Correlations between anaerobic threshold determination protocols and aerobic performance in adolescent swimmers

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ABSTRACT

The purpose of this study was to correlate the anaerobic threshold speeds (ATS) obtained from fixed lactate blood concentration (ATS 4 e ATS 3.5 mM), lactate minimum speed ($Lac_{min}S$) and the critical speed (CS) determined from different distances and number of coordinates: CS1 (50/100/200 m), CS2 (100/200/400 m), CS3 (50/100/200/400 m) and CS4 (200/400 m) with the performance in 400 meters (s) in adolescent swimmers. The sample was constituted by 15 swimmers (10 boys and five girls = 14.7 ± 0.7 years; 61.9 ± 8.5 kg; 171.1 ± 8.8 cm) of national level, with five to seven years of experience in competitive swimming. The correlation between the indexes and the performance in 400 m (s) was made using Pearson correlation coefficients. Significance was set at $p < 0.01$. The correlations between ATS 4 mM, ATS 3.5 mM, $Lac_{min}S$ and the performance in 400 m (s) were: r = -0.63, r = -0.90 e r = -0.91, respectively ($p < 0.01$). The correlations between CS1 (50/100/200 m), CS2 (100/200/400 m), CS3 (50/100/200/400 m), CS4 (200/400 m) and the performance in 400 m (s) were: r = -0.62, r = -0.97, r = -0.98 e r = -0.94, respectively ($p < 0.01$). We suggest that ATS obtained from fixed lactate blood concentration of 3.5 mM, as well as $Lac_{min}S$ and the CS obtained through larger distances seem to be the most fitted indexes of prediction of the aerobic performance in the studied adolescent swimmers. Additionally, the number of coordinates seems no influencing the relation between CS and aerobic performance.

Keywords: Anaerobic threshold. Lactate minimum. Critical speed. Aerobic performance. Adolescent swimmers.

INTRODUCTION

It has been sometime that indices which are able to evaluate aerobic capacity and simultaneously make the suitable prescription of training intensity in athletes are searched for. Within this context, over the years, the oxygen maximal uptake ($\dot{V}O_2max$) has been considered the gold standard parameter for evaluation of aerobic capacity in active and sedentary individuals as well as athletes, considering its important relationship with performance, especially in prolonged physical exertions under moderate intensity[1].

In swimming**,** especially in events which involve longer distances, the existence of significant correlation between $\dot{V}O_{2max}$ and performance has not been reported in the literature. Riberio *et al.*[2] have investigated a group of trained swimmers and did not find significant correlation between $\dot{V}O_2max$ and performance in 400 m crawl. These findings corroborate the results obtained in posterior studies which used the same distance[3-5]. Similar results were reported in studies involving children, although different levels of correlation with aerobic performance have been observed[6-7]. Moreover, reports in the literature show that the $\dot{V}O_2max$, besides being influenced by the maximal cardiac debt[8], is also dependent on genetic factors[9-10].

Concerning the limitations imposed by the use of the $\dot{V}O_2max$, the blood lactate response to exercise has been widely applied from the determination of the anaerobic threshold (LAn), once it is considered an extremely interesting referential for prescription of training intensity, control of the training effects, prediction of aerobic performance, as well as evaluation of the aerobic capacity of active and sedentary subjects and athletes[11].

Among the methodologies applied for determination of LAn, there are the ones which use protocols which directly measure the blood lactate concentration, making use of steady[12-15] or variable concentrations[16-17]. It is highlighted though, that currently the minimum lactate methodology (Lac_{min}) initially proposed by Tegtbur *et al.*[17] and adapted for swimming, has been on the spotlight, especially due to its possibility to individually identify the maximum lactate steady state (MLSS)[18-19].

