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V. BILLAT a, M. FAINA b, F. SARDELLA b, C. MARINI b, F. FANTON b, S. LUPO b, P. FACCINI b, M. DE ANGELIS b, J. P. KORALSZTEIN c & A. DALMONTE b

a Laboratoire STAPS, Université Paris XII, 61 av. Général de Gaulle, Créteil, 94010, France
b Istituto di Scienza dello Sport, Italian National Olympic Committee, Roma, Italy
c Centre de Médecine du Sport, CCAS, 2 av. Richerand, Paris, 75010, France

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A comparison of time to exhaustion at \( \dot{V}O_2 \text{max} \) in élite cyclists, kayak paddlers, swimmers and runners

V. BILLAT‡§, M. FAINA‡, F. SARDELLA‡, C. MARIN‡, F. FANTON‡, S. LUPO‡, P. FACCINI‡, M. de ANGELIS‡, J. P. KORALSZTEIN* and A. DALMONTE‡

†Laboratoire STAPS, Université Paris XII, 61 av. Général de Gaulle, 94010 Créteil, France
‡Istituto di Scienza dello Sport, Italian National Olympic Committee, Roma, Italy
*Centre de Médecine du Sport, CCAS, 2 av. Richerand, 75010 Paris, France

Keywords: Maximal oxygen consumption; Time to exhaustion; Cycling; Running; Swimming; Kayaking.

A recent study has shown the reproducibility of time to exhaustion (time limit: tlim) at the lowest velocity that elicits the maximal oxygen consumption (\( \dot{V}O_2 \text{max} \)). The same study found an inverse relationship between this time to exhaustion at \( \dot{V}O_2 \text{max} \) and \( \dot{V}O_2 \text{max} \) among 38 élite long-distance runners (Billat et al. 1994b). The purpose of the present study was to compare the time to exhaustion at \( \dot{V}O_2 \text{max} \) for different values of \( \dot{V}O_2 \text{max} \), depending on the type of exercise and not only on the aerobic capacity. The time of exhaustion at \( \dot{V}O_2 \text{max} \) (tlim) has been measured among 41 élite (national level) sportsmen: 9 cyclists, 9 kayak paddlers, 9 swimmers and 14 runners using specific ergometers. Velocity or power at \( \dot{V}O_2 \text{max} \) (\( \dot{V}O_2 \text{max} \)) was determined by continuous incremental testing. This protocol had steps of 2 min and increments of 50 W, 30 W, 0.05 m s\(^{-1}\) and 2 km h\(^{-1}\) for cyclists, kayak paddlers, swimmers and runners, respectively. One week later, tlim was determined under the same conditions. After a warm-up of 10 min at 60% of their \( \dot{V}O_2 \text{max} \), subjects were concluded (in less than 45 s) to their \( \dot{V}O_2 \text{max} \) and then had to sustain it as long as possible until exhaustion. Mean values of \( \dot{V}O_2 \text{max} \) and tlim were respectively equal to 419 ± 49 W (tlim = 222 ± 91 s), 239 ± 56 W (tlim = 376 ± 134 s), 1.46 ± 0.09 m s\(^{-1}\) (tlim = 287 ± 160 s) and 22.4 ± 0.8 km h\(^{-1}\) (tlim = 321 ± 84 s), for cyclists, kayak paddlers, swimmers and runners. Time to exhaustion at \( \dot{V}O_2 \text{max} \) was only significantly different between cycling and kayaking (ANOVA test, \( p < 0.05 \)). Otherwise, \( \dot{V}O_2 \text{max} \) (expressed in ml min\(^{-1}\) kg\(^{-1}\)) was significantly different between all sports except between cycling and running (\( p < 0.05 \)). In this study, time to exhaustion at \( \dot{V}O_2 \text{max} \) was also inversely related to \( \dot{V}O_2 \text{max} \) for the entire group of élite sportsmen (\( r = -0.320, p < 0.05, n = 41 \)). The inverse relationship between \( \dot{V}O_2 \text{max} \) and tlim at \( \dot{V}O_2 \text{max} \) has to be explained, it seems that tlim depends on \( \dot{V}O_2 \text{max} \) regardless of the type of exercise undertaken.

