ORIGINAL
ARTICLE

ENGLISH
VERSION

# Energetic cost estimation and contribution of different metabolic pathways in speed kayaking

Fábio Yuzo Nakamura[1,3], Thiago Oliveira Borges[1], Odair Rodrigo Sales[2],
Edilson Serpeloni Cyrino[1] and Eduardo Kokubun[3]

## ABSTRACT

The performance of the speed kayaking depends on the organism capacity of regenerating ATP in large amounts and high rates from different metabolic pathways. Thus, the objective of the present study was to combine two bioenergetic models, the first a generic one, called critical power, and the other specific for kayaking, proposed by Zamparo *et al.* (1999), in the attempt of producing estimations of aerobic and anaerobic fitness for this modality, as well as establishing non-invasive estimations of the contribution of aerobic and anaerobic systems for different distances performed. In that purpose, 11 male kayaking athletes (16.0 ± 1.2 years; 174.0 ± 2.4 cm; 65.2 ± 4.4 kg), performed different distances (500, 1,000 and 1,790 m), at the maximal speed as possible in kayaks type K-1 in a calm water lake. The informations obtained were initially converted into work generated quantity (kJ) and internal power (W). The estimated individual values were afterwards applied to three predictive equations of critical power (PCrit) and anaerobic work capacity (CTAnaer). Finally, the values produced were transformed into oxygen equivalence units for the estimation of the aerobic contribution ($O_2$ equivalence for PCrit x time required to perform the distance) and anaerobic contribution ($O_2$ equivalence for CTAnaer x time required to perform the distance) at the different distances. The relative anaerobic contribution found for the different distances analyzed (500, 1,000 and 1,790 m) was of 60.6; 78.6 and 89.4%, respectively. The results found corroborate the information previously produced by other investigations, suggesting that the procedures adopted in this study may provide reliable estimations on the participation of the energetic pathways on the kayaking performance.

**Key words:** Kayaking. Critical power. Metabolic pathways. Performance.

## INTRODUCTION

The speed kayaking, a sportive modality widely diffused throughout the European continent, is not yet much known in Brazil, despite a large number of river and lakes considered as quite adequate for this sports practice is found in the country, in several regions. However, due to the expressive results recently obtained by Brazilian athletes in international meetings, the speed kayaking has been drawing the media's attention and the sports enthusiasts, in a general manner.

Although the kayaking modality has been disputed since the Berlin Olympic Games (1936), in Germany, few are the available investigations in literature about this modality. This may be explained by the fact that in outdoor modalities such as the kayaking, the behavior of several variables to be investigated may be influenced by weather elements such as the wind, temperature and the air relative humidity.

Thus, the few studies developed on kayaking attempted to characterize the anthropometric profile of athletes(1), to evaluate specific physical fitness indicators for the modality(2), as well as to address bioenergetic aspects associated to submaximal and maximal endurance under controlled laboratory conditions(3,4).

The competition performance of maximal cyclic sportive modalities such as the kayaking depends on the organ-

---

1. Metabolism, Nutrition and Exercise Research and Study Group. Sports and Physical Education Center. Londrina State University.
2. Environmental Protection and Ecosports Association "Patrulha das Aguas" – Londrina.
3. Biosciences Institute. Physical Education Department. State of São Paulo University – Rio Claro, SP.

Received in 13/11/03
2nd version received in 11/1/04
Approved in 21/1/04

**Correspondence to:**
Fábio Yuzo Nakamura
Grupo de Estudo e Pesquisa em Metabolismo, Nutrição e Exercício
Centro de Educação Física e Desportos
Universidade Estadual de Londrina
Rod. Celso Garcia Cid, km 380, Campus Universitário
86051-990 – Londrina, PR – Brasil
E-mail: fabioy_nakamura@yahoo.com.br

ism capacity of regenerating ATP consumed in the muscular contraction at sufficient rates and quantities for the performance of the external work. It is presumed that the capacity of maintaining the intensity of a given maximal exercise is depending on the anaerobic capacity that, when depleted, the exhaustion is established(5).

