Use of the y-intercept in the evaluation of the anaerobic fitness and performance prediction of trained swimmers

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ABSTRACT

The objective of this study was to verify the use of y-intercept from the critical velocity model in the evaluation of the anaerobic fitness and prediction of maximal performance in trained swimmers in crawl style. Fourteen swimmers with ages ranging from 15 to 18 years participated in this study. The athletes performed the tied swimming test, maximal performances tests and critical velocity (CV) for the determination of anaerobic swimming capacity (AWC). 1) The tied swimming test was applied through maximal effort during 30 seconds fixed to the equipment with load cells for the measurement of the peak force, anaerobic fitness and peak lactate. 2) The subjects also performed maximal performances at distances of 100, 200, 300, 400 and 600 meters with two hours interval between each swim. 3) AWC at CV model was determined utilizing all possible combinations by maximal performances applying the distance-time linear regression model. The AWC value obtained was of 25.07 ± 4.22 m, with linear regression coefficient between 0.99 and 1.00, and linear coefficient error of 19.30 ± 5.9%. AWC was not correlated with all maximal performances, peak force (227.81 ± 63.02 N), anaerobic fitness (85.55 ± 13.05 N), and peak lactate (6.80 ± 1.08 mM). However, the anaerobic fitness was correlated with all maximal performances. Thus, it was concluded that the AWC obtained by y-intercept of the distance/time of swim relation does not seem to be a good parameter for the anaerobic fitness evaluation neither to predict the maximal performances between 100 and 600 meters in crawl style.

Key words: Swimming anaerobic capacity. Anaerobic fitness. Tied swimming. Critical velocity. Performance. Lactate.

INTRODUCTION

In swimming, the methods used to measure anaerobic variables are not quite well developed such as those that evaluate the aerobic qualities, although these variables are important aspects for the swimmer evolution[(1)]. Maglischo[(2)] suggested the determination of the blood lactate concentration after maximal efforts as a way to evaluate the anaerobic capacity, where low lactate values along with unsatisfactory performances could indicate deterioration of this capacity. Although the use of the lactacidemia is a tool sensible to small adaptations in the swimmers training[(3)], its reduction after maximal efforts may also be a result of an overtraining state[(4-7)]. Methodologies that evaluate the strength of swimmers out of the water through the use of the swim bench[(8)] and in the water through semi tied swim[(9)] and tied swim[(10-12)] situations are also frequent. The latter, besides presenting higher specificity when compared with the swim bench, is a reproducible ergometer[(11,13)], highly correlated with the swim velocity at distances between 25 and 400 m in crawl style[(10,11)], and sensible to variations on the training volume and intensity[(12,14)].

Unfortunately, not all swimming teams count on the financial support required for the acquisition of specific equipment for strength and power measurement or for the performance of constant evaluations using lactacidemia.

The critical power test, initially proposed by Monod and Scherrer[(15)] and validated by Moritani *et al.*[(16)], has as concept the maximal exercise intensity that can theoretically be maintained for a long period of time with no fatigue. This evaluation method has been objective of many studies, not only for being a low-cost non invasive test, but also for providing indicatives of aerobic and anaerobic capacities.

Wakayoshi *et al.*[(17)] linearized the hyperbolic equation applied in the prediction of the critical power and verified whether the critical velocity (CV) may be used to estimate the performance of high-level swimmers. In this study for the CV and the anaerobic swimming capacity (AWC) determination, the swimmers were submitted to six efforts until exhaustion in the swimming flume. The six points obtained from the relation between the limit time (Tlim) and the swim distance (SD) were submitted to linear regression procedure, where the angular coefficient represented the CV and the linear coefficient (y-intercept) represented the AWC. The authors observed high correlation of CV with lactate threshold for concentration of 4 mM (r = 0.95) with the oxygen uptake at the anaerobic threshold intensity (r = 0.82) and with maximal velocity of 400 m (r = 0.86). Later, these authors made available and popular the use of the CV by determining this parameter in conventional swimming pool using the linear relation between prefixed distance (200 m and 400 m) and swim time[(18)].

As previously mentioned, the AWC, represented by the linear coefficient (y-intercept), when determined with stimuli in which the participants perform efforts until exhaustion, seems to correspond to the anaerobic variable of the CV model. It has been demonstrated that this parameter is sensible to eight high-intensity training weeks with intervals[(19)] and to six endurance training weeks[(20)]. Furthermore, the AWC was significantly correlated with the Wingate test[(21)], anaerobic production of muscular ATP (r = 0.70), anaerobic capacity determined through the ATP change and phosphocreatine (r = 0.73) in well-trained cyclists[(22)], and with the maximal accumulated oxygen deficit (MAOD), demonstrating that the y-intercept may be a valid index to represent the anaerobic work capacity[(22,23)].