1. Introduction

Numerous authors have studied the velocity that elicits maximal oxygen uptake \( (\dot{V}O_2 \text{max}) \) (Astrand 1960, Saltin and Astrand 1967, di Prampero et al. 1986, Gleser and Vogel 1973, Hill 1927, Lacour et al. 1991, Léger and Bouchier 1980, Péronnet and Thibault 1989). The time during which the velocity at \( V_0 \text{max} \) was sustained (time limit at \( \dot{V}O_2 \text{max} \)) was measured in the laboratory and in the field for modelling the
velocity–duration relationship (Briggs 1977, Gleser and Vogel 1973, McLellan and Cheung 1992, Moritani et al. 1981). Recently, Billat et al. (1994a) have examined the reproducibility of the time limit at V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max} (t\text{lim}), which generally lies between 4 and 11 min depending on the subject; t\text{lim} was negatively correlated with V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max} and velocity at V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max}.

The purpose of this study was to compare the time of exhaustion at the power output (or velocity) at V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max} for different values of V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max}, depending on the type of sports or muscle mass involved in exercise (Astrand and Saltin 1961, Gleser et al. 1974, Holmer et al. 1974, Bergh et al. 1976, Franklin 1985, Bouchard et al. 1979, Shephard et al. 1988, McArdle et al. 1973, Hartling et al. 1989).

2. Method

2.1. Subjects

The subjects were 41 national class sportsmen: road cyclists (n = 9), flatwater kayak paddlers (1000 m) (n = 9), middle distance swimmers (400 m) (n = 9) and middle- and long-distance runners (3000–10000 m) (n = 14) whose physical characteristics are given in Table 1. All were informed of the protocol before participating as subjects in this study. Ethical approval for the present study was obtained from the Italian department of university and scientific research.

2.2. Experimental

Each subject performed two exercise bouts to exhaustion, on separate days one week apart. The first test was to determine V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max} and the minimal velocity or power associated with V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max}. The second test was an all-out exercise bout performed at the power or velocity that elicited V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max} to determine the time to exhaustion at V\textsubscript{\text{O}}\text{\textsubscript{2}}\text{max}. Verbal instruction in the all-out test was controlled for each subject. The subjects were instructed to perform as long as possible during the test time.

2.3. Data collection

Each subject performed the two tests on their specific ergometer. Cyclists pedalled on an electronically braked Ergoline cycle ergometer (Ergoline, West Germany), which was mechanically modified to enable them to utilize the saddle and position of their bike. They wore cycling shoes equipped with 'clip-less' compatible pedal interfaces. They had an optimal pedal rate for the high power output equal to 100 rev/min (Coast et al. 1986). Kayak paddlers were tested on an arm cranking ergometer (multifunctional ergometer, Dal Monte 1989) with specifically designed handbars to simulate (from a

<table>
<thead>
<tr>
<th>Sportsmen</th>
<th>Age (years)</th>
<th>Mass (kg)</th>
<th>Stature (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclists</td>
<td>24.2 ± 2.3†</td>
<td>78.1 ± 10.5</td>
<td>1.80 ± 0.6</td>
</tr>
<tr>
<td>Kayak paddlers</td>
<td>21.4 ± 5.1</td>
<td>75.2 ± 10.5</td>
<td>1.78 ± 0.7</td>
</tr>
<tr>
<td>Swimmers</td>
<td>18.4 ± 2.3</td>
<td>74.5 ± 8.9</td>
<td>1.81 ± 0.7</td>
</tr>
<tr>
<td>Runners</td>
<td>27.8 ± 3.8‡</td>
<td>68.6 ± 5.8*</td>
<td>1.78 ± 0.5</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>23.6 ± 5.0</td>
<td>73.5 ± 9.2</td>
<td>1.80 ± 0.6</td>
</tr>
</tbody>
</table>