The relationship between power and effort duration until exhaustion has been objective of many recent studies. Thus, the critical power model has become one of the most frequently models adopted, once it seems to describe properly the responses of the aerobic and anaerobic systems to exhaustive maximal exercise, besides the fact that its physiologic validity has been tested by several studies(6,7).

It is worthy emphasizing that both parameters of the hyperbolic model, the critical power and the anaerobic work capacity, respectively describe the maximal power to be aerobically maintained during the physical exercise and the maximal anaerobic capacity, once these parameters are correlated to other aerobic and anaerobic fitness indicators, also being sensible to the effects of specific trainings.

Originally proposed by Monod & Scherrer(7) for monoarticular exercises, subsequent studies have indicated that the hyperbolic relationship between power and time until exhaustion may be extended to physical efforts involving dislocations, and the existence of a linear relationship between speed and power is admitted. In kayaking, particularly, the internal work that the organism performs, especially by the upper members, should be used in order to overcome the resistance the water provides against the boat advance. In such conditions, the relationship between speed and power does not occur linearly, especially at higher speeds(4).

Therefore, with the purpose of estimating the contribution of the aerobic and anaerobic systems on the kayaking performance, this study attempted to combine two different models of human bioenergetic performance(4,7). For this, the parameters of the critical power model were estimated through the conversion of the dislocation speed of maximal efforts into power units, mechanical work and oxygen equivalents.

## METHODOLOGY

### Subjects

Eleven male speed-kayaking athletes (16.0 ± 1.2 years; 174.0 ± 2.4 cm; 65.2 ± 4.4 kg), of national level competitions from cadet and junior categories with over one year of practical experience in this modality, voluntarily participated in this investigation. After being informed about the objectives of the present study and procedures they would be submitted to, all participants and their parents signed up an informed consent form.

### Kayaking tests

The athletes performed different distances (500, 1,000 and 1,790 m), at maximal speed as possible in kayaks type K-1 (maximal length of 5.2 m and minimal mass of 12 kg) in a calm water lake. Each one of the three tests was preceded by a quick warm-up, where the athletes were to run for 1,000 m at a self-selected rhythm.

At the end of the warm-up exercise, the subjects were positioned at a preestablished point for the start of the distance to be performed at that day. At the sound sign emitted by one of the investigators, the athletes were encouraged to perform at the shortest time as possible the distance proposed, which was recorded with the aid of a digital watch calibrated in seconds. The same procedure was repeated in the three testing occasions.

All three tests were applied along a seven-day period with a 24-hour minimal interval between each. In the attempt of reducing the possible impact of the wind speed, the tests were rather performed in sunny days, with winds both favorable to and against the kayaks' linear movement direction. It is worthy emphasizing that it rained only one out of the seven days. Tests programmed for that day were postponed until weather conditions were reestablished.

### Calculations

The individual time data for the different distances (500, 1,000 and 1,790 m) and the respective average speeds were recorded to be analyzed by means of equations proposed in literature(4,6).

Based on these information, the internal work required to perform the fixed distance of one meter was estimated through equation 1, proposed by Zamparo *et al.*(4) for the different average speeds of water dislocation, recorded at distances of 500, 1,000 and 1,790 meters.

$$C_k = 0.02.\ v^{2,26} \qquad \text{(equation 1)}$$

where $C_k$ represents the dislocation energetic cost in kayaking (kJ.m$^{-1}$), whereas v is the dislocation speed (m.s$^{-1}$). Therefore, according to equation 1, the energetic cost per distance unit is related to the dislocation speed through a power function.

From the conversion of measure units promoted by the equation 1, it was possible to estimate the internal mechanical work required for the distances of 500, 1,000 and 1,790 m to be achieved, as well as the internal mechanical power. In this purpose, the total internal work was calculated through the simple multiplication of $C_k$ by the distance performed, while the power was obtained through the division of the internal mechanical work by the effort time, in seconds.

