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Correlation between the Curvature Constant Parameter (W') from the Velocity-Exhaustion Time Relationship, Maximal Accumulated Oxygen Deficit and Performance in Professional Soccer Players

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ABSTRACT

Loures JP, **Kalva-Filho CA, Franco VH, Kaminagakura EI, Zagatto AM, Papoti M.** Correlation between the Curvature Constant Parameter (W') from the Velocity-Exhaustion Time Relationship, Maximal Accumulated Oxygen Deficit and Performance in Professional Soccer Players. **JEPonline** 2012;15(5):79-87. The aim of this study was to investigate possible associations between the curvature constant (W') from the critical power model by two linear models with maximal accumulated oxygen deficit (MAOD) and performance in soccer players. Nine professional soccer players (age, 16.1±1.2 yrs) were recruited. The subjects performed an incremental maximal test, four bouts of 10 min of submaximal exercises, and three supra-maximal exercises to determine the MAOD, W' and performance in soccer, which was assumed as time until exhaustion at each applied supra-maximal intensity. MAOD corresponded to 3.43±1.35 L and 52.18±19.86 $ml \cdot kg^{-1}$, while W' determined by the linear distance time model (W'_{dt}) was 193.7±52.2m, and W' determined by the velocity over inverse of time model ($W'_{tlim}{}^{-1}$) was 185.9±60.4 m. No significant correlation was found between the W's and MAOD. The only significant correlations were between the W's with time limit (r=0.80 for W'_{dt} and r=0.70 for $W'_{tlim}{}^{-1}$; P=0.05). We can therefore conclude that W' determined in treadmill running using these linear models allows the prediction of exhaustive efforts of approximately 130s duration, but is not associated with MAOD.

Key Words: MAOD, Critical Power

INTRODUCTION

Although soccer is characterized as an intermittent and predominantly aerobic sport with anaerobic stimuli throughout the game (2), events that determine success during the game seem to be closely related to the anaerobic (lactic and alactic) metabolism (28). Yet, despite the importance of anaerobic metabolism in soccer matches, the procedures for evaluating the anaerobic contribution of soccer players are found primarily in the laboratory.

Maximal accumulated oxygen deficit (MAOD) proposed by Medbo and colleagues (18) is considered the gold standard test for anaerobic capacity. However, the test is often criticized due to the amount of time taken and the large number of exercise sessions used to determine it. In general, the test consists of performing constant submaximal exercises to determine theoretical oxygen demand for any intensity followed by an exhaustive supra-maximal exercise until exhaustion (100 to 120% maximum oxygen consumption, VO_2 max), (18,29). MAOD is assumed as the difference between predicted VO_2 demand (product of VO_2 necessary and exercise duration) needed for the respective supra-maximal intensity and total area of the oxygen uptake (VO_2) (calculated from total VO_2 area) during exertion, (18). However, because the VO_2 analysis during the exercise and the time spent to apply the test (approximately 4 days), it does not form part of most soccer team training regimes.

The Wingate test has also been described as a good procedure for anaerobic component evaluation, (1,8). It consists of performing maximum exertion for 30 sec on a cycle ergometer supporting a load of approximately 7.5% of bodyweight. The Wingate test can be used to determine several variables related to the anaerobic metabolism including peak and mean power and fatigue index (1,31). More recently, Zagatto et al. (30) adapted and validated the Wingate test for running, and named it the Running Anaerobic Sprint Test (RAST). Due to its practicality and low cost, the Wingate test is probably the most popular available anaerobic test in soccer. However, it has limitations with regard to the specificity of soccer movements, and despite that it is correlated with MAOD, it is a test that estimates anaerobic power and not anaerobic capacity (19).

