{-1}·kg^{-1}</th>
<th>Athletic characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soccer players</td>
<td>24</td>
<td>79.6</td>
<td>182</td>
<td>80.8* (22.3–76.1)</td>
<td>Players from the best league in Denmark</td>
</tr>
<tr>
<td>(n = 15)</td>
<td>(18–38)</td>
<td>(57.5–96.5)</td>
<td>(168–195)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runners</td>
<td>25</td>
<td>69.9</td>
<td>184</td>
<td>72.5+ (68.4–79.5)</td>
<td>Distance mean range (n) mincs</td>
</tr>
<tr>
<td>(n = 14)</td>
<td>(18–32)</td>
<td>(61.6–78.8)</td>
<td>(175–192)</td>
<td>800 m: 1:53, 1:49–1:56 (6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1500 m: 3:52, 3:35–4:03 (9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10000 m: 30:20, 28:40–31:45 (12)</td>
<td></td>
</tr>
<tr>
<td>Carssen</td>
<td>26</td>
<td>77.2</td>
<td>181</td>
<td>55.7 (61.7–67.8)</td>
<td>Second in the World Championship (light weight)</td>
</tr>
<tr>
<td>(n = 5)</td>
<td>(24–30)</td>
<td>(72.5–81.9)</td>
<td>(175–188)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclists</td>
<td>23</td>
<td>79.8</td>
<td>180</td>
<td>62.4* (58.0–65.1)</td>
<td>Sprint: 1st, 3rd and 4th in Denmark</td>
</tr>
<tr>
<td>(n = 3)</td>
<td>(22–24)</td>
<td>(77.7–82.0)</td>
<td>(177–192)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means and range are given
* Significant (p < 0.05) difference between soccer players and runners
+ Significant (p < 0.05) difference between runners and carssen
* Significant (p < 0.05) difference between runners and cyclists

The experiment before giving their informed consent to participate. The study was approved by the local ethics committee.

Procedures

Each subject performed two tests separated by at least two days. The runners, soccer players, and carssen ran on a treadmill with the running surface at a + 5% grade, while the cyclists were evaluated on a cycle ergometer. The carssen were also tested on a rowing ergometer. Prior to the tests the subjects were familiarized with the equipment and procedures. In the first test the subjects performed several 6 min submaximal exercise bouts separated by rest periods of progressively increasing duration (2–10 min). The starting work rate corresponded to an O_2 uptake (VO_2) of about 50% of individual maximal VO_2 (VO_{2max}), and power output was stepwise increased until the subject was unable to complete 6 min at that power output (6–10 periods). In the second test a 10 min warming-up period at a work rate corresponding to 50% of VO_{2max} was followed by 5 min of rest. Subsequently, the subject performed exhaustive exercise at a work rate corresponding to 120–140% of the power output required to elicit VO_{2max}. When tested on a rowing ergometer, the carssen completed 6 min exhaustive rowing twice on separate days. On one day the exercise was performed with a constant rowing frequency until the last minute of the test, while on another day a free rowing frequency was employed. The total work performed, the VO_2 and the accumulated O_2 deficit were the same for the two exhaustive rowing bouts, and the mean values were used.

In each protocol expired air was collected in Douglas bags, and VO_2 was determined from two bags during the last two minutes of the submaximal exercise bouts and continuously during the exhaustive exercise. There were no systematic differences between VO_2 determined from the two bags at submaximal work rates. The highest VO_2 during the exhaustive exercise was termed "peak VO_2". Before exercise a teflon catheter was inserted percutaneously into an antecubital vein. Blood samples for lactate analysis were obtained immediately after the submaximal exercises. In addition, blood samples were collected from all subjects, except for the carssen, at two minute intervals during the first ten minutes of recovery from the exhaustive exercise. The highest blood lactate concentration after the exhaustive exercise was defined as "peak lactate". A biopsy was taken at rest from m. vastus lateralis of the cyclists and from m. gastrocnemius of the soccer players and six of the runners.

Analyses

The volume of the collected expired gas was measured with a Tissot spirometer. Oxygen and carbon dioxide concentrations were determined with paramagnetic O_2 (Servomex) and infrared CO_2 (Beckman LB-II) analysers, respectively. These analyses were regularly calibrated with known gas concentrations, which were determined by the Scholander technique and spanned the range of expired O_2 and CO_2. Each blood sample (0.2 ml) was immediately added to 1 ml of 0.6 M perchloric acid and stored on ice until centrifuged. The supernatant fluid was analysed spectrophotometrically for lactate (22).

