Peak Power Output Predicts Rowing Ergometer Performance in Elite Male Rowers

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Abstract

The aim of the present study was to test the hypothesis that peak power output (Ppeak) sustained during maximal incremental testing would be an overall index of rowing ergometer performance over 2000 m (P2000), and to study the influence of selected physiological variables on Ppeak. A group of 54 highly trained rowers (31 heavyweight [HW] and 23 lightweight [LW] rowers) was studied. Body mass, maximal oxygen uptake ($\dot{V}O_{2max}$), oxygen consumption corresponding to a blood lactate of 4 mmol · l^{-1} expressed in percentage of $\dot{V}O_{2max}$ ($\dot{V}O_2La4\%$), and rowing gross efficiency (RGE) were also determined during the incremental test. In the whole group Ppeak was the best predictor of P2000 ($r = 0.92$, $p < 0.0001$). Body mass ($r = 0.65$, $p < 0.0001$), $\dot{V}O_{2max}$ ($r = 0.84$, $p < 0.0001$), $\dot{V}O_2La4\%$ ($r = 0.49$, $p < 0.0001$) and RGE ($r = 0.35$, $p < 0.01$) were significantly correlated with P2000 as well. To take the influence of body mass into account, $\dot{V}O_{2max}$ was related to kg$^{0.57}$. Ppeak was significantly related to body mass ($r = 0.56$, $p < 0.0001$), $\dot{V}O_{2max} \cdot kg^{-0.57}$ ($r = 0.63$, $p < 0.0001$), $\dot{V}O_2La4\%$ ($r = 0.45$, $p < 0.001$) and RGE ($r = 0.34$, $p < 0.05$). Multiple regression analysis indicated that the above parameters taken together explained 82.8 % of Ppeak variation in the whole group. It was also demonstrated that Ppeak was the best predictor of P2000 when LW and HW groups were considered separately. It was concluded that, by integrating the main physiological factors of performance, Ppeak is an overall index of physiological rowing capacity and rowing efficiency in heterogeneous as well as in homogeneous groups. It presents the further advantage of being easily measured in the field.

Key words
Testing · efficiency · maximal oxygen uptake · blood lactate

Introduction

In the laboratory, maximal oxygen uptake ($\dot{V}O_{2max}$) and blood lactate kinetics are determined during incremental testing to exhaustion. In this procedure, the last bout is often not performed entirely. Snoeckx et al. [17] proposed balancing the power of this last bout by its duration; the calculated power output was called peak power (Ppeak). Kuipers et al. [9] have tested the reproducibility (approximately 25 tests) of Ppeak measured on a cycloergometer and investigated its relationship to physiological variables determined during progressive exercise. They demonstrated that Ppeak varied less than $\dot{V}O_{2max}$ and that variation in $\dot{V}O_{2max}$ was not related to that of Ppeak. Kuipers et al. [9] also observed that, in subjects showing high Ppeak values, blood lactate concentration was lower at any workload, resulting in a rightward shift in the blood lactate vs. power output curve. Finally, the authors suggested that variations in Ppeak could also be related to changes in gross mechanical efficiency.

These finding had practical applications in testing. Noakes et al. [12] showed peak running velocity to be the best laboratory-measured predictor of distance running performance. This pre-

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Accepted after revision: August 10, 2003

Bibliography
Int J Sports Med 2004; 25: 368 – 373 © Georg Thieme Verlag KG · Stuttgart · New York · DOI 10.1055/s-2004-815844 · Published online May 18, 2004 · ISSN 0172-4622

dicting value was substantially higher than that of any physiological parameter including $\dot{V}O_{2max}$. Hawley and Noakes [5] showed Ppeak to be a better predictor of cycling performance over 20 km of cycling than $\dot{V}O_{2max}$ in a large heterogeneous group of trained cyclists (54 men and 46 women). These results demonstrate that Ppeak is an index of performance in several endurance disciplines. The increased predictive value associated with the use of maximal power or running velocity instead of $\dot{V}O_{2max}$ suggests that movement efficiency influenced this index. However, the possible influence of physiological parameters on the predictive value of Ppeak has never been analysed.

