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Artigo original

Fábio Yuzo Nakamura [1]
Nilo Massaru Okuno [1]
Camila Ferreira Infante Rosa [1]
Edilson Serpeloni Cyrino [1]
Herbert Gustavo Simões [2]
Fernando Roberto de-Oliveira [3]
Jefferson Rosa Cardoso [1]
Eduardo Kokubun [4]

EFFECTS OF PREVIOUS SEVERE EXERCISE ON TWO AND THREE PARAMETER CRITICAL POWER MODELING

EFEITO DO EXERCÍCIO PRÉVIO SEVERO NO MODELO DE POTÊNCIA CRÍTICA DE DOIS E TRÊS PARÂMETROS

Resumo

The purpose of this study was to apply the two and three-parameter critical power model equations after depletion of a fixed amount of anaerobic work capacity (AWC), followed by a short rest period. Sixteen subjects underwent: (1) two practice trials for ergometer familiarization to severe exercise; (2) 4-5 exercise bouts on different days for the estimation of critical power (CP) and AWC using the two and three parameter models; (3) the same procedures as described in stage 2 were repeated after 30 s recovery from 180 s of exercise completed at an intensity that would have elicited exhaustion in around 300 s. The $CP_{2parameter}$ (130-174 W versus 131-170 W) and $CP_{3parameter}$ (108 versus 100 W) estimated after prior severe exercise followed by a short rest period remained stable compared to the fatigue-free tests. The $AWC_{2parameter}$ was reduced in response to prior severe exercise. The $AWC_{3parameter}$ was not significantly reduced. The correlations between $CP_{2parameter}$ derived from the same equation with and without prior $AWC_{2parameter}$ reduction were strong (r = 0.97-0.99, P < 0.001). The correlation was merely moderate (r = 0.62, P = 0.01) when $CP_{3parameter}$ was analyzed. It can be concluded that the two-parameter critical power model provides a coherent mathematical description of the reduced mechanical output induced by a prior fatiguing task, since $AWC_{2parameter}$ was affected while $CP_{2parameter}$ estimates remained constant.

Key words: Critical power; Anaerobic work capacity; Prior exercise.

Abstract

O propósito do presente estudo foi aplicar as equações do modelo de potência crítica de dois e três parâmetros após a depleção de uma quantia fixa de capacidade de trabalho anaeróbio (AWC), seguido de um período curto de repouso. Dezesseis sujeitos realizaram: (1) duas familiarizações ao exercício severo no cicloergômetro; (2) 4-5 exercícios máximos em dias diferentes para a estimativa da CP e AWC por meio dos modelos de dois e três parâmetros; (3) os mesmos procedimentos descritos no #2 foram realizados após 30 s de repouso e de um exercício de 180 s a uma intensidade em que a exaustão provavelmente ocorreria em ~300 s. A $CP_{2parameter}$ (130-174 W versus 131-170 W) e $CP_{3parameter}$ (108 versus 100 W) estimadas após o exercício prévio severo e seguido por um curto período de repouso permaneceu estável quando comparado às estimativas sem o exercício prévio. A $AWC_{2parameter}$ foi diminuída em resposta ao exercício prévio severo. A $AWC_{3parameter}$ não foi significativamente reduzida. As correlações entre $CP_{2parameter}$ derivados da mesma equação com e sem a redução prévia da $AWC_{2parameter}$ foram fortes (r = 0,97-0,99; P < 0,001). Para a $CP_{3parameter}$ a correlação foi somente moderada (r = 0,62; P = 0,01). Assim, pode ser concluído que o modelo de potência crítica de dois parâmetros promove descrições matemáticas coerentes quando é induzido um exercício prévio, sendo que a $AWC_{2parameter}$ foi alterada enquanto que a estimativa da $CP_{2parameter}$ permaneceu constante.

Palavras-chave: Potência crítica; Capacidade de trabalho anaeróbio; Exercício prévio.