Following, the individual data regarding effort time, work and power were applied into three models mathematically equivalent(6), according to the critical power model(7), which are presented as follows:

time = CTAnaer/(power – PCrit) (equation 2)
work = CTAnaer + (PCrit . time) (equation 3)
power = PCrit + [CTAnaer . (1/time)] (equation 4)

The estimations of critical power (PCrit) in watts (W) and the anaerobic work capacity (CTAnaer) in joules (J) were then converted into $O_2$ equivalents through the known relationship between the metabolized $O_2$ volume and the mechanical work (20.9 kJ. $lO_2^{-1}$). Thus, one could obtain the respective estimations of the $O_2$ equivalent for the critical power ($EqO_{2PCrit}$), which represents the average oxygen cost for exercises performed at PCrit and the maximal accumulated oxygen deficit (MAOD), that would be a fixed quantity of anaerobic energetic reserve available for the supramaximal effort (above PCrit).

The aerobic and anaerobic energetic contributions were estimated taking into consideration that the MAOD was reached in all distances, once the distances have been performed at maximal speed. Thus, the MAOD value establishes the absolute anaerobic energetic contribution in the exercise. The aerobic contribution was estimated multiplying $EqO_{2PCrit}$ by the effort time in each distance.

### Statistical treatment

The data were initially treated through descriptive procedures. For the estimations of the critical power parameters (PCrit and CTAnaer), the determination correlation coefficient ($r^2$) and the estimation standard errors (EPE) were calculated for each parameter. The analysis of variance (ANOVA) for repeated measures was employed for the comparison between the results obtained from the three tests adopted (500, 1,000 and 1,790 m) as well as for the comparisons between the different equations (1, 2 and 3), according to the critical power model. The Scheffé *post hoc* test for multiple comparisons was used for the identification of differences between averages. The preestablished significance level was of $P < 0.05$.

## RESULTS

The time required for the kayakists to accomplish the distances of 500, 1,000 and 1,790 m and the respective dislocation average speeds are presented on table 1. The average speed values decreased significantly with the increase of the distances performed ($P < 0.05$). The decrease found was on the order of ~4% when the distance was doubled (500 versus 1,000 m) and of ~8% when compared to the distances of 500 and 1,790 m. It is also worthy emphasizing that, although the decrease on the average speed has been proportionally larger when compared to the distances of 500 versus 1,000 m than when compared to the distances of 1,000 versus 1,790 m, statistically significant differences were verified in all comparisons, following the modifications observed in the tests execution time ($P < 0.05$).

**TABLE 1**
**Average values (± SD) of the maximal tests duration of 500, 1,000 and 1,790 m and speed at different distances**

| Distance (m) | Time (s) | Speed ($m.s^{-1}$) |
|---|---|---|
| 500 | 151.4 ± 16.5 | 3.34 ± 0.39 |
| 1,000 | 315.8 ± 33.6* | 3.20 ± 0.36* |
| 1,790 | 591.1 ± 62.5# | 3.06 ± 0.34# |

* Significant difference with relation to 500 m ($P < 0.05$).
\# Significant difference with relation to 500 m and 1,000 m ($P < 0.05$).

The estimations of the $C_k$, the internal mechanical work and the internal mechanical power from the equation proposed by Zamparo *et al.*(4) are found in table 2. Statistically significant differences were verified in the $C_k$ ($P < 0.05$), in the internal work ($P < 0.05$) and in the internal mechanical power ($P < 0.05$) between the different distances. A reduction on $C_k$ (9% and 18%), when analyzed relatively to the distance performed in meters and at the absolute internal mechanical power (13% and 25%), followed by an increase on the absolute internal work (81% and 193%), was verified in the comparisons between 500 and 1,000 m and between 500 and 1,790 m, respectively ($P < 0.05$).