Muscle biopsies

Muscle biopsies were dissected into two parts. One piece was frozen directly in liquid N_2 and used for biochemical analyses. The remaining part was mounted in an embedding medium for histochemical analysis and frozen in isopentane cooled to its freezing point.

Biochemical analysis

The muscle samples were freeze-dried and blood, fat, and connective tissue were dissected and discarded. A portion of the fibre fragments was homogenized in a solution containing 145 mM KCl, 10 mM NaCl, and 5 mM isocitric acid adjusted to pH 7.0. The muscle buffer capacity was determined by a titration procedure previously described (28). The buffer capacity was calculated as the number of moles of H^+ required to change the pH from 7.0 to 6.0 per g of dry weight tissue (μmol·g^{-1}·d.w.·pH^{-1}). The obtained value was con-
Fig. 1 Oxygen uptake (VO₂) during submaximal running and peak VO₂ during intense exhaustive running for soccer players (x), runners (○) and oarsmen (v). Means ± SEM are given.
* Significant (p < 0.05) difference between soccer players and runners
$ Significant (p < 0.05) difference between soccer players and oarsmen
$ Significant (p < 0.05) difference between runners and oarsmen

Oxygen uptake (VO₂) was determined by titrating back to 7.0 with 0.01 M NaOH. The remaining portion of the fibre fragments was homogenized in a 1:400 solution in an ice-chilled 0.3 M phosphate buffer and containing 0.5 mg ml⁻¹ of bovine serum albumin adjusted to pH 7.7. Citrate synthase (CS), 3-hydroxyacyl-CoA dehydrogenase (HAD) and lactate dehydrogenase (LDH; pyruvate to lactate) were determined by using fluorometric methods with NAD-NADP coupled reactions as described by Essén-Gustavsson and Henriksson (11) and Karlsson et al. (19).

Histochemical analyses

Serial cross-sections (10μm) were cut and stained for myofibrillar ATPase after alkaline and acid preincubation (6) for classification of fibre types and determinations of fibre type area. Subsequent sections were stained with the amylase-PAS method to visualize capillaries (1).

Calculations

An individual linear relationship between power output and VO₂ was determined for each subject based on the measurements from the submaximal exercises on the first test. In this relationship the VO₂ obtained at the lowest and highest individual submaximal work rate were excluded, and a value was not used if VO₂ was more than 3 ml·min⁻¹·kg⁻¹ lower or higher than VO₂ at the preceding or following work rate, respectively (i.e. classified as deviant). The mean number of deviant values was 1.1 per 100 submaximal measurements.

Fig. 2 Blood lactate immediately after submaximal and intense exhaustive running for soccer players (x), runners (○) and oarsmen (v). Means ± SEM are given.
* Significant (p < 0.05) difference between soccer players and runners
$ Significant (p < 0.05) difference between soccer players and oarsmen
$ Significant (p < 0.05) difference between runners and oarsmen

By extrapolating the individual linear relationship of power and VO₂, the energy demand for the exhaustive exercise was estimated and expressed in O₂ equivalents ("O₂-Eq"). The accumulated O₂ deficit was determined as the difference between the total energy demand and the actual volume of O₂ consumed during the exhaustive exercise.

Statistics

Differences between groups were determined by Mann-Whitney’s test for unpaired data, and differences between values obtained during treadmill running and rowing for the oarsmen were evaluated by the Wilcoxon ranking test for paired data (Pratt’s modification, 34). A standard procedure was used for correlation analysis (34). A significance level of 0.05 was chosen.

Results

VO₂ during submaximal running was similar for the soccer players, runners, and oarsmen (Fig. 1). The lowest blood lactate concentrations, on the other hand, were found in the runners followed by the oarsmen with the soccer players displaying the highest values (Fig. 2).
Table 2 Work rate, exercise time, energy demand, initial VO₂ (0–45 s) and peak VO₂ during the exhaustive exercise, and accumulated O₂ deficit.