1 Universidade Estadual de Londrina – Londrina, PR
2 Universidade Católica de Brasília – Brasília, DF
3 Universidade do Estado de Santa Catarina – Florianópolis, SC
4 Universidade Estadual Paulista – Rio Claro, SP

Rev. Bras.Cineantropom. Desempenho Hum. 2007;9(3):215-222

INTRODUCTION

The physiological significance of the two-parameter traditional critical power model[1] has been extensively investigated. In general, maintenance of critical power ($CP_{2parameter}$) intensity is associated with the occurrence of maximal steady state of physiological variables such as blood lactate and oxygen consumption in different exercise modes[2,3]. However, some studies have contested these collective findings, reporting evidence of low and/or no significant association between $CP_{2parameter}$ and different aerobic capacity indexes[4,5]. On the other hand, $CP_{2parameter}$ has been associated with long term endurance performance[6,7] and was demonstrated to be responsive to continuous and intermittent endurance training programs.[8,9]

Anaerobic work capacity ($AWC_{2parameter}$) exhibits equivalence and correlation with maximal accumulated oxygen deficit (MAOD)[10,11] in addition to being moderately correlated with mean power output recorded during the 30 s Wingate test.[12] Furthermore, it was demonstrated that $AWC_{2parameter}$ is acutely diminished after glycogen depletion[13] and increases chronically in response to both anaerobic intermittent training[9] and resistance training[14].

Despite the relative success of employing the two-parameter critical power model, some weaknesses can be raised with regard to the assumptions it makes. At first glance, the asymptotes of the power-time hyperbola do suggest infinite behaviors for both variables. This fact violates the empirical existence of limits to the human body's ability to generate infinite work and/or power at the extreme boundaries of exercise. Morton[15] suggests that the glycogen stores are not completely depleted by anaerobic metabolism during exhaustive exercise trials. Therefore, the real AWC is probably underestimated by the two-parameter critical power model.

Aiming to overcome these limitations of the two-parameter model, the author[15] proposed the introduction of a third parameter, representative of the maximal muscular power output generated during instantaneous activities (P_{max}). If the validity of this alternative model is confirmed by the literature, new theoretical bridges to the critical power model must be tested in the future. The CP and AWC parameters of Morton's model[15] and of Monod and Scherrer[1] exhibit systematic differences[16-18]. Generally, the $CP_{2parameter}$ is greater than $CP_{3parameter}$, whilst the opposite pattern is observed when the $AWC_{2parameter}$ and $AWC_{3parameter}$ are compared.

Concerning the physiological significance of the parameters originated from Morton's model, Gaesser *et al.*[16] reported no differences between exercise intensities associated with the three-parameter critical power ($CP_{3parameter}$) and long-term ventilatory threshold as identified by the exercise intensity at which no increase in minute-ventilation is observed between 20 and 40 min of exercise. Bull *et al.*[19] demonstrated that the amplitude of EMG signals does not describe a slope different from zero during 60 min of exercise on a cycle ergometer at $CP_{3parameter}$, suggesting there is no neuromuscular fatigue at this intensity.

As is observed with $AWC_{2parameter}$, the anaerobic work capacity derived from Morton's model ($AWC_{3parameter}$) is correlated with MAOD[11]. To our knowledge, there are no further studies concerning possible experimental manipulations of this parameter, or determination of its physiological correlates.

The parameters of the traditional critical power model are relatively independent of each other in response to isolated experimental manipulation. For example, Moritani *et al.*[20] demonstrated that under acute hypoxia, only $CP_{2parameter}$ was reduced, while $AWC_{2parameter}$ remained stable. In a comprehensive study, Morton and Billat[21] proposed a critical power model for intermittent exercise. According to their results, the estimated CP from intermittent bouts of running was significantly lower than $CP_{2parameter}$ as derived from continuous trials, while AWC remained stable under both exercise conditions. Their calculations were based on the drain on anaerobic stores during work bouts and partial repletion during rest periods. The latter variable was assumed to be dependent on the difference between $CP_{2parameter}$ and power output during rest phases.

Despite evidence concerning the validity and physiological significance of the critical power model parameters in continuous and intermittent exercise, there are few investigations on the stability of $CP_{2parameter}$ and $CP_{3parameter}$ after partial AWC utilization using different depletion models. For example, Heubert *et al.*[22] pointed out that, after partial reduction of $AWC_{2parameter}$ induced by 7 s sprint stimulus, $CP_{2parameter}$ was not significantly modified. However, there was no pause between the 7 s sprint stimulus and the different predictive trials used to estimate $CP_{2parameter}$.

Considering that the effects of these types of intervention have not yet been analyzed for $CP_{3parameter}$, the purpose of this study was to extend the findings of Morton and Billat[21] and Heubert *et al.*[22] by the application of both two and three-parameter critical power model equations after depletion of a fixed amount of AWC, followed by a short rest period. The hypothesis was that both $CP_{2parameter}$ and $CP_{3parameter}$, as identified after partial depletion of AWC, would be stable even under reduced performance during predictive trials. Furthermore, it was expected that $AWC_{2parameter}$ and $AWC_{3parameter}$ would not be stable after the partial depletion period, even with the inclusion of the rest period.