Considering that the obtained LAn from descriptive methods is invasive, requires blood samples collection, is pricy and has specific analyses equipment, it is important to search for more viable alternative methods to be applied. Within this context, the critical velocity (CV) which corresponds to the swimming velocity which theoretically can be kept for a longer period of time with no exhaustion, has been pointed out as one of the non-invasive indices of highest potential for evaluation of aerobic performance and LAn prediction of adult[3-5,20-21], children and adolescent swimmers[22-30], regardless the performance level[25].

It is worth mentioning that the combination of shorter distances in the CV prediction in young swimmers, determines significantly higher CV values when compared with combinations which involve longer distances[29], which could mainly contribute for differences in the relationship between CV and swimming performance and consequently in its prediction. Another relevant factor for CV is associated with the number of coordinates used in its determination, which represents the number of distances or workloads and their respective reached times[31]. Some studies have suggested that the number of coordinates does not seem to change the CV values[32-33] and critical power (CP)[31] at least when longer distances or lighter loads which enable longer effort time are applied. However, these studies do not report influence of the number of coordinates used in CV determination in the relationship with physical performance.

Considering that few studies have tried to investigate the physiological indices which are able to determine performance in events with aerobic predominance in swimming, the aim of the present study was to correlate the LAn velocity obtained from the lactate steady concentrations (LAn 4 and LAn 3.5 mM), at Lac_{min} velocity and CV determined from different distances and number of coordinates with performance obtained in 400 meters (s) in swimming, in adolescent swimmers.

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METHODS

Subjects

The sample consisted of fifteen swimmers (10 boys and 5 girls) from national level, with experience between 5 and 7 years in competitive swimming. Eleven subjects were specialists in free style (short and medium distances: n = 7, and long distance: n = 4), three in back stroke (short and medium distances) and one in breast stroke (short and medium distances).

All subjects were involved in a systematized training program of six weekly sessions and weekly mean volume between 36.000 and 40.000 m before the beginning of the data collection, with the purpose to improve the swimming main physical capacities. During collection the subjects were in the polishing phase, which is the final preparation process of a swimmer for the main competition season and consists of gradual reduction of the training volume-intensity ratio[34]. The responsible ones for the subjects, after having been informed about the aims of the study and the procedures to which the athletes were going to be submitted, signed a free and clarified consent form. This study was approved by the Ethics Committee in Research from the Medical Sciences College of UNICAMP.

Experimental procedures

All tests were performed in the same semi-Olympic swimming pool (25 m) with water temperature ranging between 26 and 27°C, where the subjects, always using the free style, participated in seven or eight evaluations with 24 to 48 hour-interval between them. Warm-up was freely performed prior to each experimental session. In all tests the swimmers have received visual instructions from the researcher positioned at the side edge of the pool along the 25 m which have been set at each 5 m by cones in order to keep the pre-set velocities for the 25 m distance. The time of the evaluation sessions were the same during the entire experimental protocol. The volunteers were submitted to a pilot test for familiarization with the protocols as well as the used equipments.

Weight and height measurement

Body weight was measured in a digital platform scale, Urano®, model PS 180, with 0.1 kg precision, and height was determined in wooden stadiometers with 0.1 cm precision. All individuals were measured and weighted bare feet, only wearing a swimming suit. These measurements were performed with the purpose to characterize the subjects involved in the experiment.

Anaerobic threshold velocity

The anaerobic threshold velocity (VLAn) was determined through methodology similar to the one proposed by Mader *et al.*[12] using steady concentrations of 4 mM (VLAn 4 mM) and 3.5 mM (VLAn 3.5 mM) of blood lactate[15]. Therefore, two 200 m submaximal swimming repetitions were performed, being the first at 85% and the second at 95% of maximal velocity for the 200 m distance, with interval of 20 minutes between repetitions at passive recovery. After the first, third and fifth minutes of performance of each sprint, 25 µL of artery blood from the earlobe were collected, with the aid of a heparinized and calibrated capillary for blood lactate dosing. Mean velocities corresponding to VLAn 4 mM and VLAn 3.5 mM were determined by linear interpolation between the highest lactate concentration of each sprint and its respective velocities.