However, other studies did not demonstrate association between AWC with MAOD[(24)], and the Wingate test average power[(25)]. In addition, in swimming, the vast majority of studies found no asso-

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ciation between AWC and performance[26-28], thus emphasizing the necessity of researches aimed at investigating the meaning of the AWC as performance predictor in swimming. Thus, the objective of the present study was to verify the use of the y-intercept in the evaluation of the anaerobic fitness and in the performance prediction of trained swimmers.

METHODOLOGY

Participants

Fourteen state and national level swimmers (three female and 11 male) from the city of Bauru-SP with ages ranging from 15 to 18 years and minimum swimming competition time of two years, who trained approximately 5000 $m.d^{-1}$ with frequency of six $days.week^{-1}$ were evaluated. The participants were only confirmed after authorization through the consent form, approved by the Unesp Ethics Committee, campus of Rio Claro, signed by parents and team coaches.

Tests

The swimmers were evaluated during three days, when the anaerobic fitness and maximal performances tests were conducted.

No exercises of any type were performed during the 24 hours preceding the tests. This caution was taken so that no acute effect as result of training sessions could influence the results.

Before the beginning of tests, a warm-up period with duration of ten minutes at moderate intensity subjectively determined by swimmers in crawl style was performed.

Determination of anaerobic fitness (FIT_{ANA}), peak force (F_{peak}) and lactate peak concentration ($[la^-]_{peak}$) in tied swim

For the anaerobic fitness determination (FIT_{ANA}), a tied swim protocol standardized by Papoti *et al.*[11] was used due to the high stability and reproducibility of measurements (r = 0.93). This system contains load cells (strain gages) as primary sensor element, being suspended on two wooden beams fixed to the ground at a distance of one meter parallel to the border of the swimming pool. A steel wire of 4.08 m length was connected to the center of the dynamometer with a nylon belt at its opposite extremity around the swimmer's waist at a distance of three meters in relation to the border of the swimming pool and four meters in relation to the equipment (figure 1).

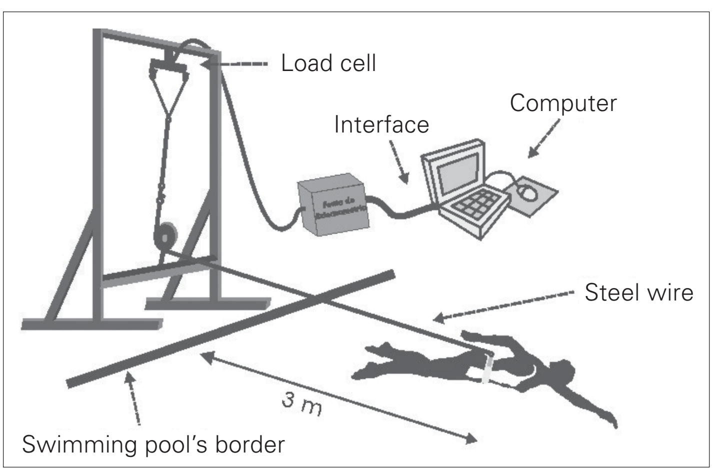

***Fig. 1** – Schematic model of the system used to determine anaerobic fitness of swimmers[11]*

The test itself consisted of the application of a maximum effort in crawl style with duration of 30 s with swimmers tied to the measurement apparatus. During the entire test, the participants were verbally encouraged to perform maximum efforts. The beginning and end of the test were determined by a sound signal (whistle). The deformation detected by the load cells (strain gages) due to the tension generated by the swimmer's effort was amplified through a portable extensometry source (*Sodmex ME-01D*). The values obtained during efforts were sent to a computer by an interface and stored in the *Lab View* data acquisition at 400 Hz. The values were submitted to the residual analysis process and soothed using the fourth order "butterworth" filter with frequency of three hertz (Hz). The 400 initial points were disregarded so that the peak force values (F_{peak}) were not overestimated in function of the transition from moderate swim to intense swim[11,29].

With the use of the calibration straight line (obtained through the superposition of known weights), the values obtained were converted into force units (N) through the *Matlab 5.3* program, thus enabling the determination of peak force (F_{peak}) and average force (AF_{NA}). F_{peak} was determined as the average of the five highest values during the test. AF_{NA} was considered as indicative of anaerobic fitness (FIT_{ANA})[11]. One, three and five minutes after FIT_{ANA} test, blood samples were collected from the ear lobe (25 μL), diluted into 50 μL of NaF 1% and analyzed in electrochemical lactimeter (*YSI* model *Sport 1500*, Yellow Spring Co., USA) for lactate peak concentration determination ($[la^-]_{peak}$).