METHODS

Sixteen subjects (11 males and five females) took part of this study (22.7 ± 3.3 yrs; 73.6 ± 11.9 kg; 175.1 ± 9.0 cm). They provided written free and informed consent to participation in the study, which itself was given ethical approval by the local Human Research Ethics Committee.

This study was divided in three phases: (1) two practice trials for ergometer familiarization to the severe exhaustive exercise; (2) 4-5 exercise bouts on different days for the estimation of CP and AWC using the two and three-parameter models; (3) the same procedures as described in phase 2 were undertaken

Rev. Bras.Cineantropom. Desempenho Hum. 2007;9(3):215-222

after 30 s recovery from 180 s of exercise at an intensity corresponding to that at which the participant would be exhausted in around 300 s. The prior severe exercise intervention was applied in order that the subsequent exercise trials would be performed in a state of partial AWC depletion.

Subjects were asked to avoid participation in vigorous physical activities in the 24 h period before each test. They were instructed to remain in a fasting state in the 3 h period preceding the tests, and not to ingest beverages containing alcohol or caffeine in the preceding 24 h. All procedures were conducted within a four-week period.

Practice trials

A Monark® cycle ergometer with frictional flywheel resistance was employed for all stages of this study. The seat height was adjusted according to the individual's lower limb length (aligned to the greater trochanter of the femur when subjects were in a standing position). On alternate days, the volunteers underwent two bouts of very high intensity exercise on the ergometer until voluntary exhaustion. The aim of these practice trials was to allow the subjects to become familiarized with the type of effort to which they would be submitted during the predictive trials for estimating critical power model parameters. In general, the predictive trials provoked exhaustion within a range of 0.5-10 min. These trials served to inform the choice of intensities for subsequent phases of the study. Their results were not used in any analyses. All practice sessions were preceded by a five minute warm-up period without load, followed by a rest period of equal duration.

Predictive trials

Four or five all-out exhaustive trials were used to estimate $CP_{2parameter}$, $CP_{3parameter}$, $AWC_{2parameter}$ and $AWC_{3parameter}$. In general, participants reached exhaustion within 0.5-10 min during trials. In some cases, the longest trial exceeded the duration range previously established by some minutes. None exceeded a duration of 15 min. The choice of power output that would induce exhaustion within this period was based on the duration of the practice trials. Subjects performed the predictive trials in a random order on subsequent days with at least a 24-hour recovery interval. It was assumed that this period was long enough to allow glycogen stores to be replenished[23]. A previous study had shown that a 3 h period of rest was sufficient to provide valid estimation of parameters[24].

Velocity was fixed at around 28 $km.h^{-1}$ and exhaustion was defined as when the subjects were unable to maintain trials at this velocity for longer than five seconds despite strong verbal encouragement. Time to exhaustion was measured to the nearest second.

In order to fit individual results to the two-parameter critical power model, the following equations were solved[25]:

$Time = AWC_{2parameter} / (Power - CP_{2parameter})$ [Nonlinear-2]
$Work = AWC_{2parameter} + CP_{2parameter} \cdot time$ [Linear W-T]
$Power = CP_{2parameter} + AWC_{2parameter} / time$ [Linear P-1/T]

The three-parameter critical power model equation according to Morton[15] is:

[Nonlinear-3]
$$Time = [AWC_{3parameter} / (Power - CP_{3parameter})] + [AWC_{3parameter} / (CP_{3parameter} - P_{max})]$$

Where $AWC_{2parameter}$ is the two parameter anaerobic work capacity; $CP_{2parameter}$ is the two parameter critical power; $AWC_{3parameter}$ is the three parameter anaerobic work capacity; $CP_{3parameter}$ is the three parameter critical power; and P_{max} is the maximal muscular power output generated during instantaneous activities.

Critical power parameter estimates after partial AWC depletion.

The participants performed the same 4-5 power output trials performed in the preceding stage, after partial AWC depletion. Partial depletion was induced by means of an exercise trial of 180 s duration at a power output that, according to the Nonlinear-2 equation, corresponded to that at which the subject would become exhausted in 300 s. Subjects remained seated and recovered for 30 s following the high intensity exercise. The subjects then performed one trial according the description of the 4-5 predictive trials mentioned above, until voluntary exhaustion was attained.

The test results after partial AWC depletion were fitted to the equations of the two and three-parameter critical power models.

Statistical analysis.