Minimum lactate velocity

In order to determine the minimum lactate velocity ($VLac_{min}$) an adaptation of the protocol proposed by Tegtbur *et al.*[17] for runners was used, according to what was suggested by Ribeiro *et al.*[19] Initially, the individuals performed two maximal efforts of 50 m, with 1 minute-interval between them, for induction of considerable accumulation of lactate in the blood stream (lactic acidosis). After a period of 8 minutes of passive recovery, the volunteers initiated an incremental exercise protocol with 300 m stages, with initial velocity ranging from 1.10 to 1.25 $m.s^{-1}$ and increments of 0.05 $m.s^{-1}$ at every repetition until exhaustion[19]. The initial velocity was chosen by each individual so that they could perform from four to six efforts. In the seventh minute after lactic acidosis induction and immediately after each repetition during the incremental phase, approximately 25 µl of artery blood from the earlobe were collected, through a heparinized and calibrated capillary, for blood lactate dosing. $VLac_{min}$ was considered that in which the lowest blood lactate concentration during the progressive phase of the test was observed[19].

Critical velocity

For the critical velocity determination (CV) maximal sprints were performed in the 50, 100, 200 and 400 m distances, being the respective times registered, with sprints exit from the pool, next to the edge. The sprints were randomly performed during the training sessions, with one try per session. CV was determined through the inclination (b) of the linear regression line between the distances and their respective times obtained at each repetition[3]. In order to determine CV1, 50, 100 and 200 m distances were used; for CV2, 100, 200 and 400 m distances were used; for CV3, 50, 100, 200 and 400 m were used and, for CV4, 200 and 400 m distances were used. The athletes were evaluated in groups to motivate them to get their best performance. The time was registered with a hand digital time watch (SEIKO S140, JAPAN) with milliseconds precision.

Blood lactate analysis

Blood samples collected for lactate dosing were immediately placed in polyethylene microtubes with 1.0 ml Eppendorff lid, containing 50 µl of haemolysing solution (sodium fluoride, 1%) and then stored at –70°C. Lactate analysis was performed by an electrochemical analyzer (YSL 2300 STAT Yellow Spring Co., USA).

Statistical analysis

Data statistical treatment was performed by *Statistica*™ computer package for Windows 6.0® (*STATSOFT INC., USA*). After data normality was stated (S*hapiro-Wilk* test), descriptive statistics procedures were used and, later, simple regression analysis as well as the *Pearson* simple coefficient correlation for analysis of the correlations among VLAn 4 mM, VLAn 3.5 mM, $VLAc_{min}$, CV1, CV2, CV3, CV4 and performance in 400 m (s). Significance level adopted was of $p < 0.01$.

RESULTS

In table 1, the anthropometric characteristics of the studied subjects are found.

In table 2, the mean values for VLAn 4 mM, VLAn 3.5 mM, $VLac_{min}$, CV1, CV2, CV3 and CV4 are found.

TABLE 1
Anthropometric characteristics of the studied subjects (N = 15)

	Mean	Standard deviations	Minimum	Maximal
Age (years)	14.7	0.7	14.0	15.00
Height (cm)	171.1	8.8	155.0	187.0
Weight (kg)	61.9	8.5	48.0	76.0

TABLE 2
Mean values (± SD) of the velocities ($m.s^{-1}$) corresponding to the anaerobic threshold of 4 mM (VLAn 4), anaerobic threshold of 3.5 mM (VLAn 3.5), minimum lactate ($VLac_{min}$), and critical velocities (CV) 1, CV2, CV3 and CV4 (n = 15)

VLAn 4 ($m.s^{-1}$)	VLAn 3,5 ($m.s^{-1}$)	$VLac_{min}$ ($m.s^{-1}$)	VC1 ($m.s^{-1}$)	VC2 ($m.s^{-1}$)	VC3 ($m.s^{-1}$)	VC4 ($m.s^{-1}$)
1.34 ± 0.05	1.28 ± 0.04	1.27 ± 0.05	1.33 ± 0.05	1.26 ± 0.06	1.27 ± 0.06	1.25 ± 0.07