Determination of anaerobic swimming capacity (AWC) and maximal performances (P_{MAX})

For the determination of the maximal performance (P_{MAX}), five maximal efforts randomly established at distances of 100 m, 200 m, 300 m, 400 m and 600 m in crawl style were performed in 25 m swimming pools at temperature of 27 ± 1°C with a minimum rest period of two hours.

The distance and time values were submitted to linear regression procedure for the estimation of AWCs (distance-time model), where the linear coefficient (y-intercept) of each individual regression represented the anaerobic swimming capacities (AWCs) (figure 2).

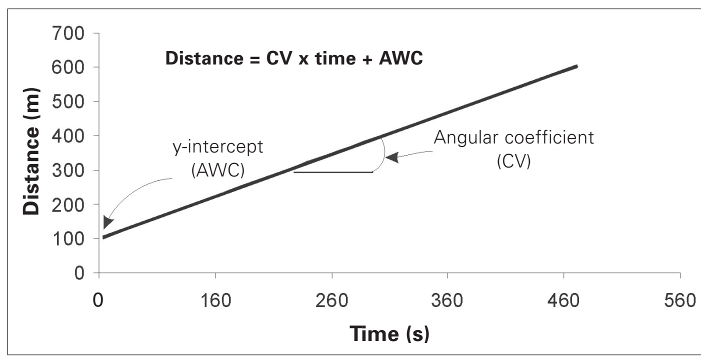

***Fig. 2** – Representative model of anaerobic swimming capacity determination (AWC) through the linear regression model between distance and time*

Using all possible combinations with number of points ranging from three to five, besides the AWC originated from protocol proposed by Wakayoshi *et al.*[18], which only uses distances of 200 m and 400 m, 16 AWCs were obtained (AWC_{12346}, AWC_{1234}, AWC_{1246}, AWC_{1346}, AWC_{123}, AWC_{124}, AWC_{126}, AWC_{134}, AWC_{136}, AWC_{146}, AWC_{234}, AWC_{236}, AWC_{2346}, AWC_{246}, AWC_{346} and AWC_{24}).

Statistical treatment

Values are presented as average + standard deviation. The one-way analysis of variance (ANOVA) was used with *post hoc* Newman Keuls test if necessary for all AWC obtained in this study. The relations between AWCs with F_{peak}, Fit_{ANA}, $[la^-]_{peak}$ and performances (P_{100}, P_{200}, P_{300}, P_{400} and P_{600}), as well as the crossing between F_{peak}, Fit_{ANA}, $[la^-]_{peak}$ and performances were obtained from the Pearson correlation analysis. In all cases, the significance level adopted was of 5%.

With the use of the *Origin 6.0* program, the linear coefficient errors (LCE) for the AWCs obtained from three to six velocities, called by Hill *et al.*[32] as estimation standard error.

RESULTS

Figure 3 presents the performance values ($m.s^{-1}$) used for the determination of the anaerobic swimming capacities, while table 1 presents the values of F_{peak}, Fit_{ANA}, $[la^-]_{peak}$, respectively.

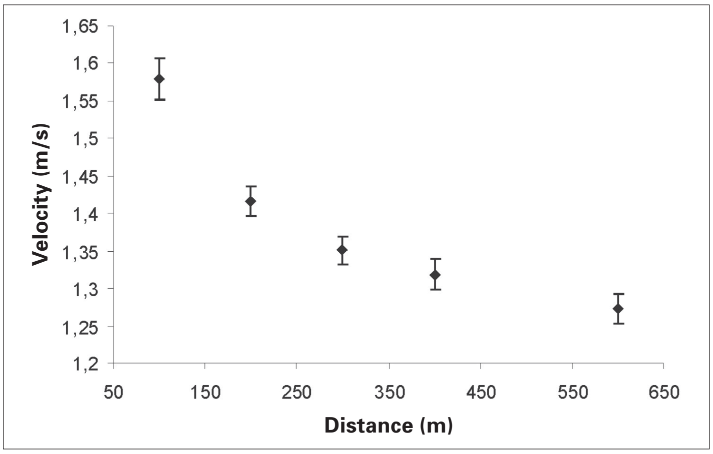

***Fig. 3** – Average values + standard deviation of velocity obtained during the performance of maximal efforts at distances of 100 m, 200 m, 300 m, 400 m and 600 m in crawl style*

TABLE 1
Average values ± standard deviation of the peak force (F_{peak}), anaerobic fitness (Fit_{ANA}) and peak lactate concentration $[la^-]_{peak}$ after 30-second maximal effort

F_{peak} (N)	Fit_{ANA} (N)	$[la^-]_{peak}$ (mM)
227.81 ± 63.02	86.55 ± 13.05	6.80 ± 1.03

The relation between distance and swimming time seems to be highly linear with determination coefficient (r^2) ranging from 0.99 to 1.00. Average AWC and LCE values of 25.07 ± 4.22 m and 19.30 ± 5.9%, respectively, were observed, so that only AWC_{236} presented error below 10% (8.86%). Significant differences between AWCs ($P < 0.05$) were observed. However, these values were highly correlated ($r \cong 0.80$).