Results were expressed as means with standard deviations (± SD). Estimation of CP, AWC and P_{max} was performed by linear and nonlinear regressions. Pearson product moment correlations were used to quantify the relationships between parameter pairs. Analysis of variance for repeated measures was used to compare CP estimated by different equations, with and without prior depletion and also for AWC. Mauchly's sphericity test was applied, and whenever this test was violated, the necessary technical corrections were made using the Greenhouse-Geisser test. Whenever the F test indicated statistical significance, the analysis was complemented by means of the Bonferroni multiple comparison test. The limit of statistical significance was set at 5% ($P \leq 0.05$). Data was analyzed using the Statistical Package for Social Sciences (SPSS), version 11.5 for Windows.

RESULTS

Mean power output values for the longest and shortest tests for estimating the conventional model parameters were 169 ± 55 W and 423 ± 58 W, respectively. Their durations were 546 ± 92 s and 37 ± 7 s.

The $CP_{2parameter}$ and $CP_{3parameter}$ after partial AWC depletion were estimated at a power output of 204 ± 63 W. This value represents around 135% of mean

$CP_{2parameter}$ and 207% of $CP_{3parameter}$.

There were statistically significant differences between $CP_{2parameter}$ and $CP_{3parameter}$ estimates (Table 1). All of the estimates derived from the two-parameter model equations differed from each other, and the Linear W-T and Linear P-1/T equations provided greater $CP_{2parameter}$ values when compared to $CP_{3parameter}$ values ($P < 0.01$). The same pattern was observed when the $AWC_{2parameter}$ results were compares, with the exception that none of the $AWC_{2parameter}$ estimates exhibited significant difference when contrasted with $AWC_{3parameter}$. The pairs of estimates of $CP_{2parameter}$ derived from the three equations with and without prior AWC depletion did not differ. The same occurred when analyzing $CP_{3parameter}$, $AWC_{3parameter}$ and P_{max}. Nevertheless, $AWC_{2parameter}$ exhibited lower values in the post depletion period trials, compared to those trials that were not preceded by bouts of high intensity exercise.

Figure 1(A-D) illustrates the effects of prior AWC depletion on the CP estimates through different equations. It can nevertheless be observed that the asymptotes of the hyperbolic functions were not changed by the prior manipulation of AWC for either the two or the three-parameter model. In the linear equations, the same pattern was observed, in that in the linear W-T function the regression lines were parallel, while in the linear P-1/T function there was a common y intercept in response to both experimental conditions.

Figure 2 illustrates the relationships between $CP_{2parameter}$ estimates, as determined by the different equations, and $CP_{3parameter}$ in situations with and without prior AWC depletion. It is observed, particularly for the estimates of $CP_{2parameter}$, that these correlations were strong (r = 0.97 - 0.99; $P < 0.001$). The correlation for $CP_{3parameter}$ estimates was lower, but still significant (r = 0.62; P = 0.01). After elimination of two outliers, the correlation increased to 0.87 ($P < 0.001$).

The correlations between estimates of $AWC_{2parameter}$ and of $AWC_{3parameter}$ with and without prior depletion were moderate to strong (r = 0.62 - 0.85; $P \leq 0.01$). The correlation of estimated P_{max} for the different situations was 0.58 ($P < 0.05$).