† Cyclists are significantly older than swimmers p < 0.05.
‡ Runners are significantly older than the other sportsmen p < 0.05.
* Runners are significantly lighter than cyclists p < 0.05.
biomechanical point of view) the action of kayak paddlers. The paddling rate was chosen at 90 strokes per minute, according to the usual and optimal paddling frequency of the subjects. Swimmers performed in a swimming flume where the water was circulated in a deep loop by a motor driven propeller, providing a water flow velocity from 0 to 2.0 m s\(^{-1}\) with an increment of 0.01 m s\(^{-1}\) (Astrand and Englesson 1972, Dal Monte 1989). The runners performed on a treadmill (Gymrol 1800, Sanit Etienne, France). Throughout the tests, the slope of the treadmill was zero. Measurement of \(\text{VO}_2\text{max}\) was done with a telemetric system (K2, Cosmed, Italy, Dal Monte et al. 1989), reliability and reproducibility of oxygen uptake measurements have been checked in prior studies (Dal Monte et al. 1989, Kawakami et al. 1992, Peel and Utsey 1993, Lucia et al. 1993). The first session was dedicated to the measurement of \(\text{VO}_2\text{max}\) and the determination of the speed or power at \(\text{VO}_2\text{max}\) (\(\text{VVO}_2\text{max}\)) according to the criteria of Taylor et al. (1955) and Lacour et al. (1991) during a continuous incremental protocol with steps of 2 min. Power or speed increments were 50 and 30 W, 0-05 m s\(^{-1}\) and 2 km\(^{-1}\) for cyclists, kayak paddlers, swimmers and runners, respectively. The time limit corresponding to 100\% of \(\text{VVO}_2\text{max}\) was carried out at the same time of day at one week's interval. The subjects performed a preliminary exercise lasting 10 min at 60\% of \(\text{VVO}_2\text{max}\) and were then conducted (in less than 45 s) to their \(\text{VVO}_2\text{max}\). Then they had to sustain this power output as long as possible to exhaustion to determine time to exhaustion at \(\text{VVO}_2\text{max}\) (\(\text{tlim}\)).

Blood lactate was collected at the ear lobe and analysed by a micro-method by means of an automatic Eppendorf-ESAT 6001 analyser, Germany. The blood samples were taken from the ear lobe before and immediately after exercise and at 3, 6 and 9 min during the recovery period following each test, in order to detect the peak lactate concentration. In the \(\text{tlim}\) test blood samples were also taken in the last minute of warm-up. Heart rate was measured and registered continuously by a heart rate meter (Sporttester PE 3000, Polar, Finland). Heart rate, HR, (beats min\(^{-1}\)), blood lactate (mmol l\(^{-1}\)), ventilation (\(\dot{V}_E\)), ventilatory equivalent for oxygen (\(\dot{V}_O_2/\dot{V}_E\)) and oxygen pulse (\(\text{VO}_2/\text{HR}\) in ml cycle min\(^{-1}\)) were compared in the two incremental tests versus time limit tests for each sport. Also \(\text{VO}_2\text{max}\) in the incremental test was compared with \(\text{VO}_2\text{peak}\) in the \(\text{tlim}\) test.

### 2.4. Statistical analyses

Mean and standard deviations were computed for all variables within each group and also for the entire group of élite sportsmen. Analysis of variance (ANOVA) comparisons were used to test for significant differences in the main physical and physiological characteristics for the incremental and time limit test between the four groups of sports. The cardiorespiratory variables obtained at the end of incremental and time limit tests were subjected to a paired Student’s \(t\)-test for the statistical analysis of difference. In investigating relationships between respective items of measurement, a Pearson’s correlation coefficient between two arbitrary items was calculated. In all statistical analyses, the level of significance was set at \(p < 0.05\).

### 3. Results

#### 3.1. Physical characteristics

There were no significant differences in stature between the four groups, for mass, except for the mass between runners and cyclists (table 1). The runners were significantly older than the other sportsmen, and the cyclists were significantly older than the swimmers.
Table 2. Velocity and power output at $\dot{V}O_2$ max and $\dot{V}O_2$ max values obtained at the end of incremental and time limit tests.

