Determination of Force Coresponding to Maximal Lactate Steady State in Tethered Swimming

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ABSTRACT

Int J Exerc Sci 2(4): 269-279, 2009. The main aim of the present investigation was to verify if the aerobic capacity (AC) measured in tethered swimming corresponds to the maximal lactate steady state (MLSS) and its correlation with 30 min and 400m free style swimming. Twenty-five swimmers were submitted to an incremental tethered swimming test (ITS) with an initial load of 20N and increments of 10N each 3min. After each stage of 3min, the athletes had 30s of interval to blood sample collections that were used to measure blood lactate concentrations ($[La^-]$). The AC_{BI} was determined by the abrupt increase in $[La^-]$ versus force (F). The points obtained between $[La^-]$ versus force (N) were adjusted by an exponential curve model to determine AC corresponding to 3.5mmol.l^{-1} ($AC_{3.5}$) and 4.0mmol.l^{-1} ($AC_{4.0}$). After these procedures, the swimmers performed maximal efforts of 30min and 400m in free style swimming. We used the distance performed in 30min and the time performed in 400m to calculate the median velocities (i.e. V30 and V400) of these protocols. After one week, in order to measure the MLSS, nine athletes performed three 30-min tethered swimming efforts with intensities of 90, 100, and 110% of AC_{BI}. The ANOVA one-way was used to compare the AC_{BI}, $AC_{3.5}$ and $AC_{4.0}$. Correlations between ACs, and between ACs and V30 and V400 ($p<0.05$) were determined using the Pearson's correlation coefficient. The intensity corresponding to 100% of AC_{BI} was similar to the MLSS. It was observed significant correlations of the aerobic capacities (i.e. AC_{BI}, $AC_{3.5}$ and $AC_{4.0}$) with V30 ($r>0.91$) and V400 ($r>0.63$). According to our results, it is possible to conclude that the AC_{BI} corresponds to the MLSS, and both the AC - individually determined - and the AC - determined using fixed blood lactate concentrations of 3.5 and 4.0mmol.l^{-1} - can be used to predict the mean velocity of 30min and 400m in free style swimming. In addition to that, the tethered swimming system can be used for aerobic development in places where official sized swimming pools are not available, such as rehabilitation clinics and health clubs.

KEY WORDS: Swimming, aerobic capacity, system data acquisition, load cell, elastic cord

INTRODUCTION

The determination of the aerobic capacity in swimmers using both blood lactate concentrations (10, 24, 27) and non-invasive methods (25, 30, 32-35) has been widely used to evaluate and monitor the swimming training (25). The gold standard protocol for the aerobic capacity determination is the maximal lactate steady state (MLSS) (2-7); however, the cost of the test and the requirement for individuals to complete 3-6 constant-load exercise bouts on separate days are the main disadvantages of this procedure.

Despite the methodological limitations and the contradictions between the nomenclatures used in swimming, the determination of the aerobic capacity during incremental tests using the relationship between exercise intensity and blood lactate concentration is the most commonly used method. While some authors proposed the interpolation to fixed blood lactate reference concentrations of 4 $mmol.L^{-1}$ (20, 30) and 3.5 $mmol.L^{-1}$ (24), other studies used the lactate minimum test (27, 28) and the abrupt increase of the blood lactate concentration as a function of exercise intensity (18, 19). However, it is important to point out that depending on the method used to analyse the relationship between exercise intensity and blood lactate concentration, the results may differ as much as 15% (29).

Based on the information that the training intensities of the swimmers corresponded to workloads below, at and above the aerobic capacity (15, 16), some alternative forms of training are suggested to improve their performance. The training involving the development of maximal force against blocks fixed to the depth of the pool (31), the tethered swimming with suspension weights (15) and the training using elastic cords (12) are some of the alternative forms of training used to improve the athletes' performance.

Although the mechanics of swimming changes with tethering (17, 18), the methods described above are also used to evaluate aerobic capacity. In addition to that, some authors have shown that aerobic capacity can be determined in tethered swimming using blood lactate concentration (18) and non-invasive methods as the critical power (14), that may be defined as a theoretical maximal swimming velocity that could be maintained for a long period of time without exhaustion. However, up to date, we do not know if the swimming intensity obtained by these methods corresponds to the maximal force that can be maintained during a long period with equilibrium between blood lactate production and removal, as well their relationships with aerobic performances in free swimming. The hypothesis of the present investigation is that the aerobic capacity determined during the incremental test in tethered swimming corresponds to the MLSS. Therefore, the main purpose of the present investigation was to verify if the aerobic capacity (AC) measured in tethered swimming corresponds to the maximal lactate steady state (MLSS) and its correlation with 30 min and 400m free style swimming.

METHOD

Participants

Twenty-five swimmers (mean ± SD: age 16±3 years, 168.3±5.04cm, weight 63±6.07kg), members of the Sao Paulo

Aquatic Sports Federation, participated in the present study (10 females and 15 males). The swimmers have been participating a in training program and competing at the national level for a minimum of five years. Participants were currently training a mean of 4300±500m.d^{-1}, six days per week. The athletes were previously informed of all experimental procedures and provided a written informed consent which was approved by the Institute's Ethics Committee. The best 100m free style swimming performed by these swimmers corresponded to 70.3±8% of the world record.