**TABLE 2**
**Average values (± SD) of the energetic cost estimation ($C_k$), the internal mechanical work and the internal mechanical power in maximal tests of 500, 1,000 and 1,790 m**

| Distance (m) | $C_k$ ($kJ.m^{-1}$) | Internal work (kJ) | Internal power (W) |
|---|---|---|---|
| 500 | 0.311 ± 0.085 | 155.5 ± 42.6 | 1,070 ± 431 |
| 1,000 | 0.282 ± 0.074* | 282.1 ± 74.2* | 928 ± 359* |
| 1,790 | 0.255 ± 0.066# | 455.8 ± 117.4# | 800 ± 301# |

* Significant difference with relation to 500 m ($P < 0.05$).
\# Significant difference with relation to 500 m and 1,000 m ($P < 0.05$).

The figure 1 illustrates the values of the internal mechanical work, the internal mechanical power and the effort time of an investigated athlete, applied to the equations 2, 3 and 4, according to the critical power model. Through visual inspection, the performance data seem to

### TABLE 3
### Average values (± SD) of the critical power (PCrit), the anaerobic work capacity (CTAnaer), the estimation standard error (EPE) and the determination coefficient ($r^2$), provided by the equations (2, 3 and 4) according to the critical power model

| Equation | PCrit (W) | EPE (1) | CTAnaer (kJ) | EPE (2) | $r^2$ |
|---|---|---|---|---|---|
| (2) | 682 ± 250 | 15.6 ± 11.2 | 67.0 ± 27.3 | 10.1 ± 6.5 | 0.987 ± 0.012 |
| (3) | 702 ± 258 | 39.8 ± 27.5* | 58.9 ± 22.7* | 15.3 ± 9.9$^{\$}$ | 0.998 ± 0.002 |
| (4) | 732 ± 270$^{\#}$ | 48.1 ± 33.6* | 49.9 ± 20.0$^{\#}$ | 10.7 ± 7.0 | 0.963 ± 0.037$^{\#}$ |

* Significant difference with relation to 500 m ($P < 0.05$).
# Significant difference with relation to 500 m and 1,000 m ($P < 0.05$).
$ Significant difference with relation to 500 m and 1,790 m.
**Note:** EPE (1) with regard to PCrit; EPE (2) with regard to CTAnaer.

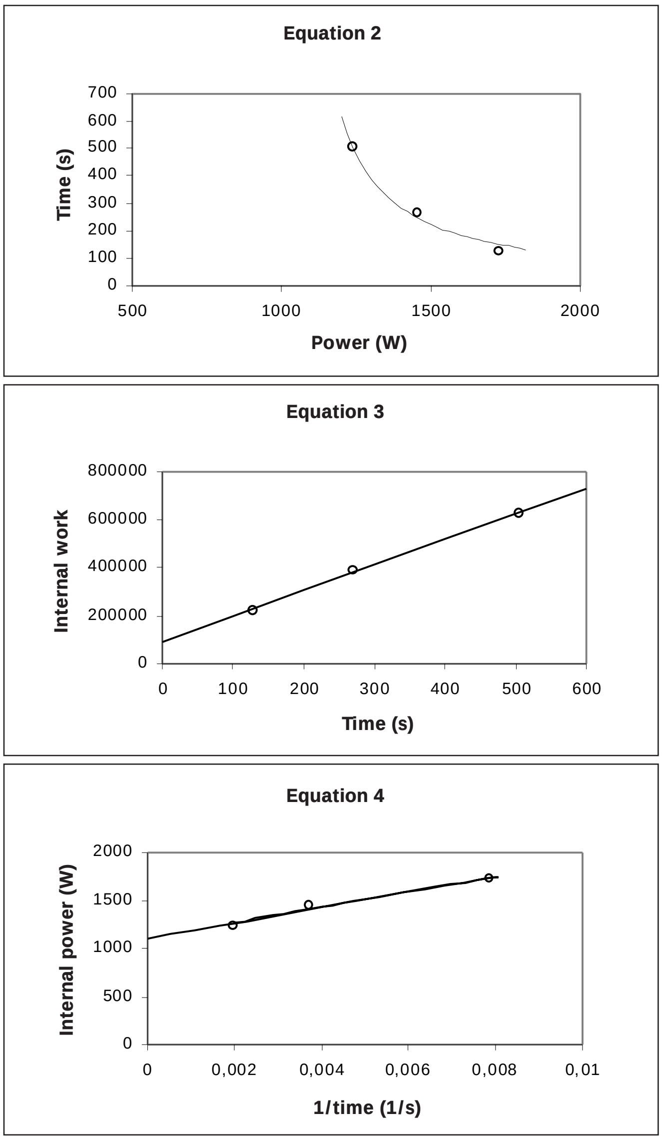

***Fig. 1** – Illustrations of the application of equations 2, 3 and 4 from the article to data of internal mechanical work, internal mechanical power and efforts duration of an analyzed kayakist*