It has been suggested that the curvature constant (W') from the hyperbolic relationship between intensity and time can be used to estimate anaerobic capacity in humans using a simple non-invasive method, (7,9,12,13,20-22). According to the classic definition, W' theoretically corresponds to a finite store of intramuscular anaerobic energy, which consists of phosphocreatine and glycogen reserves with a small aerobic component (oxygen bound to hemoglobin and myoglobin) (20,22-24), while the asymptote of this hyperbolic relationship corresponds to the maximum intensity that can theoretically be indefinitely maintained without reaching exhaustion (critical power) (23). In running, the W' has generally been determined by two linear models derived from the hyperbolic relationship between time and velocity (4,5), which correspond to the following equations:

$$D=CV \cdot t + W' \quad (1)$$
$$V= W' \cdot tlim^{-1} + CV \quad (2)$$

where: D=distance; CV= critical velocity (aerobic parameter); t=time; $tlim^{-1}$ = inverse of time limit, and W'= curvature constant from the critical power (velocity) model.

The W' from the critical power model (9,13) is a good alternative to evaluate athletes. However, it was recently suggested that the W' does not correspond to a fixed store of anaerobic substrate (14,15,31), but to a capacity for mechanical work that can be used under suitable phosphocreatine and pH conditions (14). This acceptance of W' as a procedure which can estimate anaerobic capacity is still controversial in the literature, requiring more evidence to give a more concrete direction. With this in

mind, the aim of our study was to evaluate associations between W' using two linear models with MAOD and the performance of soccer players.

METHODS

Subjects

Nine male youth professional soccer players participated in this study (16.1±1.2 yrs, 62.5±4.6 kg, and 176±3, 27 cm). All subjects were familiarized with the experimental procedures and equipment. They were instructed to have the same individual light meal at least 2 hrs before the tests, to maintain hydration habits, and to avoid additional sessions of hard physical activity, alcohol, and caffeine during the experimental period. All procedures were approved by the University's Institutional Review Board for Human Subjects (Human Research Ethics Committee), and were conducted according to the Declaration of Helsinki and Ethical Standards in Sport and Exercise Science Research (10). Athletes and their parents, when pertinent, were informed about experimental procedures and risks, and signed an informed consent prior to their participation in the study.

Procedures

The tests were performed over a one-week period with five visits to the laboratory. During the first visit, the subjects were submitted to a progressive test to determine VO_2 max and associated running velocity (vVO_2 max). In the following visits, (2nd, 3rd, 4th, and 5th), the subjects were submitted to four submaximal exercises (50, 60, 70, and 80% vVO_2 max) and three exercises until exhaustion (100, 110, and 120% vVO_2 max).

The 50, 60, and 70% vVO_2 max submaximal exercises were performed before the 120, 110, and 100% exercises to exhaustion, respectively, while the 80% vVO_2 max was performed (5th day) 24 hr after the end of the exhaustion exercises. The 50 and 120%, 60 and 110%, and 70 and 100% vVO_2 max intensities were randomly applied always with an interval of 24 hr. Between the submaximal and exhaustion exercises, the subjects rested in a sitting position for 10 min.

Pulmonary gas exchange was measured breath-by-breath in all sessions by determining the concentrations and ventilation of O_2 and CO_2 through a metabolic gas analysis system (True-One 2400, ParvoMedics, East Sandy, Utah, USA) (6). The gas analyzer was calibrated immediately before and verified after each test using a certified gravimetrically determined gas mixture, while the ventilometer was calibrated pre-exercise and verified post-exercise using a three liter syringe in accordance with the manufacturer's instructions. Following removal of outliers to exclude discrepant breaths, breath-by-breath VO_2 data were interpolated to give 1 sec values and smoothed using rolling 30-sec averages (OriginPro 8.0 , OriginLab Corporation, Microcal, Massachusetts, USA) to enhance the underlying VO_2 response characteristics. In every test, the start and end time of each run (i.e., exercise stage) was recorded for later synchronization between ventilatory data and running events. Heart rate (HR) was continuously monitored by a Polar Heart Rate Monitor (Polar Electro Oy, Kempele, Finland) with a HR value recorded beat-by-beat (R-R intervals) from the ECG channel of a TrueOne system (ParvoMedics, East Sandy, Utah, USA). Strong verbal encouragement was given for subjects to achieve maximal exercise.