Protocols

All swimmers were submitted to both incremental test in tethered swimming to determine their aerobic capacities, and maximal performances during 30min and 400m in free style swimming. The minimum interval between these tests was 48h. After one week, in order to measure the MLSS, nine athletes performed three 30-min tethered swimming efforts with intensities of 90, 100, and 110% of AC_{BI}. The minimum rest period between these trials was 24h. The tests were performed in a 25-m swimming pool with water temperature maintained at 27ºC.

Before the physical tests, the swimmers performed their warm up consisting of approximately 500m of low and moderate intensity in free style swimming (subjectively determined by the swimmers). To minimize possible learning effects, the athletes remained daily 5 minutes in tethered swimming during 6 days using free style swimming.

Aerobic capacity in tethered swimming (AC)

Aerobic capacity in tethered swimming (AC) was determined by an incremental test (IT) to voluntary exhaustion with swimmers connected to a 1000N load cell with 4 attached strain gauges by a commercial elastic cord (Auriflex - nº204, Brazil). Strain gauge deflection from swimmer effort was amplified by portable extensometer (SODMEX ME-01D). The signals were captured by computer interface and stored in a data acquisition program at 400 Hz. After reading and converting the data to units of force (N) with LabVIEW (National Instruments) and MATLAB 5.3 software, the swimming force was determined through straight line calibration (with reference weights of 2 kg and 10 kg).

The experimental protocol had an initial load of 20N, increments of 10N and duration of 3min. After each stage of 3min, the athletes had 30s of interval to blood sample collections that were used to measure blood lactate concentrations ([La$^-$]). Cones were placed 2m apart on the pool sides. During each stage (i.e. 3min), swimmers were required to keep their head as close as possible to the cone placed on the side of the pool. The increase of the intensity consisted of moving the swimmer to the next cone. Exhaustion was assumed when the swimmer was unable to maintain position in a specific stage for 10 seconds (figure 1).

The points (i.e. min = 4 and max = 9) obtained from the relationship between blood lactate concentrations ([La$^-$]) and force (N) in tethered swimming were used to determine individual aerobic capacity by

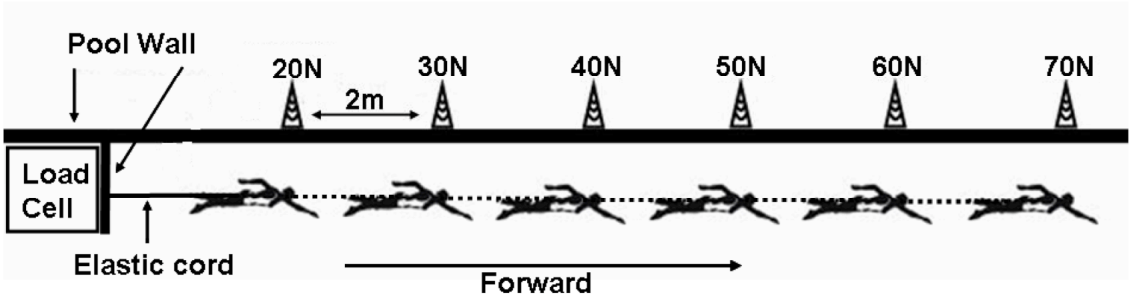

Figure 1. Diagram of cone positions at the side of the pool used as references for increased intensities during the incremental tethered swimming test.

the "bi-segmented" method (AC_{BI}) and by the fixed blood lactate concentrations of 3.5mmol.l^{-1} ($AC_{3.5}$) and 4mmol.l^{-1} (AC_4).

The AC_{BI} was assumed as the swimming force corresponding to the intersection of two inclined straight lines (18, 19, 30). These points were then adjusted by the exponential growth curve model (24) in such a way that tethered swimming force corresponded to the two fixed blood lactate concentrations of $AC_{3.5}$ and AC_4 respectively (figure 2).

Velocities for 30 min (V30) and 400m (V400) free style swimming

Two days after the IT, the swimmers performed the maximal distance during 30min in free style swimming. In addition to that, they performed a 400-m maximal effort in free style swimming. We used the distance performed in 30min and the time performed in 400m to calculate the median velocities (i.e. V30 and V400) of these protocols.

Blood lactate

Blood samples were taken from the earlobes in 25-µL heparinized capillary tubes and were stored in 1.5ml Eppendorfs tubes containing 50 µl of sodium fluoride at 1% (NaF). Blood lactate concentrations ([La-]) were assayed by a lactate analyzer (YSI 1500 Sport, Yellow Spring Instruments, OH, USA) and were expressed as mmol.l^{-1}.