be suitable for the equations used. This fact could be also confirmed through the high determination coefficient values ($r^2$) presented on table 3.

The table 3 contains information about PCrit and CTAnaer estimated through equations 2, 3 and 4, followed by the respective estimation standard errors (EPE) and by the determination coefficient ($r^2$). Significant differences were verified in both, the estimations of PCrit provided by the different equations ($P < 0.05$), with the largest values found through equation 4 ($P < 0.05$) and the estimations of CTAnaer ($P < 0.05$) with the largest values found through equation 2 ($P < 0.05$). The average EPE of PCrit provided by the equation 2 was smaller ($P < 0.05$) than those verified in equations 3 and 4, whereas the average EPE of CTAnaer provided by equation 3 was smaller ($P < 0.05$) than those verified in equations 2 and 4. With regard to the values of $r^2$, associations significantly higher in equations 2 and 3 when compared to the equation 4 ($P < 0.05$) were verified.

The conversion of the PCrit and CTAnaer values into $O_2$ equivalents produced estimated values of $EqO_{2PCrit}$ and MAOD (table 4). Significant differences were verified in the comparisons between the equations both for the $EqO_{2PCrit}$

### TABLE 4
### Average values (± SD) of the $O_2$ equivalent for the critical power ($EqO_{2PCrit}$) and maximal accumulated oxygen deficit (MAOD)

| Equation | $EqO_{2PCrit}$ ($l.min^{-1}$) | MAOD (l) |
|---|---|---|
| (2) | 1.96 ± 0.72 | 3.21 ± 1.31 |
| (3) | 2.02 ± 0.74 | 2.82 ± 1.08* |
| (4) | 2.10 ± 0.78$^{\#}$ | 2.39 ± 0.96$^{\#}$ |

* Significant difference with relation to 500 m ($P < 0.05$).
$^{\#}$ Significant difference with relation to 500 m and 1,000 m ($P < 0.05$).
**Note:** Values estimated from the different equations (2, 3 and 4) according to the critical power model.

($P < 0.05$) and for the MAOD ($P < 0.05$). The highest value of $EqO_{2PCrit}$ was found through the equation 4 ($P < 0.05$), approximately 7% and 4% higher than the values generated through equations 2 and 3, respectively. On the other hand, the MAOD found through equation 2 was significantly higher ($P < 0.05$) than the value estimated through equations 3 (14%) and 4 (34%).

Table 5 presents the estimations of the distance total $O_2$ cost (the sum of the absolute contributions of the aerobic and anaerobic systems of energetic transference) as well as the aerobic and anaerobic contributions estimated for the distances of 500, 1,000 and 1,790 m, from the presupposed application of the critical power model(7), combined with the equation proposed by Zamparo *et al.*(4), for the calculation of $C_k$. Statistically significant differences were verified both in the $O_2$ ($P < 0.05$) cost and in the contribution percentage of the aerobic and anaerobic systems ($P < 0.05$). The $O_2$ cost for the distance of 500 m was 39% and 64% lower than the cost observed for the distances of 1,000 m and 1,790 m, respectively. Thus, the results indicated a smaller contribution of the aerobic system for the distance of 500 m and, as result, a larger contribution of the anaerobic system (23% and 32%, when compared to the distances of 1,000 m and 1,790 m, respectively).