Maximal Incremental Test

Maximal oxygen uptake (VO_2 max) and velocity associated with VO_2 max (vVO_2 max) were obtained from the maximal incremental test with an initial velocity of 8 $km \cdot h^{-1}$ incremented by 1 $km \cdot h^{-1}$ every 3 min. Treadmill gradient was set at 1%. VO_2 max was considered as the highest VO_2 average during the last 30 sec of exercise, with at least two of the following criteria obtained: heart rate (HR) ≥90% maximal age-predicted HR (220-age); respiratory gas exchange ratio (RER= VCO_2/VO_2) ≥1.15; and

VO_2 plateau (variation ≤2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ between last two exercise stages). vVO_2 max was considered as the lowest achieved running velocity at VO_2 max. If exhaustion occurred before the end of the exercise stage, vVO_2 max was determined in accordance with Kuipers et al. (16) (Equation 3), where Economy corresponds to intensity at the last exercise stage; time is the exercise time performed in the last stage; 180 = time (sec) of each exercise stage and; Increment corresponds to the increase of the velocity.

$$vVO_2 \text{ max} = \text{Economy} + (\text{time} / 180) \bullet \text{Increment} \quad (3)$$

Maximal Accumulated Oxygen Deficit Determination (MAOD)

Initially, four submaximal exercise bouts were performed during a 10-min period corresponding to 50, 60, 70, and 80% vVO_2 max. Treadmill gradient was set at 1%. VO_2 was measured throughout each 10-min exercise period as previously described, and the VO_2 values measured during the last 2 min of exercise were averaged and used as the steady-state VO_2 for the corresponding velocity. The submaximal velocity data and respective VO_2 demand (VO_2 steady-state) were fitted in linear regression. The linear regression was extrapolated to measure estimated oxygen demand at 110% vVO_2 max. After the submaximal efforts, a supra-maximal exercise between 100 and 110% vVO_2 max was performed to measure VO_2, exercise time until exhaustion (*t*lim), and determine MAOD, (29). MAOD was calculated by the difference between the estimated VO_2 demand area (estimated VO_2 demand multiplied by time to exhaustion) and VO_2 integrated over time in the maximal exercise.

Determination of the Curvature Constant (W') from Critical Velocity Test and Running Performance

To determine the curvature constant (W') from the critical velocity test, the soccer players performed three exercise exhaustion bouts in intensities corresponding to 100%, 110%, and 120% vVO_2 max, applied randomly. The time until exhaustion in each exercise intensity was recorded, and they were assumed as performance ($tlim_{100}$, $tlim_{110}$, and $tlim_{120}$, respectively). The W' was determined using the linear distance-time relationship (W'_{dt}), (24) (Equation 4) and the linear velocity-inverse of time relationship ($W'_{tlim}{}^{-1}$) (Equation 5).

$$D = (CV \bullet tlim) + W' \quad (4)$$
$$V = (W' \bullet tlim^{-1}) + CV \quad (5)$$

Statistical Analyses

The data were analyzed using Statistica 7.0 (Statsoft, Tulsa, USA). The results are shown as means ± standard error of the mean (SEM). Variable normality was measured by the Shapiro–Wilk's W test. The paired t-test was used to compare the W's (W'_{dt} and $W'_{tlim}{}^{-1}$). Analysis of the association between W' values with the $tlim_{100}$, $tlim_{110}$, and $tlim_{120}$, and between the W' values with MAOD was carried out by the Pearson product-moment correlation test. In all cases, a probability level of 95% (P=0.05) was used for statistical significance.