<table>
<thead>
<tr>
<th></th>
<th>Work rate</th>
<th>Exercise time</th>
<th>Energy demand</th>
<th>VO₂</th>
<th>O₂ deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km·h⁻¹</td>
<td>min</td>
<td>ml·O₂-Eq⁻¹·min⁻¹·kg⁻¹</td>
<td>0–45 s</td>
<td>peak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ml·kg⁻¹·min⁻¹</td>
<td>ml·O₂-Eq⁻¹·kg⁻¹</td>
</tr>
<tr>
<td>Treadmill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soccer players</td>
<td>16.17*</td>
<td>3.42</td>
<td>65.5*</td>
<td>35.6*</td>
<td>58.1*</td>
</tr>
<tr>
<td>(n = 15)</td>
<td>±0.24</td>
<td>±0.21</td>
<td>±1.7</td>
<td>±1.2</td>
<td>±1.2</td>
</tr>
<tr>
<td>Runners</td>
<td>19.19*</td>
<td>3.01</td>
<td>78.1*</td>
<td>40.8</td>
<td>69.6</td>
</tr>
<tr>
<td>(n = 14)</td>
<td>±0.23</td>
<td>±0.16</td>
<td>±1.3</td>
<td>±0.8</td>
<td>±1.2</td>
</tr>
<tr>
<td>Oarsmen</td>
<td>16.17</td>
<td>4.05</td>
<td>69.0</td>
<td>35.6</td>
<td>64.5</td>
</tr>
<tr>
<td>(n = 5)</td>
<td>±0.19</td>
<td>±0.50</td>
<td>±1.4</td>
<td>±1.0</td>
<td>±1.0</td>
</tr>
<tr>
<td>Rowing ergometer</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oarsmen</td>
<td>326</td>
<td>6.00</td>
<td>66.4</td>
<td>37.8</td>
<td>61.1</td>
</tr>
<tr>
<td>(n = 9)</td>
<td>±0.00</td>
<td>±0.00</td>
<td>±1.7</td>
<td>±1.8</td>
<td>±1.4</td>
</tr>
<tr>
<td>Cycle ergometer</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclists</td>
<td>430</td>
<td>2.98</td>
<td>73.9</td>
<td>38.2</td>
<td>62.4</td>
</tr>
<tr>
<td>(n = 3)</td>
<td>±11</td>
<td>±0.13</td>
<td>±5.6</td>
<td>±3.8</td>
<td>±2.2</td>
</tr>
</tbody>
</table>

Means ± SEM are given
* Significant (p < 0.05) difference between soccer players and runners
§ Significant (p < 0.05) difference between soccer players and oarsmen (treadmill running)
* Significant (p < 0.05) difference between runners and oarsmen (treadmill running)
+ Significant (p < 0.05) difference between oarsmen (treadmill running) and oarsmen (rowing ergometer)

The estimated energy demand for the runners was higher (p < 0.05) than for the soccer players and oarsmen as a result of the higher speed during the exhaustive running (78.1, 65.5 and 69.0 ml “O₂-Eq⁻¹·min⁻¹·kg⁻¹” b.w., respectively) (Table 2). The energy demand was 73.9 ml “O₂-Eq⁻¹·min⁻¹·kg⁻¹” for the cyclists during exhaustive cycling and 64.6 ml “O₂-Eq⁻¹·min⁻¹·kg⁻¹” for the oarsmen during exhaustive rowing (Table 2). Initial and peak VO₂ during the exhaustive treadmill running were higher (p < 0.05) for the runners than for the soccer players and oarsmen. For the oarsmen VO₂ during the intense rowing was similar to that of the treadmill running (Table 2).

The accumulated O₂ deficit for the runners, soccer players and oarsmen during treadmill running was 51.9 (range: 26.5–85.5), 49.5 (34.3–73.7) and 47.3 (29.6–62.4) ml “O₂-Eq⁻¹·kg⁻¹” b.w., respectively, while it was 56.5 (47.5–73.2) ml “O₂-Eq⁻¹·kg⁻¹” for the cyclists during cycling (Table 2). Higher (p < 0.05) values (64.1 [58.9–81.2] ml “O₂-Eq⁻¹·kg⁻¹”) were found for the oarsmen when rowing was compared to running.

While the groups were not different in the accumulated O₂ deficit, the peak blood lactate concentration after the exhaustive treadmill running was lower (p < 0.05) for the runners (10.7 mmol·l⁻¹) than for soccer players and cyclists (12.9 and 12.7 mmol·l⁻¹, respectively) (Fig. 3). No relationship was found between the accumulated O₂ deficit during the exhaustive exercise and peak lactate (Fig. 4).

When compared to the soccer players and cyclists, the runners had a greater percentage of slow twitch (94ST) fibres, larger activities of HAD and CS, higher capillary density and a lower LDH activity (p < 0.05; Table 3). The cyclists had a higher number of capillaries than the soccer players (Table 3). The muscle buffer capacity of 210–220 µmol·g⁻¹ d.w. was the same in the three groups (Table 3). None of the muscle variables were related to the accumulated O₂ deficit (Figs. 4 and 5).
Table 3  Fibre type distribution, capillaries, buffer capacity (µmol·g⁻¹ d.w.·pH⁻¹) and enzyme activities (µmol·g⁻¹ d.w.·min⁻¹) in m. vastus lateralis for cyclists and in m. gastrocnemius for soccer players and runners.