**TABLE 5**
**Average values (± SD) of the total energetic cost in $O_2$ equivalent of distances of 500, 1,000 and 1,790 m and aerobic and anaerobic contributions for the different distances**

| Distance (m) | $O_2$ cost (l) | Aerobic contribution (%) | Anaerobic contribution (%) |
|---|---|---|---|
| 500 | 8.0 ± 2.2<br>(6.5-9.5) | 60.6 ± 9.2<br>(54.4-66.8) | 39.4 ± 9.2<br>(28.7-41.1) |
| 1,000 | 13.1 ± 3.4*<br>(10.8-15.4) | 78.6 ± 4.9*<br>(75.3-81.9) | 21.4 ± 4.9*<br>(18.1-24.7) |
| 1,790 | 22.4 ± 5.8#<br>(18.5-26.3) | 89.4 ± 2.6#<br>(87.7-91.1) | 10.6 ± 2.6#<br>(8.9-12.3) |

* Significant difference with relation to 500 m ($P < 0.05$).
# Significant difference with relation to 500 m and 1,000 m ($P < 0.05$).
**Note:** Values between parentheses represent the confidence interval limits of 95%.

## DISCUSSION

The speed kayaking is a sport modality performed in calm waters in kayaks for one (K-1), two (K-2) or four (K-4) athletes, while the competition official distances are 200, 500 and 1,000 m. In this study, only athletes using kayaks type K-1 were investigated.

In the present study, the contribution of the energetic systems was estimated from the different distances performed by competition kayakists. Furthermore, the combination between two mathematical models: a generic bioenergetic model called critical power model and a specific model for the kayaking energetic cost estimation was tested in the attempt of producing parameters of aerobic and anaerobic fitness specific for speed kayaking.

The first model, known as the critical power model(7), presupposes the existence of two energetic parameters (PCrit and CTAnaer) related to the performance at different types of physical exercises. The PCrit represents the maximal power that could be maintained for a long period at the expense of the aerobic metabolism(7,8), while the CTAnaer represents the maximal quantity of work generated from the intramuscular reserve of high energy phosphagen and from the anaerobic glycolisis(7). Thus, the PCrit is coincident with the maximal steady-state of $\dot{V}O_2$ and lactate(9), being used as an indicator of the aerobic capacity(10).

On the other hand, the CTAnaer may be quantitatively compared to the MAOD, also showing a good correlation with this index(11), thus being considered as a valid measure of the anaerobic capacity(12).

The second model was developed specifically for speed kayaking(4). Through the direct measures of $\dot{V}O_2$ and blood lactate, and through the estimation of the muscular phosphagen concentrations, the model's authors proposed an equation for the forecast of the energetic cost of human dislocation in kayaks at different speeds.

Therefore, the approach proposed in the present study may be considered as original, once it seeks to combine two different mathematical models of mechanical and bioenergetic performances.

The equation of Zamparo *et al.*(4) for the determination of the kayaking energetic cost was employed for the forecasting of the internal work and power produced in each distance performed by kayakists. These data, in addition to the respective tests duration, were used for solving equations 2, 3 and 4, which provided estimations of PCrit and CTAnaer. The estimations produced are non-conventional, once they reflect internal parameters rather than parameters externally measured, as proposed by Monod & Scherrer(7).

One of the criterions for the estimations provided by equations 2, 3 and 4 to be reliable is that the differences between the values of PCrit and CTAnaer produced by such equations are not significant(6). Thus, it would be desirable that the variability between the equations was below 10%, above all for the CTAnaer could be considered as an accurate measure of the anaerobic capacity(11), which valid measure is provided by the MAOD.

In the present study, the presence of significant differences between the estimations of CTAnaer and consequently of MAOD between the three equivalent equations reflects the presence of probable systematic errors in the empiric data regarding the tests. This may indicate that the equation proposed by Zamparo *et al.*(4) or the critical power model are not adequate for the conditions of this study.

The variability between the estimations of CTAnaer from the three equations in this study was higher than the variability proposed by Hill & Smith(11), reaching 25% when the lowest and the highest average values are compared (equations 4 and 2, respectively). On the other hand, the values of PCrit varied only 7%. As the difference between the parameters provided by the different equations was significant, the random utilization of any of them in the subsequent analyses could influence the results interpretation. Thus, the equation 2 was adopted as referential of analysis in this study, once it places mathematically right the dependent (time) and the independent (power) variables, fact that does not occur to the other equations, thus being considered by some researchers(13), as the most adequate equation among all equations employed.