<table>
<thead>
<tr>
<th>Sportsmen</th>
<th>$v\dot{V}O_2$ max</th>
<th>$\dot{V}O_2$ max incremental test (ml min$^{-1}$) (% of cyclists' values)</th>
<th>$\dot{V}O_2$ max incremental test (ml min$^{-1}$ kg$^{-1}$) (% of cyclists' values)</th>
<th>Time limit at $v\dot{V}O_2$ max (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclists</td>
<td>419 ± 49†</td>
<td>5632 ± 649 (100%)</td>
<td>72.4 ± 5.4 (100%)</td>
<td>222 ± 91</td>
</tr>
<tr>
<td>Kayak paddlers</td>
<td>239 ± 56†</td>
<td>4034 ± 624-6 (72%)</td>
<td>53.8 ± 6.1 (74%)</td>
<td>376 ± 134</td>
</tr>
<tr>
<td>Swimmers</td>
<td>1.46 ± 0.09‡</td>
<td>4444 ± 729 (79%)</td>
<td>59.6 ± 6.7 (82%)</td>
<td>287 ± 160</td>
</tr>
<tr>
<td>Runners</td>
<td>6.22 ± 0.22‡</td>
<td>5129 ± 332 (91%)</td>
<td>74.9 ± 3.0 (103%)</td>
<td>321 ± 84</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>—</td>
<td>4809 ± 710</td>
<td>65.2 ± 10.1</td>
<td>302 ± 65</td>
</tr>
</tbody>
</table>

$p < 0.05.$
† Units are watts.
‡ Units are m s$^{-1}$. 

3.2. \( \dot{V}O_2 \text{max} \)

Times to exhaustion at \( \dot{V}O_2 \text{max} \) were not significantly different between the sports except between cycling and kayaking (table 2). On the contrary, \( \dot{V}O_2 \text{max} \) when expressed in \( \text{ml min}^{-1} \text{kg}^{-1} \) was significantly different for all sports except between cycling and running. When \( \dot{V}O_2 \text{max} \) is expressed in \( \text{ml min}^{-1} \), it was significantly different between all sports except between kayaking and swimming.

3.3. Velocity or power output at \( \dot{V}O_2 \text{max} \) (\( \ddot{V}O_2 \text{max} \)) and time to exhaustion at \( \dot{V}O_2 \text{max} \) (tlim) obtained in different sports

Table 2 shows the power output or velocities at \( \dot{V}O_2 \text{max} \) and time to exhaustion at \( \dot{V}O_2 \text{max} \) (tlim) obtained in different sports. The power output of kayak paddlers at \( \dot{V}O_2 \text{max} \) was only 57% that of the cyclists, which can be explained by the smaller muscle mass involved in kayaking. However, time to exhaustion for kayak paddlers was significantly higher than that of the cyclists tlim (\( p < 0.05 \)) (equal to 169%). Velocity (and tlim) at \( \dot{V}O_2 \text{max} \) for swimmers and runners, respectively and tlim was not significantly different.

3.4. Comparison between physiological parameters obtained at the end of the incremental test and tlim tests

There were no significant differences for sports between the physiological values obtained in the two tests, i.e. \( \dot{V}O_2 \), HR, blood lactate, VE, \( E\dot{V}O_2 \) and oxygen pulse (table 3). The runners had significantly higher values of \( O_2 \) uptake, oxygen pulse and \( l\% \) at the end of the incremental test. Kayak paddlers had significantly higher values for blood lactate at the end of the tlim test. All of these variables obtained at the end of the incremental and time limit test are correlated in table 4.

Table 3. Cardiorespiratory variables and blood lactate values obtained at the end of the incremental and time limit tests in the four groups of elite sportsmen.