TABLE 2
Pearson correlation coefficient (r) of anaerobic swimming capacities (AWCs) with maximal performances ($m.s^{-1}$) at distances of 100 m, 200 m, 300 m, 400 m and 600 m, and with the peak force (F_{peak}), anaerobic fitness (Fit_{ANA}) and peak lactate concentration $[la^-]_{peak}$

AWCs	P_{100}	P_{200}	P_{300}	P_{400}	P_{600}	F_{peak}	Fit_{ANA}	$[la^-]_{peak}$
AWC_{12346}	0.00	–0.16	–0.28	–0.47	–0.54	0.16	0.30	0.37
AWC_{1234}	0.02	–0.11	–0.20	–0.51	–0.45	0.23	0.14	0.48
AWC_{1246}	0.04	–0.14	–0.30	–0.41	–0.52	0.13	0.35	0.37
AWC_{1346}	–0.03	–0.19	–0.31	–0.48	–0.56	0.12	0.27	0.35
AWC_{123}	0.12	–0.06	–0.29	–0.22	–0.34	0.04	0.33	0.35
AWC_{124}	0.01	–0.13	–0.22	–0.53	–0.47	0.22	0.13	0.50
AWC_{126}	0.03	–0.13	–0.29	–0.45	–0.52	0.16	0.32	0.41
AWC_{134}	–0.01	–0.14	–0.21	–0.54	–0.47	0.21	0.08	0.46
AWC_{136}	–0.04	–0.19	–0.29	–0.52	–0.56	0.16	0.22	0.39
AWC_{146}	0.01	–0.17	–0.34	–0.50	0.03	0.03	0.35	0.28
AWC_{234}	0.02	–0.08	–0.13	–0.49	–0.39	0.27	0.10	0.45
AWC_{236}	–0.00	–0.14	–0.24	–0.48	–0.52	0.20	0.29	0.38
AWC_{2346}	–0.02	–0.16	–0.27	–0.47	–0.53	0.18	0.31	0.37
AWC_{246}	0.06	–0.09	–0.26	–0.33	–0.47	0.13	0.42	0.31
AWC_{346}	–0.06	–0.18	–0.25	–0.41	–0.51	0.11	0.29	0.23
AWC_{24}	0.03	–0.08	–0.16	–0.49	–0.41	0.27	0.15	0.49

No significant correlations were observed between AWCs and maximal performances or between AWCs and F_{peak}, Fit_{ANA} and $[la^-]_{peak}$ (table 2). F_{peak} and $[la^-]_{peak}$ did not present significant correlation with P_{MAX} either. However, Fit_{ANA} was significantly correlated with all P_{MAX} (table 3).

TABLE 3
Pearson correlation coefficient (r) of peak force (F_{peak}), anaerobic fitness (Fit_{ANA}) and peak lactate concentration $[la^-]_{peak}$ with maximal performances ($m.s^{-1}$) at distances of 100 m (P_{100}), 200 m (P_{200}), 300 m (P_{300}), 400 m (P_{400}) and 600 m (P_{600}) in crawl style

	P_{100}	P_{200}	P_{300}	P_{400}	P_{600}
F_{peak} (N)	0.63	0.56	0.53	0.38	0.41
Fit_{ANA} (N)	0.78*	0.82*	0.75*	0.74*	0.70*
$[la^-]_{peak}$ (mM)	–0.22	–0.21	0.29	–0.36	–0.33

* Indicates significant correlation for $P < 0.05$.

DISCUSSION

The main finding of the present study was that the AWC presented no significant correlation with anaerobic fitness and swimmers performance. Experimental and literature review studies have demonstrated significant associations between AWC and the Wingate test[16,21,23], the total accumulated intermittent work[19] and the muscular ATP production[22], besides demonstrating the significant AWC contribution to the performance in running above eight km[31]. It was yet demonstrated that the AWC is a reproducible and sensible parameter[23] to the effects of enduring[20], intense[19] training, and to the creatine supplementation[32], emphasizing the possibility of this parameter being used as indirect measurement in the evaluation and prediction of anaerobic performances[22,30,33].