$\dot{V}O_{2max}$ or maximal aerobic power (Pamax) are important predictors of rowing ergometer performance [4,6,8,10,16]. Blood lactate variables have been shown to be related to rowing performance [4,6,10,15,18]. In recent studies, anthropometric and strength variables were also included in the statistical analysis to improve rowing performance prediction [6,8,15,16]. Thus, it appears that rowing performance is determined by the same variables as running and cycling. This leads to the hypothesis that Ppeak could be an overall index of rowing performance.

Few athletes have ready access to laboratory facilities capable of measuring physiological and strength variables. Therefore, it would be of interest if an overall index of rowing performance, easily measured in the laboratory and/or the field, could be validated. Ppeak, being directly measured on a rowing ergometer, meets these requirements. The aims of the present study were both to test the hypothesis that Ppeak is an overall index of rowing performance and to study the influence of selected physiological variables on Ppeak.

Table **1** Anthropometric, physiological and performance characteristics of the studied group. Values are means ± SD

	Total group (n = 54)	*LW (n = 23)*	*HW (n = 31)*
Age (years)	22.8 ± 3.7	23 ± 3.7	22.6 ± 3.7
Height (cm)	186 ± 6.6	180.4 ± 3.9	190 ± 5**
Body mass (kg)	82.4 ± 8.3	74 ± 1.8	88.6 ± 5.1**
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	5.41 ± 0.42	5.05 ± 0.2	5.68 ± 0.32**
Pamax (W)	387 ± 33	362.9 ± 23.9	405.2 ± 27.5**
$\dot{V}O_2La4\%$	90 ± 4.8	90 ± 4.3	89.9 ± 5.2
Ppeak (W)	422 ± 37.3	396 ± 23	441.6 ± 33.9**
RGE (%)	18.5 ± 0.9	18.6 ± 0.8	18.5 ± 1
T2000 (s)	371.9 ± 11.8 (6 min 11.9 s ± 11.8 s)	381.2 ± 6.6 (6 min 21.2 s ± 6.6 s)	364.9 ± 9.8** (6 min 4.9 s ± 9.8 s)
P2000 (W)	438.2 ± 42.2	405 ± 21	462.9 ± 36.8**

$\dot{V}O_{2max}$, maximal oxygen consumption; Pamax, maximal aerobic power corresponding to $\dot{V}O_{2max}$; $\dot{V}O_2La4\%$, $\dot{V}O_2$ corresponding to a blood lactate of 4 $mmol \cdot l^{-1}$ as % of $\dot{V}O_{2max}$; Ppeak, maximal power output during the incremental test; RGE, rowing gross efficiency; T2000, 2000 m rowing ergometer performance; P2000, mean power output during rowing ergometer performance. HW significantly different from LW: ** $p < 0.0001$

Methods

Subjects

The experiment was carried out on 54 French oarsmen of national to international competition level. The group included 23 lightweight (LW) and 31 heavyweight (HW) rowers. Age and anthropometric characteristics are listed in Table **1**. The results of annual physiological testing were used, in agreement with the *Fédération Française des Sociétés d'Aviron* (French Rowing Societies' Federation).

Physiological testing in the laboratory

This session was conducted within the context of training monitoring of the athletes. The rowers were fully familiarized with the use of the wind-resistance braked rowing ergometer (CII; Concept II, model C, Morrisville, VT, USA). $\dot{V}O_{2max}$ was measured during an intermittent progressive test on CII. The mean power output during exercise was delivered by the computer CII display.

The times of rowing and rest periods were 3 and 0.5 min respectively. The initial power was 150 W for lightweight and 200 W for heavyweight rowers, and was increased by 50 W after each rest period until the subject was exhausted. Expired gas was sampled during the last 30 s of each rowing bout. Blood was sampled from the ear lobe, during each rest period, to measure lactate concentration. The $\dot{V}O_2$ measured during the last rowing period was considered as maximal provided a plateau was obtained ($\dot{V}O_2$ variation less than 2 $ml \cdot kg^{-1} \cdot min^{-1}$). In the absence of plateau, $\dot{V}O_2$ measured during the last rowing bout could still be considered maximal provided the blood lactate concentration measured at the end of the period was higher than 9 $mmol \cdot l^{-1}$. The maximal aerobic power (Pamax) was defined as the power at which $\dot{V}O_{2max}$ is reached.