RESULTS

The values corresponding to VO_2 max and vVO_2 max were 51.86 $ml \cdot kg^{-1} \cdot min^{-1}$ and 13.95 $km \cdot h^{-1}$, respectively. After the submaximal exercises had been applied, linear regressions were constructed between VO_2 and intensity for each subject to estimate theoretical VO_2 demand for 110% of vVO_2 max. Linear regressions showed elevated coefficients of determination (R^2=0.98±0.02) and errors (51.7±7%) in the linear coefficients (0.54±0.50 $L \cdot min^{-1}$), but reduced errors (15.7±10%) for angular coefficients (0.2±0.1 $L \cdot min^{-1}/km \cdot h^{-1}$). Supra-maximal exhaustion exercise values, which were also

considered as performance, are shown in Table 1. In these exercises, 10% changes in velocity corresponded to alterations of 68.8±17.5% in tlim values (Table 1).

Table 1. Values of Time Limit (tlim), Intensity, and Distance during Exhaustion Exercises at 120, 110, and 100% vVO_2 max. Results are shown as means ± standard deviation.

	vVO_2 max_{120}	vVO_2 max_{110}	vVO_2 max_{100}
tlim (s)	132.0±30.2	220.4±60.0	355.2±137.3
distance (m)	2435.2±540.6	3672.2±1018.6	5415.0±1985.8
Intensity ($m \cdot s^{-1}$)	5.1±0.3	4.7±0.3	4.3±0.3
tlim (s)	132.0±30.2	220.4±60.0	355.2±137.3

Elevated coefficients of determination (R^2) were found in W' determinations between the linear relationships of velocity versus 1/tlim (R^2=0.94±0.10) and distance versus time (R^2=0.98±0.04). $W'_{tlim}{}^{-1}$ (185.9±60.4m) was not significantly different than W'_{dt} (193.7±52.2 m) and highly correlated (r=0.97; P=0.01). Both W's showed only a significant correlation with $tlim_{120}$. However, there were no significant correlations between the W's and MAOD in either an absolute (3.43±1.35L) or relative (52.18±19.86 $ml \cdot kg^{-1}$) way (Table 2).

Table 2. Coefficient of correlation results obtained between W' from the two linear models, distance versus time (W'dt) and velocity versus the inverse of time limit ($W'_{tlim}{}^{-1}$), with maximal accumulated oxygen deficit (MAOD), both in absolute ($MAOD_{abs}$) and relative ($MAOD_{rel}$) units, time (tlim), velocity (vel), and distance (Dist) during exhaustion exercises at 100, 110, and 120% vVO_2 max**.**

	W'_{dt}	$W'_{tlim}{}^{-1}$
$MAOD_{abs}$	r= -0.05	r=-0.03
$MAOD_{rel}$	r=-0.02	r=0.09
$tlim_{120}$	r=0.80*	r=0.70*
$tlim_{110}$	r=0.48	r=0.28
$tlim_{120}$	r=0.08	r=-0.09
v_{120}	r=0.08	r=0.13
v_{110}	r=0.08	r=0.13
v_{100}	r=0.08	r=0.13
$dist_{120}$	r=0.85*	r=0.77*
$dist_{110}$	r=0.54	r=0.34
$dist_{100}$	r=0.11	r=-0.06

*P=0.05.

DISCUSSION

The main finding in the present study is the non-significant correlation between MAOD and W' (when determined by two linear models in soccer players). Poole (27) and Hill (11) suggested that the predicted efforts for determining critical power result in tlim's between 2 and 10 min. Efforts that result in tlim's over 10 min can overestimate W' and efforts that result in tlim's below 2 min can underestimate critical power (11,27). In our study, tlim values were between 132.3±30.2 sec and 355.2±137 sec, thus allowing adequate determination of W's values (W'_{tlim}^{-1} and W'_{dt}).