The EPE produced by the three equations employed should also be below 10% so that the CTAnaer would reflect the MAOD precisely, keeping in mind that a high EPE leads to considerable random errors in the results modeling of exhaustion tests, according to the equations of the critical power model(11). In the present study, the EPE of the CTAnaer found ranged from 15% to 25%, whereas the EPE variation of the PCrit ranged from 2% to 6%.

The results indicate that the CTAnaer is more susceptible to the variation due to systematic and random errors of tests treated from the equation of Zamparo *et al.*(4). These results corroborate with findings of Moysés *et al.*(14) that, when investigating the critical power model in 20 m bidirectional running, reported high values of the systematic and random errors for CTAnaer, when compared to those associated to the PCrit.

The PCrit and CTAnaer estimations generated through equation 2 were used for the calculation of $EqO_{2PCrit}$ and MAOD. The MAOD confidence interval estimated in the present study includes the averages found by Faina *et al.*(15) (3,2 l and 3 l, respectively), for elite kayakists submitted to high-intensity arm cycle ergometer exercise, adapted to simulate the paddling movement and frequency, typical of the modality. It is worthy emphasizing that in this study, the researchers have determined the MAOD according to the recommendations originally proposed by Medbo *et al.*(12), through the use of indirect calorimetry procedures for the attainment of the $\dot{V}O_2$.

On the other hand, the $EqO_{2Pcrit}$ found in this study (1.96 $l.min^{-1}$) could not be compared to results from other studies available in literature by being considered as an unusual measure. It is also worthy emphasizing that the $EqO_{2PCrit}$ is an estimation of the average aerobic contribution per time unit along the complete exercise, not taking into consideration the $\dot{V}O_2$ inertia. Therefore, the $EqO_{2PCrit}$ measure overestimates the actual $\dot{V}O_2$ value at the beginning of the exercise and underestimates it at the end of it.

At the final phase of this study, the $EqO_{2Pcrit}$ and the MAOD were employed for the estimations of the aerobic and anaerobic systems percentile contribution during the different distances performed at maximal speed by kayakists. According to the presupposition of the critical power model in which the $EqO_{2Pcrit}$ and the MAOD are fixed in exhaustive activities, the aerobic system percentile contribution increased with the increased distance performed. Consequently, the anaerobic system percentile contribution was higher in shorter distances.

The estimations found for the distance of 500 m were similar to estimations reported by Zamparo *et al.*(4) (60% and 40% of aerobic and anaerobic contributions, respectively). On the other hand, for the distance of 1,000 m, Zamparo *et al.*(4) found an aerobic contribution slightly higher than the contribution found in this study (83% versus 79%), although within the confidence interval established in our study for this variable.

On figure 2, the data obtained in the present study were superposed to a data compilation from the literature performed by Gastin(16), with regard to the aerobic system relative contribution at different maximal exercises. It is observed that the confidence interval of the present study is within the compiled data. These results indicate that energetic contribution estimations according to procedures used in this study result in values comparable to those reported in literature for other types of exercise.

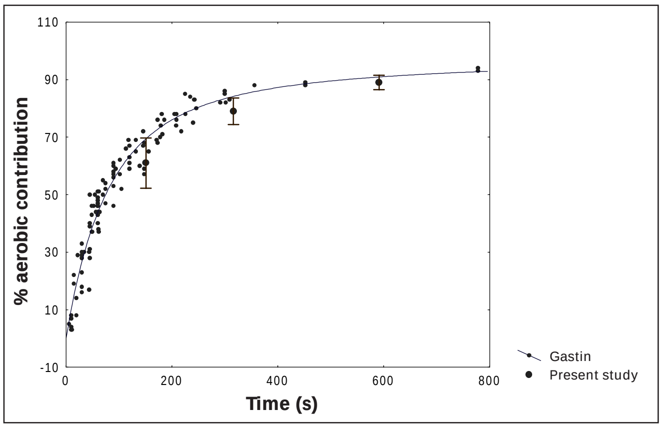

***Fig. 2** – Aerobic metabolism relative contribution in efforts of different durations. Data from literature revision work published by Gastin(16).*