The expired gas was collected through a low-resistance Hans Rudolph 2700 valve (Kansas City, MO, USA) connected to a low dead-space mixing chamber, and collected in a balanced Tissot spirometer. The O_2 and CO_2 fractions were determined by means of S3 A/I Ametek (Pittsburgh, PA, USA) and D-Fend™ Datex (Helsinki, Finland), respectively and calibrated with gas mixtures of compositions determined by the Scholander method.

Blood lactate concentrations were measured with the Kontron LA-640 lactate analyser (Roche Bio-Electronics, Basel, Switzerland).

Performance on rowing ergometer

Time performance and mean power output (T2000 and P2000 respectively) were obtained for each subject during 2000 m all-out rowing on CII. This kind of rowing ergometer competition is commonly organized by trainers to assess athletes. The competition was performed by the athletes in their respective clubs or during official rowing ergometer competitions within a month after physiological testing.

Calculations

$\dot{V}O_2$ corresponding to a blood lactate level of 4 $mmol \cdot l^{-1}$ ($\dot{V}O_2La4$) was determined by straight line interpolation between the two closest measured values. Mainly due to a scale effect, $\dot{V}O_2La4$ was highly correlated with $\dot{V}O_{2max}$ (for the whole group: $r = 0.87$, $p < 0.0001$). Therefore, in order to rule out the influence

Table **2** Relationships between mean power output during 2000 m rowing ergometer performance and selected physiological variables

	Total group (n = 54)	*LW (n = 23)*	*HW (n = 31)*
Body mass (kg)	r = 0.65 p < 0.0001	NS	NS
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	r = 0.84 p < 0.0001	r = 0.70 p < 0.001	r = 0.68 p < 0.0001
$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-0.57}$)	r = 0.55 p < 0.0001	r = 0.64 p < 0.01	r = 0.60 p < 0.001
$\dot{V}O_2La4\%$	r = 0.49 p < 0.0001	NS	r = 0.79 p < 0.0001
Ppeak (W)	r = 0.92 p < 0.0001	r = 0.76 p < 0.0001	r = 0.89 p < 0.0001
RGE (%)	r = 0.35 p < 0.01	r = 0.51 p < 0.05	r = 0.64 p < 0.001

$\dot{V}O_{2max}$, maximal oxygen consumption; Pamax, maximal aerobic power corresponding to $\dot{V}O_{2max}$; $\dot{V}O_2La4\%$, $\dot{V}O_2$ corresponding to a blood lactate of 4 $mmol \cdot l^{-1}$ as % of $\dot{V}O_{2max}$; Ppeak, maximal power output during the incremental test; RGE, rowing gross efficiency

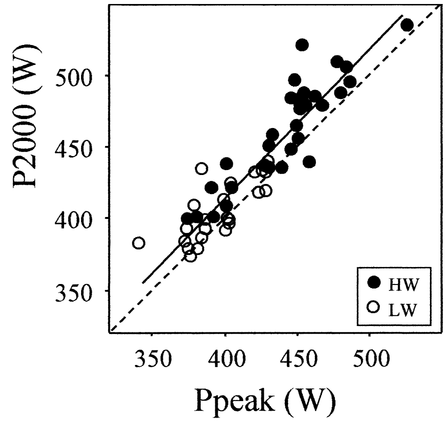

Fig. **1** Relationship between Ppeak and P2000. Ppeak is the peak power output during the incremental test; P2000 is the mean power output during 2000 m ergometer performance. HW and LW are the heavyweight and lightweight categories, respectively. The dotted line represents the identity line.

of $\dot{V}O_{2max}$ variation on $\dot{V}O_2La4$ variation, the latter was expressed as a percentage of $\dot{V}O_{2max}$ ($\dot{V}O_2La4\%$).

In line with the studies by Snoeckx et al. [17] and Kuipers et al. [9], the maximal work load during the intermittent progressive test was calculated as:

$$Ppeak = Pcom + T \cdot Tbout^{-1} \cdot \Delta P$$

where Pcom is the last work load completed, T the number of seconds of the final, uncompleted bout, Tbout the number of seconds of the bout defined in the protocol and ΔP the final load increment (commonly 50 W).