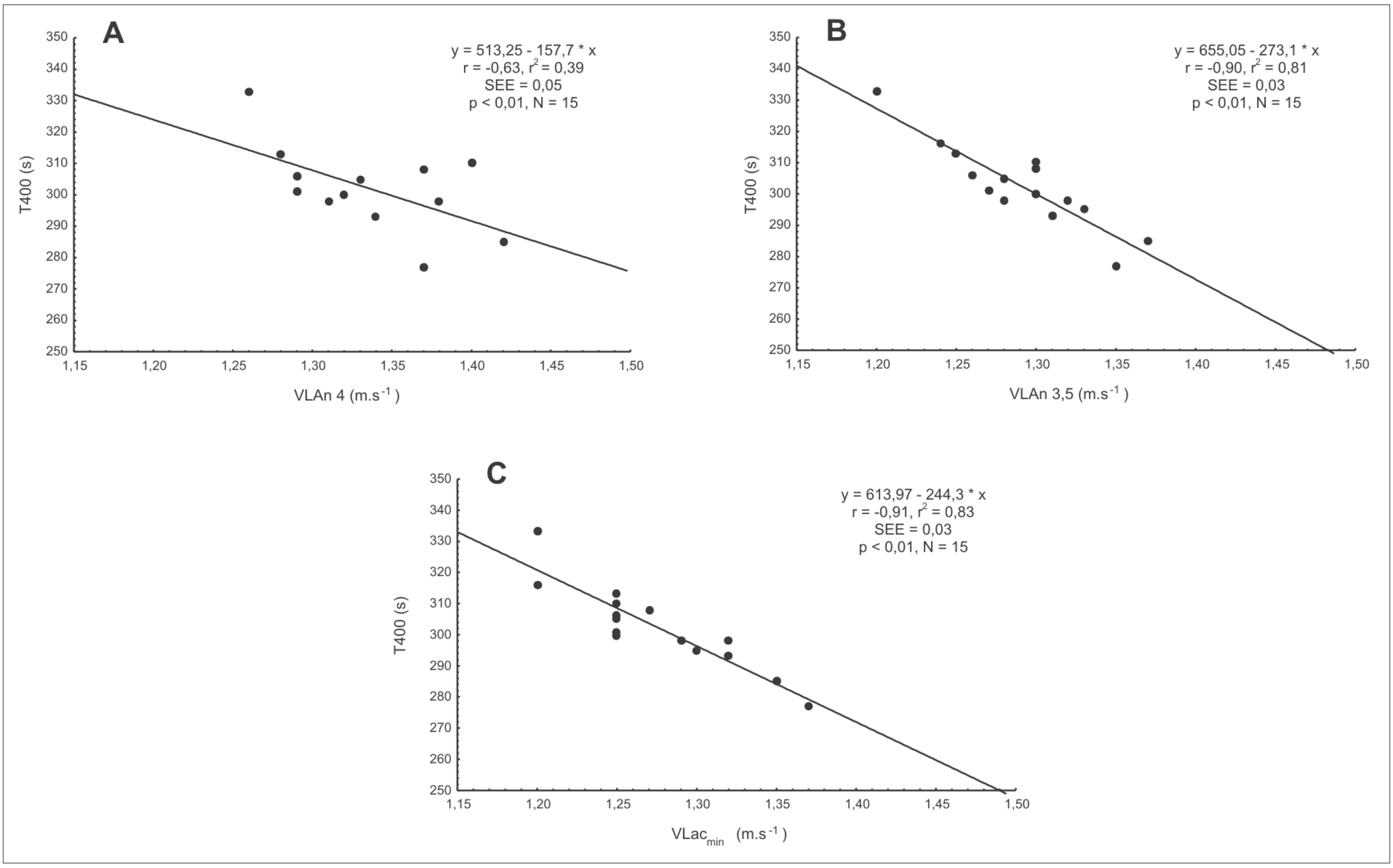

Figure 1 *– Correlations between the velocities (m.s^{-1}) corresponding to VLAn 4 mM* ***(A)****, VLAn 3.5 mM* ***(B)*** *and VLacmin* ***(C)****, and performance in 400 m (T400) (s)*