## CONCLUSIONS

The informations produced in the present study suggest that the association between the critical power model and the equation proposed by Zamparo *et al.*(4) for the determination of the kayaking energetic cost provide interesting estimations about the aerobic and anaerobic fitness, represented by $EqO_{2PCrit}$ and MAOD, respectively. Furthermore, the presuppositions adopted in this study also seem to enable the forecasting of the aerobic and anaerobic energetic systems relative contributions at different distances in the speed kayaking, with no need of invasive procedures or procedures of direct determination of physiological variables.

---

*All the authors declared there is not any potential conflict of interests regarding this article.*

---

## REFERENCES

1. Gobbo LA, Papst RR, Carvalho FO, Souza CF, Cuattrin S, Cyrino ES. Perfil antropométrico da seleção brasileira de canoagem. Rev Bras Ciên Mov 2002;10:7-12.
2. Fontes EB, Borges TO, Altimari LR, Melo JC, Okano AH, Cyrino ES. Influência do número de coordenadas e da seleção de distâncias na determinação da velocidade crítica na canoagem de velocidade. Rev Bras Ciên Mov 2002;10:S161.
3. Pendergast DR, Bushnell D, Wilson DW, Cerretelli P. Energetics of kayaking. Eur J Appl Physiol Occup Physiol 1989;59:342-50.
4. Zamparo P, Capelli C, Guerrini G. Energetics of kayaking at submaximal and maximal speeds. Eur J Appl Physiol Occup Physiol 1999;80: 542-8.
5. Morton RH, Billat V. Maximal endurance time at $VO_{2max}$. Med Sci Sports Exerc 2000;32:1496-504.
6. Hill DW. The critical power concept: a review. Sports Med 1993;16: 237-54.
7. Monod H, Scherrer J. The work capacity of a synergic muscular group. Ergonomics 1965;8:329-38.
8. Moritani T, Nagata A, DeVries HA, Muro M. Critical power as a measure of physical work capacity and anaerobic threshold. Ergonomics 1981; 24:339-50.
9. Poole DC, Ward SA, Gardner GW, Whipp BJ. Metabolic and respiratory profile of the upper limit for prolonged exercise in man. Ergonomics 1988;31:1265-79.
10. Poole DC, Ward SA, Whipp BJ. The effects of training on the metabolic and respiratory profile of high-intensity cycle ergometer exercise. Eur J Appl Physiol Occup Physiol 1990;59:421-9.
11. Hill DW, Smith JC. A method to ensure the accuracy of estimates of anaerobic capacity derived using the critical power concept. J Sports Med Phys Fitness 1994;34:23-37.
12. Medbo JI, Mohn AC, Tabata I, Bahr R, Vaage O, Sejersted OM. Anaerobic capacity determined by maximal accumulated $O_2$ deficit. J Appl Physiol 1988;64:50-60.
13. Gaesser GA, Carnevale TJ, Garfinkel A, Walter DO, Womack CJ. Estimation of critical power with nonlinear and linear models. Med Sci Sports Exerc 1995;27:1430-8.
14. Moysés EP, Nakamura FY, Nakamura PM. Confiabilidade e validade dos parâmetros do modelo de potência crítica em testes "vai-e-vem" de 20 metros. Motriz 2003;9:S53-4.
15. Faina M, Billat V, Squadrone R, De Angelis M, Koralsztein JP, Dal Monte A. Anaerobic contribution to the time to exhaustion at the minimal exercise intensity at which maximal oxygen uptake occurs in elite cyclists, kayakists and swimmers. Eur J Appl Physiol Occup Physiol 1997;76: 13-20.
16. Gastin PB. Energy system interaction and relative contribution during maximal exercise. Sports Med 2001;31:725-41.