<table>
<thead>
<tr>
<th></th>
<th>Fibre type distribution</th>
<th>Capillaries</th>
<th>Buffer capacity</th>
<th>Enzymes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%ST</td>
<td>%FTa</td>
<td>%FTb</td>
<td>Cap·fib⁻¹</td>
</tr>
<tr>
<td>Soccer players</td>
<td>60.2</td>
<td>33.7</td>
<td>6.7</td>
<td>2.26*</td>
</tr>
<tr>
<td>(n = 15)</td>
<td>±2.9</td>
<td>±3.1</td>
<td>±1.5</td>
<td>±0.09</td>
</tr>
<tr>
<td>Runners</td>
<td>78.3#</td>
<td>20.9</td>
<td>0.8</td>
<td>2.82</td>
</tr>
<tr>
<td>(n = 6)</td>
<td>±5.6</td>
<td>±5.8</td>
<td>±0.8</td>
<td>±0.20</td>
</tr>
<tr>
<td>Cyclists</td>
<td>54.0</td>
<td>44.5</td>
<td>1.6</td>
<td>2.96</td>
</tr>
<tr>
<td>(n = 3)</td>
<td>±3.3</td>
<td>±8.5</td>
<td>±0.8</td>
<td>±0.06</td>
</tr>
</tbody>
</table>

Means ± SEM are given
* Significant (p < 0.05) difference between soccer players and runners
# Significant (p < 0.05) difference between runners and cyclists
† Significant (p < 0.05) difference between soccer players and cyclists

Discussion

In the present study the accumulated O₂ deficit during exhaustive exercise was determined for elite athletes in various sports. The duration of the exercise was between 2 and 7 min, which according to Karlsson (18) and Medhe et al. (26), gives a maximal O₂ deficit, proposed to represent the anaerobic capacity (25). Findings from a study involving one-legged exercise support the use of "pulmonary" O₂ deficit as a quantitative measure of anaerobic energy turnover during an exhaustive task (4). A close relationship was found between the leg O₂ deficit and the anaerobic energy production determined from metabolic measurements during intense exhaustive exercise, and the O₂ deficits across the leg and at the lung were similar (4). On the other hand, for the runners in the present study, VO₂ at the highest submaximal running speed was significantly higher (p < 0.05) than the energy demand determined from the linear relationship between work rate and VO₂ based on the measurements obtained at lower treadmill speeds (Fig. 1). Thus the relationship between running speed and energy demand at submaximal work rates may not always be linear. This questions the validity of the estimation of energy demand during supramaximal exercise by a linear extrapolation from submaximal determinations. Consequently, the accumulated O₂ deficit may not be an accurate measure of the anaerobic energy production during intense exercise (3). It appears that further studies examining the energy demand of supramaximal exercise are needed. The following discussion is based on the assumption
that the accumulated $O_2$ deficit represents the anaerobic energy production during the intense exercise.

The mean $O_2$ deficit was similar for runners, soccer players, oarsmen, and sprint cyclists, but a large variation was found within each group. This suggests that a high anaerobic capacity may not be crucial in order to succeed in these sports as all athletes performed at top level. The explanation could be that physical performance is to a high extent determined by the rate of aerobic energy turnover or alternatively that the anaerobic energy production may not be limiting for performance during intense exercise. In other words, the mechanisms causing fatigue will override those regulating the energy supply. In accordance with the findings in the present study, Scott et al. (33) reported a lack of relationship between the accumulated $O_2$ deficit and performance on 400 and 600 m runs.

The muscle buffer capacity has been proposed to be associated with the anaerobic energy production during intense exercise and $%ST$ fibres has been shown to be inversely related to the accumulation and production of lactate during intense exercise (5,28,35). However, in the present study the accumulated $O_2$ deficit was not related to these muscle variables. Thus, it appears that for well-trained subjects neither muscle buffer capacity nor fibre type distribution are dominant factors of the anaerobic energy production during intense exhaustive exercise. It cannot be excluded that the lack of coupling between these variables is due to the biopsied muscle not being representative for the muscles which are active during the intense exercise. However, the present findings are in accordance with observations in other studies. Denis et al. (8) found that the work output during 30 s maximal bicycle exercise was neither related to the muscle buffer capacity nor to $%ST$ fibres, and Nevill et al. (29) reported that the muscle buffer capacity was unaltered after eight weeks of sprint training, although the performance of a 30 s sprint test on a nonmotorized treadmill was improved.