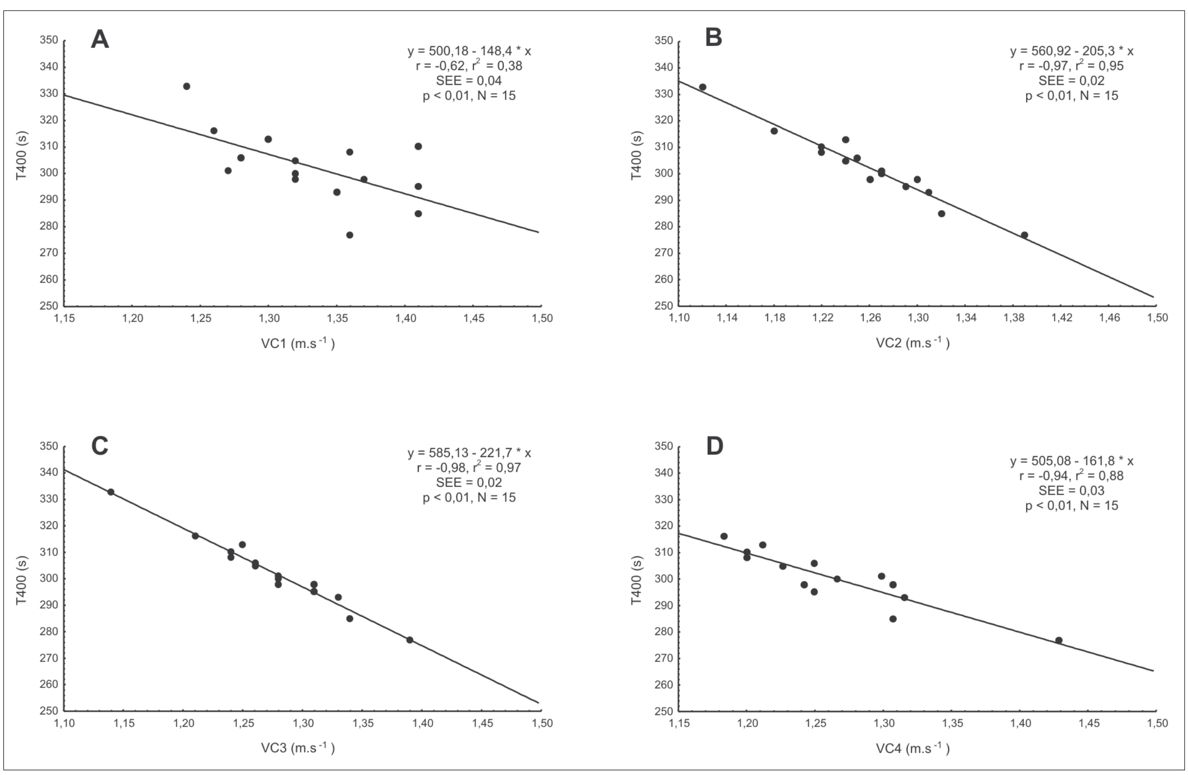

Figure 2 *– Correlations between the velocities (m.s^{-1}) corresponding to CV1* ***(A)****, CV2* ***(B)****, CV3* ***(C)*** *and CV4* ***(D)****, and performance in 400 m (T400) (s)*

In figure 1 the correlations (r) in VLAn 4 mM, VLAn 3.5 mM, $VLac_{min}$ and performance in 400 m (s) (r = -0.63, r = -0.90 and r = -0.91, p < 0.01, respectively) are presented.