Rowing gross efficiency (RGE) was calculated during exercises resulting in a blood lactate concentration lower than 3 $mmol \cdot l^{-1}$. It is assumed that the contribution of anaerobic glycolysis to ATP resynthesis is negligible at these intensities. Gross O_2 consumption was converted into watts (W) by a respiratory exchange ratio. Gross rowing efficiency was calculated by dividing power output by gross O_2 consumption.

To scale for differences in body mass, body mass is commonly raised to the power 0.75 (see [11,19]). Nevertheless, the study by Bergh et al [2] demonstrated that the value of the exponent could vary as a function of the studied group (ranging from 0.46 for trained non-athletes to 0.86 for male cross-country skiers). In line with the recommendation of Bergh et al. [2], the value of the exponent was calculated, and the results demonstrated that $\dot{V}O_{2max}$ was independent of body mass when related to $kg^{0.57}$ in the studied group.

Statistics

All data are expressed as mean ± SD for each group. Variability was the SD-to-mean ratio expressed as a percentage. The relationships between variables within each group were evaluated using correlation, linear and multiple regression analysis. The significance level was set at 0.05.

Results

The physiological and performance characteristics of the subjects are listed in Table **1**. HW subjects had higher body mass, absolute $\dot{V}O_{2max}$, Pamax, Ppeak and P2000 values. Age, $\dot{V}O_2La4\%$ and RGE were comparable between the HW and LW groups.

Whole Group

Relationship between selected variables and P2000

As shown in Table **2**, all selected variables significantly influenced P2000 in the group as a whole. The highest correlation coefficient was obtained for Ppeak, the variation of which explained 84.6% of P2000 variation (Fig. **1**). The mean value of Ppeak represented 109.2 ± 6.0% of Pamax. Conversely, RGE variation explained only 12.3% of variation in P2000, with the lowest correlation coefficient.

Influence of selected physiological variables on Ppeak variation

As can be seen in Table **3**, body mass and $\dot{V}O_{2max}$ were significantly correlated with Ppeak. Variation in body mass had no significant influence on $\dot{V}O_2La4\%$ or on RGE variation. The difference between Ppeak and Pamax expressed as % of Pamax (Ppeak – Pamax%; 9.18 ± 6.0%) was significantly correlated with $\dot{V}O_2La4\%$ (Fig. **2**; r = 0.44, p < 0.001).

Table **3** shows that $\dot{V}O_{2max}$ (as an absolute value or related to $kg^{-0.57}$) was the main determinant of Ppeak variation. Ppeak was

Table **3** Relationships between selected physiological variables and maximal power output during the maximal progressive test (Ppeak)

	Total group (n = 54)	*LW (n = 23)*	*HW (n = 31)*
Body mass (kg)	r = 0.56 p < 0.0001	NS	NS
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	r = 0.84 p < 0.0001	r = 0.54 p < 0.01	r = 0.78 p < 0.0001
$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-0.57}$)	r = 0.63 p < 0.0001	r = 0.46 p < 0.05	r = 0.74 p < 0.0001
$\dot{V}O_2La4\%$	r = 0.45 p < 0.001	NS	r = 0.70 p < 0.0001
RGE (%)	r = 0.34 p < 0.05	r = 0.52 p < 0.05	r = 0.49 p < 0.01

$\dot{V}O_{2max}$, maximal oxygen consumption; $\dot{V}O_2La4\%$, $\dot{V}O_2$ corresponding to a blood lactate of 4 mmol · l^{-1} as % of $\dot{V}O_{2max}$; RGE, rowing gross efficiency

also significantly correlated with $\dot{V}O_2La4\%$ and RGE (Fig. **3**). Multiple regression analysis demonstrated that body mass, $\dot{V}O_{2max} \cdot kg^{-0.57}$, $\dot{V}O_2La4\%$ and RGE significantly influenced variation in Ppeak ($r = 0.91$, $p < 0.0001$).