It is interesting to observe that the AWC values in the present study, unlike most investigations previously mentioned, presented no significant correlations with any of the maximal performances and anaerobic fitness test that used the same duration time as the Wingate test.

Guglielmo and Denadai[34] found no correlations between AWC of swimmers with the average power determined during 30-second maximal efforts in isokinetic arm ergometer. Papoti *et al.*[27] used a tied swim system and verified significant correlation between average force (FNA) during 30-second maximal efforts and performances of 100 m and 200 m in crawl style, but not between FNA and AWC obtained through the y-intercept of the distance x time linear relation using distances of 200 m and 400 m, proposed by Wakayoshi *et al.*[18]. In the present investigation, the FNA, assumed by Papoti *et al.*[11] as Fit_{ANA} indicative, was also significantly correlated with performances between 100 m and 600 m in crawl style.

Soares *et al.*[35] found no significant correlations between AWC (determined through the relation obtained between the prefixed distance and the swimming time) and the average power in swim bench during 45-second maximal effort in children and adult swimmers. Those authors concluded that the AWC provides no consistent information on the anaerobic capacity of swimmers, regardless the age range considered.

Dekerle *et al.*[26] also verified no significant correlation between AWC and the maximal anaerobic distance in swimmers, which was considered as the distance in which the swimming maximal velocity may be maintained, and suggested the non utilization of this parameter to control anaerobic variables.

A possible explanation for the contradiction observed in literature with regard to the use of AWC as parameter for the prediction of anaerobic performances[19-21,32] may be that the relation used for the linear regression procedure considers the limit time (Tlim). The fixed-distance model proposed by Wakayoshi *et al.*[18] considers in theory that the swimmer would not be able to support the swimming velocity imposed during efforts at any distance above the prefixed distance (200 m and 400 m). This hypothesis seems to limit the use of this model, considering the anaerobic aspect only, once some swimmers are capable to support the swimming velocity obtained at distances of 200 m and 400 m for a few more meters, probably due to the lactate tolerance capacity.

Green[33] verified that the higher accuracy on the AWC determination of well-trained cyclists was obtained when the exhaustion criterion for the attainment of limit times was extended until the intensity corresponding to the $\dot{V}O_2$ peak rather than the impossibility of maintaining a prefixed rhythm (90 rpm). The author believes that this criterion enables maximizing the use of substrates generally used in the performance of anaerobic exercises and, hence, the attainment of more accurate AWC values.

Toussaint *et al.*[28] investigated whether the concepts of critical power and AWC could be used to evaluate the aerobic and anaerobic capacities of swimmers. To do so, the authors developed a mathematical model related to the mechanics and energetics involved in the crawl style, based on previous studies and evaluations performed in the swimming flume. The authors also modeled the release of aerobic and anaerobic energy in relation to the swimming time. The authors concluded that, although the critical velocity is an indicative of the aerobic system, the AWC is influenced by variations of energy from both the aerobic and anaerobic systems, thus providing no actual estimation of the anaerobic capacity. Furthermore, the results found in literature on its reproducibility range from r = 0.62[36] to r = 0.87[23].

Other hypothesis to explain the non representativeness of AWC as performance predictive parameter of swimmers is the great fluctuation on the y-intercept values to small variations on the swimming velocity. In addition, Bishop and Jenkins[20] found high negative correlation (r = –0.94) between alterations on the critical power (CP) and on AWC after six weeks of endurance training. These authors believe that a great change on CP or AWC may influence both variables due to the rotative effect of the mathematical model emphasizing a limitation to the linear model to determine the critical power and AWC.

Hill *et al.*[32] reported that the AWC is a parameter sensible to measure the anaerobic capacity only when this one presents a linear coefficient standard error below 10%. In the present study, the average of the linear coefficient errors remained between 9% and 29%. Only the AWC determined with distances of 200 m, 300 m and 600 m presented error below 10% (9%). However, this AWC presented no correlation with Fit_{ANA} and performance. Bullbulian *et al.*[25] found no associations and significant relation between AWC and the anaerobic capacity in the Wingate test (r = 0.07), and very low when corrected by the body weight (r = 0.41), and suggested that AWC could not be an indicative of the glycolytic anaerobic via. Although more researches comparing AWC with validated anaerobic evaluation methods are required as, for instance, the oxygen maximal deficit accumulated, one may conclude that the AWC represented by the y-intercept of the distance x swimming time relation does not seem a good parameter in the evaluation of the anaerobic fitness and in the performance prediction between 100 m and 600 m in crawl style.

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