In figure 2 (r) correlations among CV1 (50/100/200 m), CV2 (100/200/400 m), CV3 (50/100/200/400 m), CV4 (200/400 m) and performance in 400 m (s) (r = -0.62, r = -0.97, r = -0.98 and r = -0.94, p < 0.01, respectively) are presented.

DISCUSSION

Since there is a need to analyze indices able to predict performance in swimming which allow a more suitable training prescription, the aim of the present investigation was to correlate the LAn velocity obtained from lactate steady concentrations (LAn 4 and LAn 3.5 mM), Lac_{min} velocity and CV determined from different distances and number of coordinates with performance in 400 meters (m) in adolescent swimmers. Thus, the findings of the present study show that: 1) the correlation values obtained among VLAn 3.5 mM, $VLac_{min}$, CV2, CV3 and CV4 and performance in 400 m (s) were highly significant; 2) VLAn 4 mM and CV1 presented low correlation values with performance in 400 m (s).

LAn has been considered an extremely interesting index for prediction of aerobic performance of athletes[11]. Studies with adult swimmers conducted by Wakayoshi *et al.*[3-5] found significantly high correlations between LAn of 4 mM and performance in 400 m (r = 0.76, r = 0.90 and r = 0.93, respectively). Likewise, Bonifazi *et al.*[35] when investigating trained athletes of both genders have verified high levels of correlation between LAn of 4 mM and performance in 400 m (r = 0.86) and 800 m (r = 0.84) distances in female swimmers, and in 200 m (r = 0.72), 400 m (r = 0.87) and 1500 m (r = 0.91) distances in male swimmers. In addition to that, Guglielmo and Denadai[36] when investigating a group of trained swimmers and triathletes observed high and significant correlation between LAn of 4 mM and performance in 400 m (s) (r = -0.90). In this same study, when LAn was determined in an arm egometer, significant correlation with performance in 400 m (s) (r = -0.74) was also found.

As seen before, the present study shows different correlation values between VLAn 4 mM and VLAn 3.5 mM with performance in 400 m (s) (r = -0.63 and r = -0.90, respectively), showing that the lactate concentration used in LAn determination interferes in the relationship with swimming performance of the studied group. A study by Greco *et al.*[29] involving male and female swimmers aged 13-15 years found correlation values significantly high between LAn 4 mM and performance in 400 m (s) (r = -0.89 at r = -0.92, respectively). Still in this study, when younger swimmers were analyzed (10 and 12 years) the boys presented correlation values of r = -0.88 and the girls of r = -0.97, between LAn 4 mM and performance in 400 m (s).

In another study also involving swimmers of both genders aged 10-12 years, Denadai and Greco[23] found correlation values significantly high between LAn 4 mM and performance in 200 m (r = 0.93). Similarly, Freitas *et al.*[27] when studying a group of young swimmers of both genders (10-12 years) found correlation values significantly high between LAn 4 mM and performance in 200 m (r = 0.88) and 400 m (r = 0.94).

It is worth mentioning that VLAn determination in our study was composed of two submaximal repetitions of 200 m, according to what has been used in other studies with young swimmers[24-25,29,37], with intensities of 85% and 95% of maximal velocity for 200 m distance, which corresponded to approximately 120 and 135 seconds of duration, respectively. Moreover, one should consider that incremental and continuous protocols with stages lower than five minutes, should use lactate steady concentration of 3.5 mM in the determination of VLAn instead of 4 mM, once the use of the latter may overestimate LAn intensity, which limits the use potential of this method both for performance prediction and determination of aerobic capacity[15]. These observations may partly explain the highest correlation values found between performance in 400 m (s) and LAn determined by the 3.5 mM blood lactate concentration.

Despite being widely used, LAn determination by results interpolation has been criticized since it does not consider the lactate kinetics individually[16], and its results do not suffer influence of previous availability of muscular glycogen[38]. Therefore, some authors have suggested the application of the minimum lactate test (Lac_{min}) for individual evaluation of LAn, since besides not having its results affected by the previous depletion of glycogen, Lac_{min} test presents objectivity in its estimation[17].