<table>
<thead>
<tr>
<th>Bioenergetic characteristics</th>
<th>Cyclists (n = 9)</th>
<th>Kayak paddlers (n = 9)</th>
<th>Swimmers (n = 10)</th>
<th>Runners (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V\dot{O}_2 \text{max} ) (( \text{ml min}^{-1} ))</td>
<td>Inc 5632 ± 649</td>
<td>4034 ± 625</td>
<td>4444 ± 729</td>
<td>5129 ± 332†</td>
</tr>
<tr>
<td>tlim 5449 ± 411</td>
<td>4145 ± 687</td>
<td>4419 ± 716</td>
<td>4828 ± 428†</td>
<td></td>
</tr>
<tr>
<td>HR max (beats min(^{-1}))</td>
<td>Inc 190 ± 7</td>
<td>190 ± 3</td>
<td>179 ± 5</td>
<td>189 ± 6</td>
</tr>
<tr>
<td>tlim 191 ± 7</td>
<td>—</td>
<td>177 ± 8</td>
<td>187 ± 8</td>
<td></td>
</tr>
<tr>
<td>Blood lactate (( \text{mmol} \text{ l}^{-1} ))</td>
<td>Inc 10.8 ± 2.1</td>
<td>8.2 ± 2.3†</td>
<td>4.3 ± 1.6</td>
<td>9.0 ± 1.6</td>
</tr>
<tr>
<td>tlim 10.2 ± 2.0</td>
<td>9.6 ± 1.7†</td>
<td>4.9 ± 1.2</td>
<td>9.7 ± 2.6</td>
<td></td>
</tr>
<tr>
<td>( \dot{V}E ) (( \text{l min}^{-1} ))</td>
<td>Inc 191.5 ± 18.7</td>
<td>134.3 ± 23.8</td>
<td>117.0 ± 12.4</td>
<td>164.0 ± 13.2</td>
</tr>
<tr>
<td>tlim 192.6 ± 8.9</td>
<td>135.9 ± 24.2</td>
<td>115.1 ± 12.7</td>
<td>164.3 ± 15.0</td>
<td></td>
</tr>
<tr>
<td>( O_2 \text{pulse} ) (( \text{ml beats} \text{ min}^{-1} ))</td>
<td>Inc 29.7 ± 3.3</td>
<td>18.6 ± 1.7</td>
<td>24.6 ± 3.6</td>
<td>27.3 ± 2.2†</td>
</tr>
<tr>
<td>tlim 29.1 ± 3.5</td>
<td>—</td>
<td>26.9 ± 4.2</td>
<td>25.9 ± 2.7†</td>
<td></td>
</tr>
<tr>
<td>( E\dot{V}O_2 ) (( \text{pmol} \text{ l}^{-1} ))</td>
<td>Inc 34.0 ± 2.3</td>
<td>33.3 ± 2.5</td>
<td>26.0 ± 3.0</td>
<td>32.4 ± 2.1†</td>
</tr>
<tr>
<td>tlim 35.5 ± 3.1</td>
<td>32.8 ± 2.3</td>
<td>26.4 ± 3.2</td>
<td>34.1 ± 2.9†</td>
<td></td>
</tr>
</tbody>
</table>

Time limit test: tlim.
Incremental test: Inc.
* \( p < 0.05 \).
† \( p < 0.001 \).
‡ \( p < 0.02 \).
Table 4. Coefficient of correlation between physiological mean values obtained at the end of the tlim test and at the end of the incremental test.

<table>
<thead>
<tr>
<th>Bioenergetic characteristics</th>
<th>Cyclists (n = 9)</th>
<th>Kayak paddlers (n = 9)</th>
<th>Swimmers (n = 10)</th>
<th>Runners (n = 14)</th>
<th>All groups (n = 41)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ max (ml min⁻¹)</td>
<td>0.775†</td>
<td>0.922‡</td>
<td>0.891‡</td>
<td>0.838‡</td>
<td>0.905‡</td>
</tr>
<tr>
<td>HR max (beats min⁻¹)</td>
<td>0.571</td>
<td>-</td>
<td>0.684*</td>
<td>0.899‡</td>
<td>0.647‡</td>
</tr>
<tr>
<td>Blood lactate (mmol l⁻¹)</td>
<td>0.395</td>
<td>0.667*</td>
<td>0.371</td>
<td>0.525*</td>
<td>0.748‡</td>
</tr>
<tr>
<td>VE (l min⁻¹)</td>
<td>0.388</td>
<td>0.747†</td>
<td>0.041</td>
<td>0.682‡</td>
<td>0.893‡</td>
</tr>
<tr>
<td>O₂ pulse (ml/beats min⁻¹)</td>
<td>0.413</td>
<td>-</td>
<td>0.528</td>
<td>0.839‡</td>
<td>0.647‡</td>
</tr>
<tr>
<td>EVO₂</td>
<td>0.324</td>
<td>0.311</td>
<td>0.335</td>
<td>0.664‡</td>
<td>0.741‡</td>
</tr>
</tbody>
</table>

†p < 0.02.
‡p < 0.01.
*p < 0.05.