LW and HW Groups

$\dot{V}O_{2max} \cdot kg^{-0.57}$ did not differ between the LW and HW groups. (441.5 ± 24.7 vs. 435.3 ± 15.3 ml · $min^{-1} \cdot kg^{-0.57}$ for LW and HW respectively).

Relationship between selected variables and P2000

In both body mass subgroups, body mass had no significant influence on P2000 variation. Ppeak was still the best predictor of variation in P2000 (Table **2**). In the HW and LW subgroups, variations in $\dot{V}O_{2max}$ and RGE significantly influenced variation in P2000. $\dot{V}O_2La4\%$ was strongly correlated with P2000 in the HW group but had no significant influence on P2000 variations in the LW group.

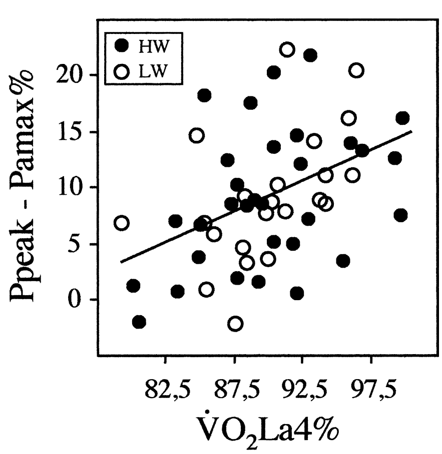

Fig. **2** Relationship between Ppeak – Pamax% and $\dot{V}O_2La4\%$. Ppeak – Pamax% is the difference between peak power output during the incremental test (Ppeak) and work rate corresponding to $\dot{V}O_{2max}$ (Pamax) as % of Pamax; $\dot{V}O_2La4\%$ is the oxygen consumption corresponding to a blood lactate of 4 mmol · l^{-1} as % of $\dot{V}O_{2max}$.

Influence of selected physiological variables on Ppeak variation

$\dot{V}O_{2max}$ was the main determinant of Ppeak variation in both LW and HW groups (Table **3**). In both groups, body mass was not related to Ppeak but variation in RGE significantly influenced variation in Ppeak (Fig. **3**). $\dot{V}O_2La4\%$ was significantly related to Ppeak in the HW but not in the LW group.

Discussion

The main finding of the present study was that, of the currently measured variables, Ppeak was the best predictor of rowing ergometer performance. In the whole group, variation in Ppeak explained 84.6% of the variation in P2000 (Fig. **1**). This finding is in line with the data for distance running [12] and cycling [5]. The slightly lower correlation coefficient may be related to the homogeneity of the studied group, which demonstrated a performance variability of 9.6% vs. 13.1% in marathon [12] and 11.3% in cycling performance [5]. It is worth noting that although rowing, running and cycling performances are similarly influenced by both $\dot{V}O_{2max}$ and movement efficiency, the predictive values of Ppeak in running and cycling were relative to performances sustained at a power output lower than $\dot{V}O_{2max}$, while in the present study, the mean value of P2000 was 113.3% of Pamax. This suggests the predictive value of Ppeak accounts for different physiological abilities. The present study makes it possible to analyse of the physiological factors accounting for the predictive value of Ppeak.

The main determinant of Ppeak was absolute $\dot{V}O_{2max}$. This result is in line with the study by Hawley and Noakes [5] who observed a highly significant relationship between Ppeak and absolute $\dot{V}O_{2max}$ ($r = 0.97$). They concluded that, for trained cyclists, $\dot{V}O_{2max}$

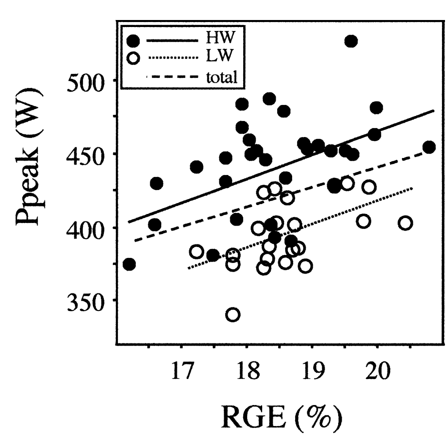

Fig. **3** Relationship between Ppeak and RGE for the whole group and heavyweight (HW) and lightweight (LW) subgroups. Ppeak is the peak power output during the incremental test; RGE is the rowing gross efficiency.

could be accurately predicted from Ppeak. In the present study, the correlation coefficient between Ppeak and absolute $\dot{V}O_{2max}$ was 0.84 (Table **3**), making the prediction less accurate. This would suggest that Ppeak is more influenced by factors independent of $\dot{V}O_{2max}$ than in cycling. The higher homogeneity of the present group probably accounts for this discrepancy as well.