Few studies have applied the Lac_{min} test in swimming for LAn determination, especially in adolescent populations. A study by Simões *et al.*[18] which had as aim to investigate the relationship between Lac_{min} and performance in 200 and 700 m distances in a group of trained swimmers, mean age of 16.0 ± 0.8 years, stated significant correlations between $VLac_{min}$ and performance in 200 m and 700 m (r = 0.97 and r = 0.96, respectively). More recently, Santos *et al.*[39] when studying swimmers of both genders, mean age of 15.3 ± 1.1 years, did not find significant correlations between $VLac_{min}$ and performance in 200 m and 400 m (r = 0.94 and r = 0.94, respectively). Our results corroborate these previous findings where the correlation between $VLac_{min}$ and performance in 400 m (s) was significantly high (r = -0.91). As already mentioned, the highest correlation values found between $VLac_{min}$ and performance in 400 m (s) compared with the ones observed for VLAn 4 mM and performance in 400 m (s) may be explained by the overestimation of the swimming velocities obtained from the LAn 4 mM method[15].

The CV which corresponds to the swimming velocity which theoretically may be kept for a long period of time with no exhaustion, has been shown as one of the non-invasive methods with the most potential for aerobic performance evaluation and LAn prediction of adult swimmers[3-5,20-21]. A study by Wakayoshi *et al.*[3] with a group of well-trained adult swimmers using *swimming-flume*, has observed significantly high correlation between CV and performance in 400 m (r = 0.86). Still in *swimming-flume*, Wakayoshi *et al.*[4] found significant correlation value between CV and performance in 400 m (r = 0.82). In the same study, when the CV determined by the 50, 100, 200 and 400 meters distances were obtained in a pool (25 m), the correlation between CV and performance 400 m was of r = 0.99.

In addition to that, studies performed in a pool by Wakayoshi *et al.*[5] who used 200 and 400 meters distances, Kokubun[20] who used 100, 200 and 400 meters distances and Rodriguez *et al.*[21] who used 100 and 400 m distances in the determination of CV in trained adult swimmers, also found significant correlations between CV and performance in 400 m (r = 0.97, r = 0.95 and r = 0.94, respectively). Moreover, it is worth highlighting that Kokubun[20] in a study observed significant correlation between CV and performance in 800 m (r = 0.99).

Hill *et al.*[22] suggest the use of CV in evaluation of aerobic performance in young swimmers (8 to 18 years). These authors, after having analyzed the relationship between CV and performance in two groups of swimmers, found for the younger group (mean of 11 years) a significant correlation between CV and performance in 457 m (r = 0.92), and for the older group (mean of 15 years) found a correlation of r = 0.92 between CV and performance in 1509 m.

In our study significantly high correlations have been found between CV2, CV3 and CV4 and performance in 400 m (s) (r = -0.97, r = -0.98 and r = -0.94, respectively). However, when the relationship between CV1 and performance in 400 m (s) was analyzed, it was low (r = -0.62). These findings suggest that the combination of different distances in CV determination, especially involving shorter distances, and, consequently, with lower times of execution, influences in the relationship between CV and performance in young swimmers, which can limit the use of this method for performance prediction. Corroborating these findings, Greco *et al.*[29] demonstrated that the combination of shorter distances (25/50/100 m) in CV prediction, with exhaustion times between 14 and 121 seconds, determined significantly higher values of CV in young swimmers of both genders, aged between 10-15 years, than when the combinations involved longer distances (50/100/400 m and 100/200/400 m).