3.5. Comparison between physiological variables obtained at the end of the incremental test between different sports

The maximal heart rate obtained at the end of the increment test was significantly lower among swimmers than the other sportsmen (179 versus 190, 190 and 189 cycle min⁻¹ among cyclists, kayak paddlers and runners, respectively, table 3). The blood lactate obtained at the end of the incremental test was significantly lower among swimmers than the other sportsmen (4.3 versus 10.8, 8.2 and 9.0 mmol l⁻¹ among cyclists, kayak paddlers and runners, respectively). VE and oxygen pulse were significantly different between all sports. EVO₂ was significantly different between all sports except between cycling and kayaking.

3.6. Relationship between tlim and vVO₂ max and VO₂ max for all sports and for each sport

In this study, time to exhaustion at vVO₂ max was inversely related to VO₂ max for all sports (r = -0.320, p < 0.05) (figure 1) but not for each individual sport, this tendency remaining (r = -0.240, -0.117, -0.171, p > 0.05) for cycling, kayaking and swimming, respectively. Velocity at VO₂ max was inversely related to tlim, in swimming (r = -0.778, p < 0.01) and in running (r = -0.558, p < 0.05). Kayak paddlers can sustain their VO₂ max power output during 376 s. They have the longest time to exhaustion among the four sport groups and the lower VO₂ max value. This result contributes to the inverse relationship that was observed between the limit time at vVO₂ max and VO₂ max.

4. Discussion

4.1. VO₂ max values obtained in the different sports

It was found that VO₂ max values obtained at the end of incremental and time limit tests were not significantly different as previously reported by McArdle et al. (1973), except in the case of runners who obtained their highest values at the end of the incremental
test. However, at the end of the incremental test, VO₂ had not reached a plateau for half of the subjects, and it would be preferable to consider this value of VO₂ as a VO₂ peak, rather than a VO₂ max.

4.1.1. Cycling: VO₂ max values obtained in this study, both in absolute (5.61 min⁻¹) and in relative terms (72.4 ml min⁻¹ kg⁻¹) are consistent with other studies that have measured VO₂ max in élite cyclists (Coyle et al. 1991). Values such as 4.91 min⁻¹ have been reported in national class, and more than 5.01 min⁻¹ in national team cyclists (international class) (Hagberg et al. 1979, Saltin and Astrand 1967). Neuman (1992) reported a power output at VO₂ max equal to 400 W and a VO₂ max of 78 ml min⁻¹ kg⁻¹ for national élite road cyclists in former West Germany (1980–88). The lower value obtained here (72.4 ml min⁻¹ kg⁻¹) can be explained by a higher body weight (78 versus 72 kg for the German national team). Also, these tests were performed in winter out of the competition season.

4.1.2. Kayaking: VO₂ max values registered in this research, both in absolute (4.01 min⁻¹) and relative terms (53.8 ml min⁻¹ kg⁻¹) are consistent with other studies that have measured VO₂ max in élite kayak paddlers (Dal Monte and Leonardi 1976, Tesch 1983).

4.1.3. Swimming: VO₂ max values recorded among swimmers, both in absolute (4.41 min⁻¹) and relative terms (59.6 ml min⁻¹ kg⁻¹) are consistent with other studies that have measured VO₂ max in élite swimmers. Lavoie et al. (1981) reported an absolute value of VO₂ max equal to 4.31 min⁻¹ in 20 years-old élite middle distance swimmers measured during the last 2 min of a 500 m free-style event in a swimming pool using the Douglas bag method. Holmer et al. (1974) reported an absolute value of VO₂ max equal to 51 min⁻¹ in 18-7 years-old (mean) élite middle distance swimmers measured in a swimming flume with a heart rate of 186 versus 179 beat min⁻¹ for the present swimmers. It could be questioned whether these élite middle distance swimmers had obtained their maximum of VO₂ value since the blood lactate obtained at the end of incremental and time limit tests were only equal to those measured at the end of a 1500 m event (Bonifazi et al. 1993).
4.1.4. Running: The $\dot{V}O_2$ max values found here, both in absolute (5.11 min $^{-1}$) and relative terms (74.9 ml min $^{-1}$ kg $^{-1}$), are consistent with other studies that have measured $\dot{V}O_2$ max in elite runners (Péronnet and Thibault 1989). Padilla et al. (1992) found a mean $\dot{v}\dot{V}O_2$ max and a $\dot{V}O_2$ max equal to 5.95 m s $^{-1}$ and 71.9 ml min $^{-1}$ kg $^{-1}$ (4.51 min $^{-1}$), respectively among 24 French male middle distance runners selected on the basis of performances over 1500 and 3000 m races (superior to 90% of the best French velocity, i.e. performance on these distances over the year).