For the studied rowers, Ppeak represented a mean value of 109.2 ± 6% of Pamax. This means that, in the whole studied group, a plateau in $\dot{V}O_{2max}$ was observed during the incremental protocol for the majority of the rowers. This observation is not in agreement with previous studies, which failed to observe any levelling off of $\dot{V}O_2$ at the point of exhaustion. This discrepancy may be due to a specificity of rowing, involving a greater proportion of muscle mass. Åstrand and Saltin [1] observed a given workload to be more easily sustained when involving a greater muscle mass. This is consistent with the ability of rowers to sustain high intensities for a long duration in competition (around 6 min at a mean relative intensity of 113.3% of Pamax for the studied group).

The Ppeak value higher than Pamax accounts for a significant reliance on anaerobic processes. Variation in $\dot{V}O_2La4\%$ significantly influenced variation in Ppeak. Furthermore, Ppeak – Pamax% was significantly related to $\dot{V}O_2La4\%$ (Fig. **2**). In line with this finding, Jacobs et al. [7] observed that a delayed lactate accumulation during incremental test contributed to avoid high blood lactate concentrations after acute exercise. Billat et al. [3] demonstrated that time to exhaustion at 100% of running velocity at $\dot{V}O_{2max}$ was correlated to $\dot{V}O_2La4\%$. The present results demonstrated that $\dot{V}O_2La4\%$ influenced power output above the one corresponding to $\dot{V}O_{2max}$. A possible explanation would be that the ability to remove lactate from the organism is significantly associated with $\dot{V}O_2La4\%$ in rowing [10]. Further studies are needed to assess whether this mechanism accounts for different physiological abilities.

RGE was related to Ppeak. The relationship between RGE and Ppeak is in line with the significant correlation between RGE and P2000. To the best of our knowledge, this relationship has never been shown before in a homogeneous group of highly trained rowers. Russell et al. [16] failed to demonstrate a relationship between efficiency and 2000-m performance time. This could be attributed to the fact that the studied group consisted of inexperienced rowers. It has previously been demonstrated that the efficiency of on-water rowing increases with boat velocity or power output [13,14]. To explain the fact that submaximal RGE was related to rowing performance, it could be supposed that the differences in rowing efficiency were maintained at maximal exercise.

However, as previously noted, the LW and HW groups showed comparable mean RGE values but different Ppeak and P2000 values (Table **1**). In consequence, Fig. **3** shows that the general regression line was situated between two distinct groups of points corresponding to LW and HW. This bias was due to the influence of body mass variation on Ppeak. A way to rule out the influence of body mass on power parameters would be to decrease body mass variability by studying relationships within the HW and LW subgroups.

Interestingly, body mass had no significant influence on P2000 or Ppeak variations in either subgroup. Once the influence of body mass was eliminated, the influence of RGE on both P2000 and Ppeak appeared stronger in the LW and HW subgroups than in the whole group. This finding would seem to indicate that, for a group homogeneous in physiological capacity, the role of technique and/or biomechanical factors is of greater importance. For a given body mass, Ppeak is still the best predictor of rowing performance. In both groups, variation in absolute $\dot{V}O_{2max}$ and $\dot{V}O_{2max} \cdot kg^{-0.57}$ had almost the same influence on P2000 and Ppeak. On the one hand, in the LW subgroup, $\dot{V}O_2La4\%$ had no significant influence on P2000 or on Ppeak. On the other hand, in the HW subgroup, the influence of $\dot{V}O_2La4\%$ on both P2000 and Ppeak appeared stronger than in the whole group. An explanation could be that variability in P2000 (5.2 vs. 7.9% for LW and HW, respectively), Ppeak (5.8 vs. 7.5% for LW and HW, respectively), and $\dot{V}O_2La4\%$ (4. 8 vs. 5.8% for LW and HW respectively) were lower for the LW group. This discrepancy underlines the limits of the use and interpretation of statistical analysis in a sample selected according to specific criteria.