In agreement with findings in other studies (7, 17,32) the runners in the present study had the lowest blood lactate concentrations during submaximal running, the highest $V_O_2$max and level of muscle mitochondrial enzymes and capillaries and further the lowest muscle LDH activity compared to the soccer players and oarsmen. This suggests that the runners had the highest endurance potential (17), and since this did not result in any difference in the accumulated $O_2$ deficit between groups, it appears that the oxidative potential of the muscles is of little importance for the anaerobic capacity. In support of this was the lack of relationship between the accumulated $O_2$ deficit and both muscle enzymes and capillary density. Similarly, Denis et al. (8) found no relationship between mitochondrial enzymes and power output during a 30 s maximal exercise bout.

Blood lactate in recovery from intense exercise may reflect the anaerobic energy production during the exercise (23). In the present study peak lactate was not related to the accumulated $O_2$ deficit, and the runners had lower values than the soccer players and cyclists, although no difference in accumulated $O_2$ deficit was observed between groups. Thus, it appears that blood lactate in recovery from intense exercise was not a sensitive measure of the anaerobic energy production. The lower blood lactate for the endurance trained runners may have been a result of a higher rate of lactate removal (9,10,24).

The highest $O_2$ deficit in the present study of 85.5 ml "O$_2$-Eq"·kg$^{-1}$·h$^{-1}$·b.w. for a European top-class middle distance runner (1500 m: 3 min 35 s) is significantly less than the values estimated from the $O_2$ deficit determined for a single muscle group (mean: 0.5 l "O$_2$-Eq"·kg$^{-1}$·active muscle; 4). This suggests that the accumulated $O_2$ deficit is related to the muscle mass involved in the exercise. It is supported by the finding that the oarsmen obtained higher $O_2$ deficits when rowing than when exercising on treadmill, and further by earlier findings of an elevated $O_2$ deficit when arm exercise was added to leg exercise (2).

The mean values obtained for the elite athletes in the present study were considerably lower than those found by Medbo et al. (range: 52–90 ml "O$_2$-Eq"·kg$^{-1}$·h$^{-1}$·b.w.; 26), when testing untrained and trained individuals. This surprising finding might be due to deviations in the procedures used, e.g. differences in the duration of the submaximal exercise bout (6 vs 10 min) and the slope of the treadmill (5.0 vs 10.5%). In the present study six minute exercise bouts were used in order to obtain measurements at high submaximal intensities. It has been demonstrated that $V_O_2$ at such work rates continues to rise (12,31,36). Thus, by using ten minute exercise bouts ($O_2$ determination between 8 and 10 min), as in the study by Medbo et al. (26), systematically higher $O_2$ are likely to be obtained at high submaximal work rates in comparison to six minute exercise bouts. Consequently, the estimated energy demand during supramaximal exercise would be higher, and so would the accumulated $O_2$ deficit.

Another possible explanation for the difference between the results of the two studies could be the use of a $+10.5\%$ slope in the study by Medbo et al. (26) compared to a $+5\%$ slope in the present study, which was chosen in order to obtain appropriate $V_O_2$ measurements at low speeds. The finding by Olesen (30) of a significantly higher (82%) accumulated $O_2$ deficit when running at a grade of $+15\%$ compared to $+1\%$, and a similar observation by Medbo et al. (25), when comparing two untrained groups at a slope of $+10.5\%$ and $+5.2\%$, suggests that a higher grade of the treadmill causes larger $O_2$ deficits. This difference may be due to the involvement of a larger muscle mass when running at the higher slope. Nevertheless, it appears that the accumulated $O_2$ deficit determination is influenced by the testing procedure used.

In summary, the accumulated $O_2$ deficit during exhaustive running was of a similar magnitude for soccer players, runners and oarsmen during treadmill running and for sprint cyclists during cycling. A large variation of the accumulated $O_2$ deficit was found within each group. The $O_2$ deficit appears to be related to the muscle mass involved in the exercise. The deficit was, however, not associated with the muscle fibre type distribution, with the muscle buffer capacity or with the muscle oxidative potential. This suggests that no single muscle factor determines the anaerobic capacity. An alternative explanation could be that the $O_2$ deficit is not an accurate measure of anaerobic energy production.

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