4.2. Time to exhaustion (tlim) values obtained among the different sports
The tlim values that have been measured in this study were in agreement with those estimated or measured in the literature in running and cycling (Billat et al. 1994a, b, c, Briggs 1977, Camus et al. 1988, McLellan and Skinner 1985, McLellan and Cheung 1992). Padilla et al. (1992) found among 24 French elite male middle distance runners a mean time limit at $\dot{V}O_2$ max calculated from the time limit of the performances over 1500 and 3000 m and which was equal to 8.40 ± 2.1 min more than the authors' tlim value (5.21 ± 1.24 min). However the pace was not strictly uniform during the races, as a strict discipline is difficult to maintain at $\dot{v}\dot{V}O_2$ max (and it is not the goal in fact).

4.3. Relationship between $\dot{v}\dot{V}O_2$ max and time to exhaustion at $\dot{V}O_2$ max overall and for each sport
An inverse relationship was observed between the limit time at $\dot{v}\dot{V}O_2$ max and $\dot{V}O_2$ max, i.e. the runners who had the highest $\dot{V}O_2$ max and the highest velocity or power at $\dot{V}O_2$ max reach their exhaustion time earlier. These findings support the study by Billat et al. (1994b) and contradict Camus et al. (1988). If this inverse relationship between $\dot{V}O_2$ max and time to exhaustion (tlim) at $\dot{v}\dot{V}O_2$ max has to be explained, it seems that tlim at $\dot{V}O_2$ max depends on $\dot{V}O_2$ max whatever the type of exercise may be. The inverse relationship between tlim and $\dot{V}O_2$ max in each sport depends on the aerobic capacity of the subject except in running and swimming where tlim is linked to the velocity at $\dot{V}O_2$ max ($\dot{v}\dot{V}O_2$ max). The velocity at $\dot{V}O_2$ max depends on the energy cost of the locomotion even though no relationship was reported between efficiency or energy cost and time to exhaustion at $\dot{V}O_2$ max. However, a previous study (Billat et al. 1994b, c) demonstrated that tlim was positively correlated with lactate threshold (expressed in %$\dot{V}O_2$ max). This experimental finding is in accordance with the model of Monod and Scherrer (1965). The present study conducted on 41 national top class sportsmen practising four different sports involving different muscle mass and so different $\dot{V}O_2$ max, is in accordance with this previous study performed on 38 runners. There is an inverse relationship between $\dot{V}O_2$ max and the time to exhaustion at $\dot{V}O_2$ max. This inverse relationship is also found for different racing animals. Thoroughbred racehorses have $\dot{V}O_2$ max values in the range of 140 to 187 ml kg $^{-1}$ min $^{-1}$ (Rose et al. 1990), about three times greater than that of the racing camel, which is of similar mass. Yet the camel can exercise at 100% of $\dot{V}O_2$ max for a much longer period than can the horse (18 versus 3 to 5 min) (Rose et al. 1992). Williams et al. (1986) have shown an inverse relationship between hypoxemia (arterial hypoxemia and haemoglobin desaturation) and the $\dot{V}O_2$ max value. A recent study has shown an inverse relationship between arterial hypoxemia and haemoglobin desaturation and the time to exhaustion at 90% of $\dot{V}O_2$ max among 16 elite long distance runners (Billat et al. 1994d). Hypoxemia is related to the alveolar hypoventilation found in top level long distance athletes who have a $\dot{V}O_2$ max over 4.51 min $^{-1}$ (Dempsey et al. 1984). Further research is necessary to understand
better the physiological background of this inverse relationship between VO₂ max and its time to exhaustion among different species.

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