Conclusion

The present results demonstrate that Ppeak is an overall index of both physiological capacity and rowing efficiency in both heterogeneous and homogeneous groups. Both P2000 and Ppeak variations are similarly explained by the same physiological variables. This index is easily obtainable by coaches in field conditions according to the protocol generally used for laboratory testing. Variation in Ppeak could be used to characterize the general ability of rowers and/or to test the efficiency of a training programme.

References

1 Åstrand PO, Saltin B. Maximal oxygen uptake and heart rate in various types of muscular activity. J Appl Physiol 1961; 16: 971 – 977
2 Bergh U, Sjödin B, Forsberg A, Svedenhag J. The relationship between body mass and oxygen uptake during running in humans. Med Sci Sports Exerc 1991; 23: 205 – 211
3 Billat V, Renoux J, Pinoteau J, Petit B, Koralsztein J. Times to exhaustion at 100% of velocity at VO2max and modelling of the time-limit/velocity relationship in elite long-distance runners. Eur J Appl Physiol 1994; 69: 271 – 273
4 Cosgrove MJ, Wilson J, Watt D, Grant SF. The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. J Sports Sci 1999; 17: 845 – 852
5 Hawley JA, Noakes TD. Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. Eur J Appl Physiol 1992; 65: 79 – 83
6 Ingham S, Whyte G, Jones K, Nevill A. Determinants of 2000 m rowing ergometer performance in elite rowers. Eur J Appl Physiol 2002; 88: 243 – 246
7 Jacobs I, Sjödin B, Schéle R. A single blood lactate determination as an indicator of cycle ergometer endurance capacity. Eur J Appl Physiol 1983; 50: 355 – 364
8 Kramer J, Léger A, Paterson D, Morrow A. Rowing performance and selected descriptive, field, and laboratory variables. Can J Appl Physiol 1994; 19: 174 – 184
9 Kuipers H, Verstappen FTJ, Keizer HA, Geurten P, vanKranenburg G. Variability of aerobic performance in the laboratory and its physiologic correlates. Int J Sports Med 1985; 6: 197 – 200

[10] Messonnier L, Freund H, Bourdin M, Belli A, Lacour J-R. Lactate exchange and removal abilities in rowing performance. Med Sci Sports Exerc 1997; 29: 396 – 401

[11] Nevill A. The need to scale for differences in body size and mass: an explanation of Kleiber's 0.75 mass exponent. J Appl Physiol 1994; 77: 2870 – 2873

[12] Noakes TD, Myburgh KH, Schall R. Peak treadmill running velocity during the VO2max test predicts running performance. J Sports Sci 1990; 8: 35 – 45

[13] Nozaki D, Kawakami Y, Fukunaga T, Miyashita M. Mechanical efficiency of rowing a single scull. Scand J Med Sci Sports 1993; 3: 251 – 255

[14] di Prampero PE, Cortili G, Celentano F, Cerretelli P. Physiological aspects of rowing. J Appl Physiol 1971; 31: 853 – 857

[15] Riechman S, Zoeller R, Balasekaran G, Goss F, Robertson R. Prediction of 2000 m indoor rowing performance using a 30 s sprint and maximal oxygen uptake. J Sports Sci 2002; 20: 681 – 687

[16] Russell A, Rossignol PL, Sparrow W. Prediction of elite schoolboy 2000 m rowing ergometer performance from metabolic, anthropometric and strength variables. J Sports Sci 1998; 16: 749 – 754

[17] Snoeckx L, Abeling H, Lambregts J, Schmitz J, Verstappen F, Reneman R. Cardiac dimensions in athletes in relation to variations in their training program. Eur J Appl Physiol 1983; 52: 20 – 28

[18] Steinacker J. Physiological aspects of training in rowing. Int J Sports Med 1993; 14: 3 – 10

[19] Svedenhag J. Maximal and submaximal oxygen uptake during running: how should body mass be accounted for? Scand J Med Sci Sports 1995; 5: 175 – 180