W'_{tlim}^{-1} and W'_{dt} significantly correlated with $tlim_{120}$. This demonstrates the potential of using W' as a predictive tool for exercises performed above VO_2 max in soccer players. However, the lack of a significant correlation between W' and MAOD adds to the contradictions reported in the literature regarding the associations between these two variables, and even questions the validity of W' as an index of anaerobic capacity (3,26). As an example, Leclair et al. (17) did not find significant correlation between W' (171.9±90.6 $J \cdot kg^{-1}$) and MAOD (205.3±50.7 $J \cdot kg^{-1}$) values in pre-puberty individuals (10.3±0.9 yrs; Tanner =3) or in adults (W'=297.1±84.9 $J \cdot kg^{-1}$; MAOD=297.5±53.7 $J \cdot kg^{-1}$). However, they reported that W' and MAOD in adults were 55% and 45% higher than in pre-puberty individuals, respectively. They also found a significant correlation between W' and MAOD (r=0.58; P=0.02) in pre-puberty individuals but not in adults (r=0.04; P=0.88). Despite showing the maturation effect on W' and MAOD values, they also showed the inconsistency of associations between these two variables.

Moreover, Papoti et al. (25) did not find correlations between W' estimated by the distance and time linear relationship with anaerobic aptitude in tethered swimming (both measured in swimming). They also did not verify associations between W' and velocity ($m \cdot s^{-1}$) at distances of 15, 25, 50, 100, 200, 300, 400, and 600 m at maximum crawl swimming (25,26). Zagatto et al. (31) adapted the critical power model for the specific table tennis test and did not verify significant correlations between W' estimated by the linear model of intensity over inverse of time with values from the Wingate tests on the cycle ergometer and the arm ergometer. They concluded that W' could not be used to estimate anaerobic capacity in table tennis players.

After determining W' on a cycle ergometer, Fukuba et al. (9) submitted their subjects to two exercise protocols until exhaustion at greater than critical power intensities. One protocol began at 134% critical power, which was maintained until half W' was depleted. The intensity was then reduced to 117% critical power and the exercise performed until exhaustion ("*UP*" protocol). In the other protocol, the initial intensity was 117% critical power. The sujbects continued until they had depleted half W', then, the intensity was abruptly increased to 134% critical power and maintained until exhaustion ("*DOWN*" protocol). Total work was quantified in both protocols. The authors found no significant differences in work values corresponding to W' (12.68±3.08 kJ) from either the "*UP*" (12.14±4.18kJ) protocol or the "*DOWN*" (12.72±4.05 kJ) protocol.

We can put forward two hypotheses to explain the lack of a correlation between *W'* and MAOD. The first is related to the limitation of the MAOD values as an anaerobic capacity parameter. In our study, MAOD was determined by adapting the protocol proposed by Medbo et al. (18); the main adaptation being the reduction in number of submaximal exercises used to establish the relationship between O_2 demand and exercise intensity. This procedure, despite its high coefficients of determination and low errors for angular coefficients, resulted in high error and variability for y-intercept values, which could have compromised (i.e., under or overestimated) O_2 demand at supra-maximal intensity (120% VO_2 max). However, the submaximal intensities were the same for all the subjects (50, 60, 70, and 80% VO_2 max) and so the possible extrapolation errors could theoretically be systemic ones.

The second and probably more acceptable hypothesis is related to the mathematical model together with the ergometer used. To our knowledge, up until now only Bosquet et al. (4) have verified significant correlations between W' and oxygen deficit in running. However, these correlations, although significant, were low (r=0.50 for the distance time linear model; r=0.49 for the velocity over inverse of time linear model; and r=0.57 for the three parameter model). During predictive exercises, exhaustion theoretically occurs by total depletion of "anaerobic stores" at different intensities. In support of this hypothesis, three investigations (7,25,26) that did not find associations between W' for anaerobic performance did not submit athletes to exercises until exhaustion. Therefore, the time used to determine W' was not the time limit until exhaustion, but rather the time required to complete a determined distance.

CONCLUSIONS

We conclude that W' determined on a treadmill using linear models permits the prediction of exhaustive efforts lasting approximately 130 sec and this can be used in the period of high intensity training. However, W' is not associated with MAOD in professional soccer players and, therefore, does not appear to be an index of anaerobic capacity.

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