DISCUSSION

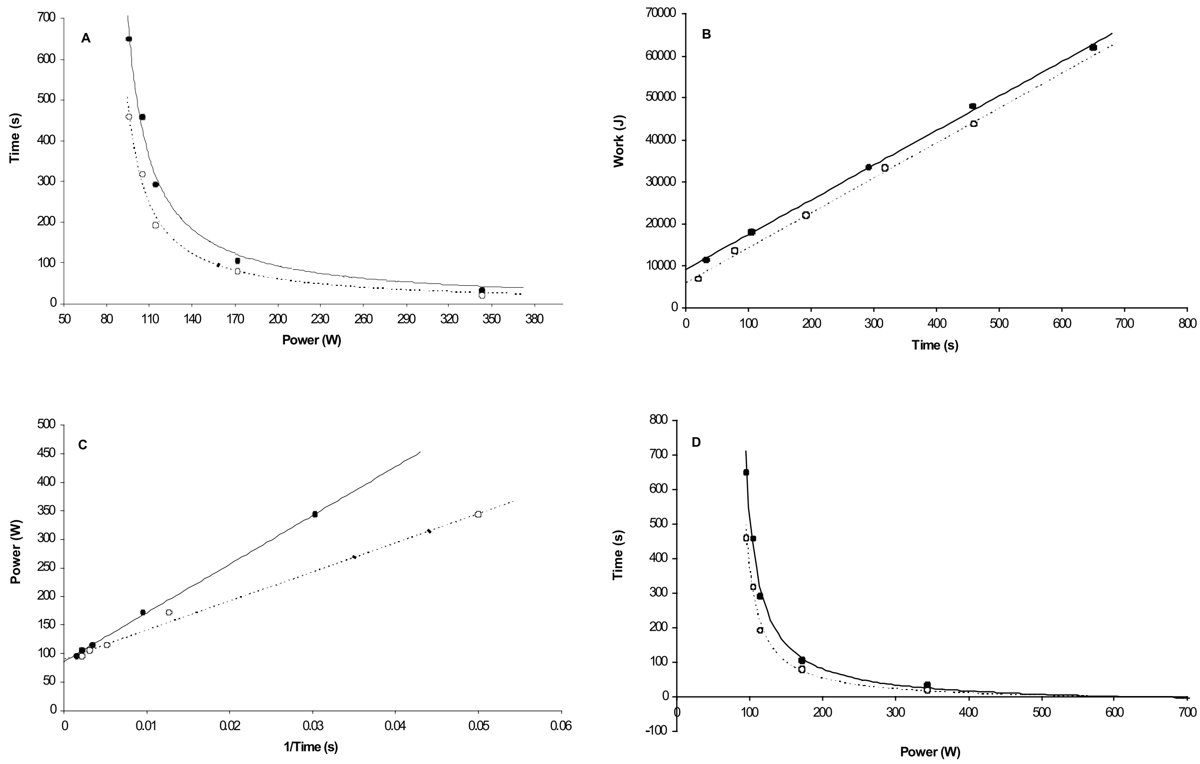
The present study investigated the effect of partial AWC depletion on the two and three-parameter critical power modeling of performance. The main finding was that both $CP_{2parameter}$ and $CP_{3parameter}$ remained stable after the fatiguing task. In contrast, AWC estimated from the two-parameter mathematical model was significantly reduced, while the estimate provided by the three-parameter model was unchanged. In general, these results corroborated the main assumptions of the critical power model constructs.

The variability between $CP_{2parameter}$ estimates and the associated standard error of estimate (SEE) of the measures may reflect the presence of errors in data acquisition, which can potentially compromise their sensitivity. Specifically in relation to the estimates of $AWC_{2parameter}$ derived using different equations and the associated SEE, Hill and Smith[10] suggested that the relatively high levels (>10-20%) of variability between the different equations and the high SEE values were

Table 1 – Mean ± SD for estimated CP, AWC and P_{max} with and without prior AWC partial depletion, with their respective standard errors of estimate (SEE) and coefficient of determination (R^2). $_{PD}$ post-AWC depletion estimation.

	CP (W)	SEE (W)	AWC (J)	SEE (J)	P_{max} (W)	SEE (W)	R^2
Nonlinear-2	130.2 ± 49.3 ^{A}	4.7 ± 4.6	21098 ± 6557 ^{D}	2629 ± 1969	-	-	0.991 ± 0.007
Nonlinear-2_{PD}	131.4 ± 48.2 ^{A}	4.7 ± 5.0	14087 ± 4138 ^{D}	1792 ± 1283	-	-	0.990 ± 0.008
Linear W-T	146.9 ± 53.0 ^{B}	14.2 ± 7.7	14733 ± 3769 ^{E}	4539 ± 2321	-	-	0.988 ± 0.010
Linear W-T_{PD}	147.4 ± 54.6 ^{B}	13.0 ± 7.3	9824 ± 2325 ^{E}	2842 ± 1411	-	-	0.990 ± 0.008
Linear P-1/T	174.1 ± 63.0 ^{C}	18.0 ± 9.6	9454 ± 1911	1343 ± 809	-	-	0.974 ± 0.026
Linear P-1/T_{PD}	169.6 ± 63.3 ^{C}	15.8 ± 7.1	6895 ± 1891 ^{F}	805 ± 395	-	-	0.983 ± 0.013
Nonlinear-3	99.9 ± 47.3	17.1 ±27.2	47276 ± 41778	16943 ± 35074	760 ± 516	1379 ± 3853	0.993 ± 0.010
Nonlinear-3_{PD}	107.7 ± 48.1	23.7 ± 43.1	26779 ± 19185	13852 ± 28882	1005 ± 1592	6479 ± 24708	0.990 ± 0.014