A study by Barsa *et al.*[26] in swimmers of both genders aged between 13-15 years found significantly high correlation values between CV determined by the 100, 200 distances and 400 m and performance in 100 m (r = 0.87), 200 m (r = 0.97) and 400 m (r = 1.00). In this same study, when the younger swimmers (10 and 12 years) were analyzed, the correlations values between CV and performance in 100, 200 and 400 m were of r = 0.91, r = 0.92 and r = 1.00, respectively. Likewise, a study by Greco *et al.*[29] involving male and female swimmers aged between 13-15 years, found significantly high correlation values between CV determined by 50, 100 and 200 m distances and performance in 400 m (s) (r = -0.95 at r = -0.88, respectively). Still in this study, when younger swimmers (10 and 12 years) were analyzed, the boys presented correlation values of r = -0.88 and the girls of r = -0.96, between CV and performance in 400 m (s).

Similarly, Denadai and Greco[23] when studying swimmers of both genders aged between 10-12 year found significantly high correlation values between CV determined by the same distances (50/100/200 m) and performance in 200 m (r = 0.98). In addition, Freitas *et al.*[27] when studying a group of young (10-12 years) swimmers of both genders found significantly high correlation values between CV determined by 100, 200 and 400 m distances and performance in 200 m (r = 0.95) and 400 m (r = 1.00). More recently, Bartholomeu-Neto *et al.*[40] when studying swimmers of both genders, mean age of 14.3 ± 1.2 years found significantly high correlation values between CV determined by the same distances (100/200/400 m) and performance in 200 m (r = 0.95) and 400 m (r = 0.98).

It can also be observed in our study that the number of coordinates used to determine CV does not seem to influence the relationship between CV and performance of young swimmers, at least when distances which allow longer time of effort until exhaustion are used. Such fact became evident from the correlation values observed between CV2, CV3 and CV4 determined by three, four, and two distances, respectively, and performance in 400 m (s), which were very close (r = -0.97, r = -0.98 and r = -0.94, respectively).

A study by Housh *et al.*[31] verified that the CP estimated from two coordinates, was significantly correlated (r = 0.96) with the values found when it was estimated by four coordinates, when the time difference between the two coordinates was higher than 2.7 minutes. However, when this difference was higher than 5 minutes, the correlation index was increased (r = 0.98). Therefore, the findings show the possibility of use of only two coordinates for swimming performance prediction, as long as they present longer effort time until exhaustion, which could contribute in the decrease in the number of sessions applied in the CV estimation. The results of this study are according to others conducted in cyclic modalities such as canoeing[32] and swimming[33].

It is important to highlight that the present study has a relative limitation concerning the generalization of results and should be analyzed only in the swimming context; besides being applied only in the reality of an adolescent swimming team of national level. Despite the reduced number of athletes used in the sample of the present study, it is verified that it is part of a restricted population, of difficult use in an investigation, since they are athletes of national level. In swimming, a club hardly ever has an athletic team of national level in the age group investigated. Additionally, coaches are usually resistant about making the athletes available for studies of this nature during the preparation phase for competitions. Stone *et al.*[41] highlight that the majority of the studies in Sports Science, differently from Exercise Science, involve multiple test sessions and a relatively low number of subjects. Nevertheless, in the authors' opinion, they are the most valuable for the training development and manipulation, due to the inherent analysis of a specific population as well as the lack of publications in this context. Therefore, the present study is very relevant, once it has been integrally and trustworthily conducted concerning the proposed experiments, as well as the control of the tests to which the subjects were submitted.

CONCLUSIONS

According to the findings of the present study, it is suggested that the choice of the lactate concentration for LAn determination interferes in the relationship with aerobic performance for the studied adolescents. Moreover, the combination of different distances in CV determination, especially concerning lower distances, influences the relationship between CV and aerobic performance. It is also suggested that, the number of coordinates does not seem to influence the relationship between CV and performance of young swimmers, at least when longer distances are applied in its determination. Therefore, it would be possible to use only two coordinates in the performance prediction. Finally, we may conclude that LAn determined from 3.5 mM, at $VLac_{min}$ and CV obtained through longer distances seem to be the most suitable predictors of aerobic performance in the adolescent swimmers studied.

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