^{A} CP: Nonlinear-2 different to Linear W-T, and to Linear P-1/T under the same experimental conditions ($P \leq 0.01$).
^{B} CP: Linear W-T different to Linear P-1/T, and to Nonlinear-3 in under the same experimental conditions ($P < 0.05$).
^{C} CP: Linear P-1/T different to Nonlinear-3 under the same experimental conditions ($P < 0.01$).
^{D} AWC: Nonlinear-2 different to Linear W-T, and to Linear P-1/T under the same experimental conditions, and Nonlinear-2 different to the same equation under different experimental conditions ($P < 0.001$).
^{E} AWC: Linear W-T different to Linear P-1/T under the same experimental conditions, and Linear W-T different to the same equation under different experimental conditions ($P < 0.001$).
^{F} AWC: Linear P-1/T_{PD} different to Linear P-1/T and to Nonlinear-3_{PD} ($P < 0.01$).



Note: Unbroken lines and full circles – without prior AWC-depletion. Dotted lines and open circles – with prior AWC-depletion.

Figure 1. Effects of short-term exercise for AWC depletion on $CP_{2parameter}$ and $CP_{3parameter}$ estimates for a single participant. (A) Nonlinear-2 function; (B) Linear W-T function; (C) Linear P-1/T function and; (D) Nonlinear-3 function.

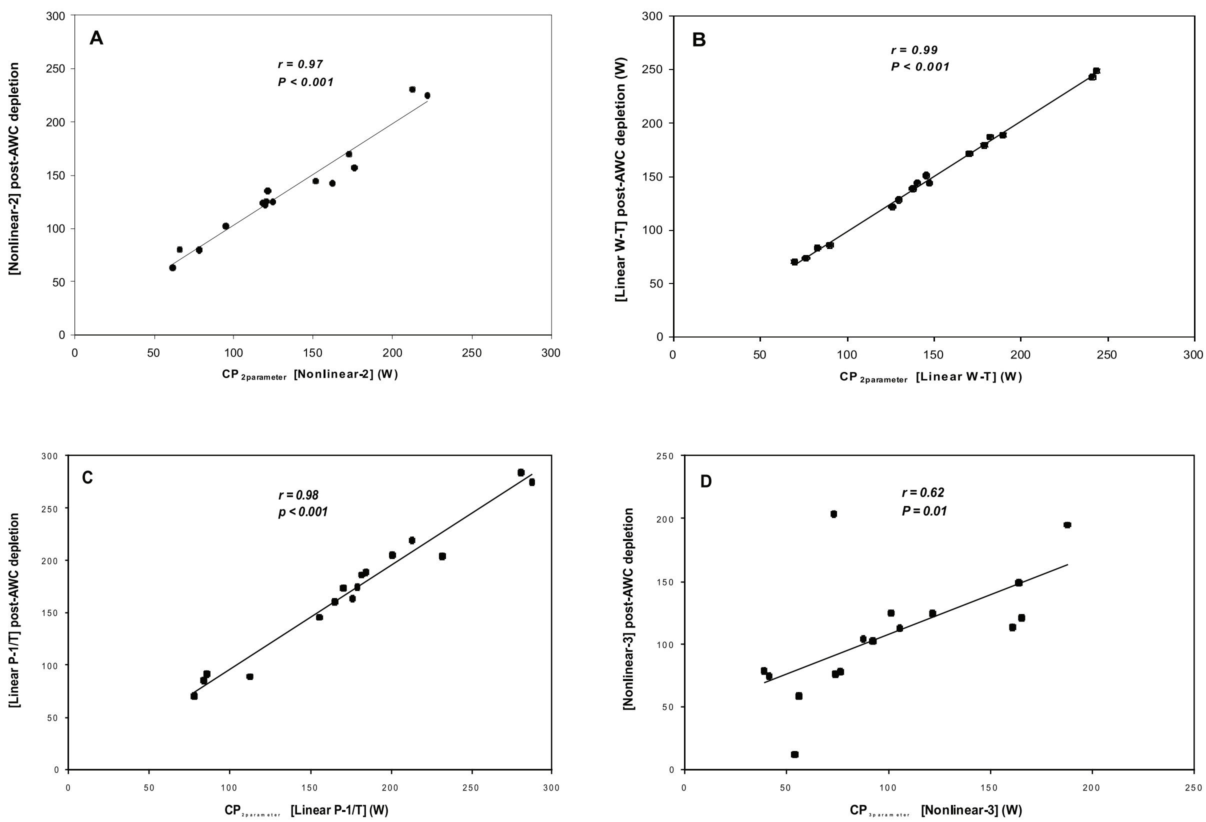


Figure 2. Correlations between $CP_{2parameter}$ and $CP_{3parameter}$ estimates in experimental settings with and without prior AWC partial depletion.

associated with unacceptable levels of systematic and random errors, respectively. Although the three different two-parameter equations used are mathematically equivalent, they usually result in quite different parameters estimation[16-18]. This is probably caused by the fact that analyses are computer-generated and performed by interactive statistical procedures. These attribute different weights to any empirical errors possibly resulting from performances during the predictive trials.

Analysis of variance indicated statistically significant differences between $AWC_{2parameter}$ estimates. The variability among equation outputs was >10%, attesting to relatively high levels of systematic errors associated with the measures. In addition, the SEE (<10%) reached critical values that could compromise the precision of the estimates. Therefore, the data acquisition seems to have resulted in high levels of random errors. The validity of $AWC_{2parameter}$ in the MAOD prediction is dependent upon simultaneous low systematic and random error levels[10]. The presence of these errors, associated with the estimation of $AWC_{2parameter}$, can probably be attributed to the inclusion of a <1 min trial, which, according to Poole,[26] can compromise measures because it is too short and can be influenced by aerobic "inertia"[12]. The exclusion of this data point provided low levels of both types of potential errors associated with the $AWC_{2parameter}$ (data not shown). However, we have no reasons to believe that these errors of estimation invalidate our analyses, because the main comparisons were made with and without prior AWC depletion, using the same equation.

In the present study, CP estimates presented statistically significant difference (P < 0.01) when compared to the two and three-parameter models. These results corroborate those reported in studies by Chatagnon *et al.*,[11] Morton,[15] Gaesser *et al.*,[16] and Hill *et al*[17].

Nevertheless, the existence of major methodological variability must be taken into account when considering the above-mentioned studies. Only Hill *et al.*[17] respected Morton's contention that at least one of the predictive trials should have a duration of about 1 min or a little less. Additionally, only Hill[18] did not detect differences between $CP_{2parameter}$ and $CP_{3parameter}$ estimates, using predictive trials with >2 min duration.

As hypothesized, $CP_{2parameter}$ and $CP_{3parameter}$ showed stability when comparing settings with and without prior AWC depletion. This has occurred in conformity with earlier findings[22]. The methodological differences between our study and that presented by Heubert *et al.*[22] include: (1) the type of exercise utilized to induce AWC depletion; (2) the presence of a short interval of passive recovery after the depletion task in the present study and; (3) the simultaneous analyses of the two and three-parameter critical power model, also in this study. To our knowledge, the three-parameter critical power model has not been tested under this type of experimental conditions.

Some examples exist in the literature of results associated with the consistency of the parameters tested simultaneously in experimental settings that induce acute alteration of one of the parameters, or the stability of both $CP_{2parameter}$ and $AWC_{2parameter}$ in response to manipulations in protocol types during non-square-wave predictive trials.

Supra-$CP_{2parameter}$ power output variation during non-square-wave predictive trials does not alter the $AWC_{2parameter}$. Both parameters were derived from the nonlinear hyperbolic function. Fukuba *et al.*[27] proposed the use of protocols starting with exercise at 117% and 134% of $CP_{2parameter}$ for a duration that would expend approximately half of AWC. Power output was then abruptly increased to 134% or decreased to 117%, respectively, until exhaustion. There were no differences between the total work estimates accomplished above $CP_{2parameter}$ (i.e. AWC indices) in either set of conditions, when compared to the conventional square-wave results. These studies provide evidence of the model's validity by demonstrating that the parameters are consistent despite the types of exercise being quite different from the square-wave protocols, and that exercise tolerance is modulated by their interaction in providing energy.

The stability of $CP_{2parameter}$ and $CP_{3parameter}$ was expected in the present investigation because prior severe non-exhaustive exercise should only influence the amount of anaerobic energy stores and not the estimates of power output provided by aerobic processes. The indirect evidence that has *a priori* strengthened this hypothesis was the relatively stable maximal tolerance of exercise at $CP_{2parameter}$ after partial $AWC_{2parameter}$ depletion[28]. Thus, exercise tolerance is probably only affected by prior partial $AWC_{2parameter}$ depletion when the intensity of the next trial is superior to $CP_{2parameter}$. The 30 s interval between partial AWC depletion and the predictive trials is apparently a short period to allow significant recovery of performance. However, Bogdanis et al.[29] have shown that phosphocreatine stores can be replenished rapidly (half time of 56.6 s) leading to mean power output being partially recovered during an all-out 30 s test despite the low pH levels. Therefore, it can be assumed that AWC was recovered, to a great extent, due to the alactic component.

Prior high intensity exercise followed by resting recovery causes alterations to some VO_2 kinetic parameters, but does not alter the end exercise VO_2 value.[30] In this manner, if the $O_2.W^{-1}$ cost remains constant, the steady state aerobic contribution, manifested as CP estimates derived from the different models, will also remain constant. The reduction in $AWC_{2parameter}$ is probably associated to the lack of complete repletion of phosphocreatine stores and attenuation of the effects of blood lactate accumulation during the short resting interval[29].

In another study[31] six subjects underwent three different exercise trials until exhaustion immediately after cycling to the limit of their tolerance for around 360 s at a severe fixed power output. At 110% $CP_{2parameter}$, subjects were exhausted after just 30 s. In contrast, at intensities corresponding to 90% of $CP_{2parameter}$ and to 80% of ventilatory threshold, exercise could be maintained for 577 s and for the target duration of 1200 s, respectively. According to the authors, replenishment of $AWC_{2parameter}$ after its complete depletion requires a sub-$CP_{2parameter}$ work rate. Once more there is a consistent theoretical relationship between the constructs of the critical power model, and this relationship modulates the exercise tolerance to different types of protocols.

Miura *et al.*[13] showed that in a glycogen-depleted state the curvature constant ($AWC_{2parameter}$) of the Nonlinear P-T was less than when starting with normal glycogen stores. On the other hand, $CP_{2parameter}$ was not altered by this experimental manipulation. This evidence seems to converge with our findings. Unfortunately, there are no such manipulations with the three-parameter model that would allow for comparisons with our results. However, according to our interpretation of the results of the present study, the three-parameter critical power model seems to respond adequately in relation to the logical prediction that could be delineated.

The correlation between estimates of $CP_{3parameter}$ when comparing the two experimental conditions was moderate ($r = 0.62$; $P = 0.01$). In contrast, the exclusion of one outlier (± 1.96 SD) raised the correlation to 0.84 ($P < 0.001$), improving its significance. This is evidence that $CP_{3parameter}$ can also exhibit stability under prior AWC partial depletion. There were no outliers when $CP_{2parameter}$ estimates were contrasted. However, the estimates of $CP_{3parameter}$ in some subjects can be compromised using the three parameter critical power model. The lower correlation between the measures can be attributed to the greater values of the associated SEE, which increase the probability of estimation errors.

In contrast with our expectations, P_{max} and $AWC_{3parameter}$ from Morton's model were not changed by prior exercise. There is evidence that the repetition of a sequence of three Wingate tests, with 5 min intervals, results in a decline in peak power output.[32] On the other hand, the P_{max} in Morton's model does not seem to be necessarily comparable to the peak power of short-term anaerobic tests, because according to Morton,[15] P_{max} is representative of an instantaneous ability to generate a great amount of work in a few seconds. Chatagnon *et al.*[11] have specifically addressed this issue. They made comparisons between maximal power output, derived using force-velocity (F-V) curves produced on a cycle ergometer by performing six 5 s all-out tests, and P_{max} from Morton's model. The maximal power output from the F-V relationship did not significantly correlate with P_{max}. Furthermore, the physiological interpretation that P_{max} represents maximal instantaneous power output may be counterintuitive, because it is defined by extrapolation to a power output at time=0,[33] which cannot in fact exist. Therefore, the validity of P_{max} from Morton's model can be called into question. This being so, future studies should aim to establish the physiological significance of P_{max}. Additionally, new evidence on the three-parameter model validity is necessary. It is probable that the nonexistence of $AWC_{3parameter}$ changes after prior exercise, followed by the short rest period, can be attributed to the great inter-individual variability of this measure, making it difficult to find any statistically significant difference. Alternatively, non-exhaustive prior exercise may not have been severe enough to cause a significant $AWC_{3parameter}$ depletion, since it is much greater than $AWC_{2parameter}$.

CONCLUSION

Both $CP_{2parameter}$ and $CP_{3parameter}$ remained stable after partial AWC depletion induced by a non-exhaustive severe exercise. The same phenomenon was observed in P_{max} derived from the three-parameter critical power model. However, estimated AWC was lowered only when using the two-parameter model.

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Endereço para correspondência
Fábio Yuzo Nakamura
Grupo de Estudo das Adaptações Fisiológicas ao Treinamento (GEAFIT).
Centro de Educação Física e Desportos - Universidade Estadual de Londrina
Rod. Celso Garcia Cid, km 380, Campus Universitário
CEP 86051-990 - Londrina, PR – Brasil
E-mail: fabioy_nakamura@yahoo.com.br

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