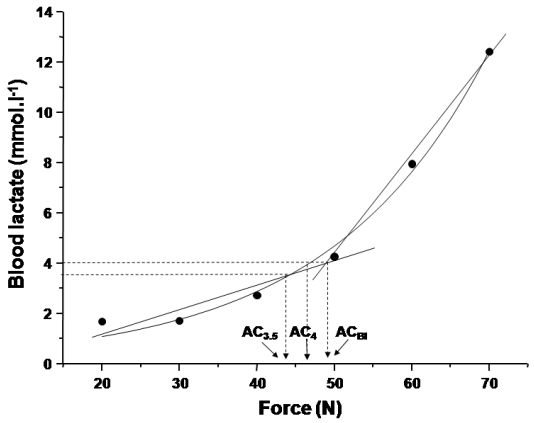

Figure 2. Aerobic capacity determination for an individual swimmer from different methods "bi-segmented" (AC_{BI}), 3.5mmol.l^{-1} ($AC_{3.5}$), and 4mmol.l^{-1} (AC_4) fixed blood lactate concentrations.

Statistical Analysis

According to the Shapiro-Wilk's W test (W= 0.98; P= 0.19), the set of data presented normal distribution and the homogeneity was confirmed by Levene's test (F=0.20; P=0.82). Therefore, the analysis of variance

with Newman-Keuls' post hoc was used for statistical comparisons between AC_{BI}, $AC_{3.5}$, and $AC_{4.0}$. Correlations between the AC values determined by the different methods and between AC_{BI}, $AC_{3.5}$ and $AC_{4.0}$ values with V30 and V400 were analyzed using the Pearson's correlation coefficient. In addition to that, Bland & Altman (8) plots were used to evaluate concordance between AC values. A significance level of 5% was chosen. Data are expressed as mean ± standard deviation.

RESULTS

By the linear regression between the distance (D) of the swimmers from the end of the pool where the load cell was located and the respective forces (F) during the incremental test, the relationship between D and F was expressed by F = (5.2936 x D) - 18.791 (r^2 = 0.99). We were able to estimate AC_{BI}, $AC_{3.5}$ and $AC_{4.0}$ for all swimmers. Figure 3 shows the individual behaviour between [La^-] and exercise intensity of the swimmers.

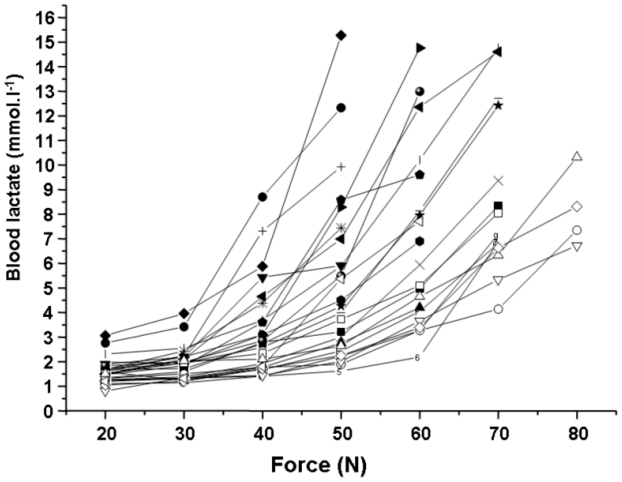

Figure 3. Individual values of the relationship between blood lactate concentrations and exercise intensities during the incremental tethered swimming test.

According to table 1, no significant differences (F=0.20; P=0.82) were found between AC_{BI}, $AC_{3.5}$ and $AC_{4.0}$. However, the $AC_{3.5}$ and $AC_{4.0}$ corresponded to 99.4 and 103.5% of AC_{BI}, respectively. In addition to that, the AC_{BI}, $AC_{3.5}$ and $AC_{4.0}$ presented significant correlations (R>0.81, P<0.05).

Table 1. Mean ± standard deviation of force values (N) corresponding to aerobic capacities determined by straight line bi-segmented (AC_{BI}) and fixed blood lactate concentrations of 3.5 ($AC_{3.5}$) and 4mmol.l^{-1} (AC_4).

AC_{BI}	$AC_{3.5}$	$AC_{4.0}$
54.10±10.39	54.19± 14.01	56.10 ± 10.39

In addition to the high correlations, Bland and Altman (8) graphical analysis showed that the differences for AC_{BI} versus $AC_{3.5}$; AC_{BI} versus AC_4; and $AC_{3.5}$ versus AC_4 were randomly distributed in terms of systematic errors (Bias). However, in contrast to $AC_{3.5}$ versus AC_4, AC_{BI} showed weak concordance with $AC_{3.5}$ and AC_4 (figure 4).

In figure 5, it is possible to observe blood lactate concentration stabilization from the 10^{th} to the 30^{th} minute in the intensities corresponding to 90 (10^{th} = 2.33±0.75mmol.l^{-1}; 30^{th} = 2.47±0.74mmol.l^{-1}) and 100% (10^{th} = 3.56±1.29mmol.l^{-1}; 30^{th} = 4.52±1.23mmol.l^{-1}) of AC_{BI}, but not in the intensity corresponding to 110% of AC_{BI}. In fact, the participant 2 presented stabilization of the blood lactate concentration in 110% of AC_{BI}.

Table 2 demonstrates that the aerobic capacities (i.e. AC_{BI}, AC_4, and $AC_{3.5}$) were

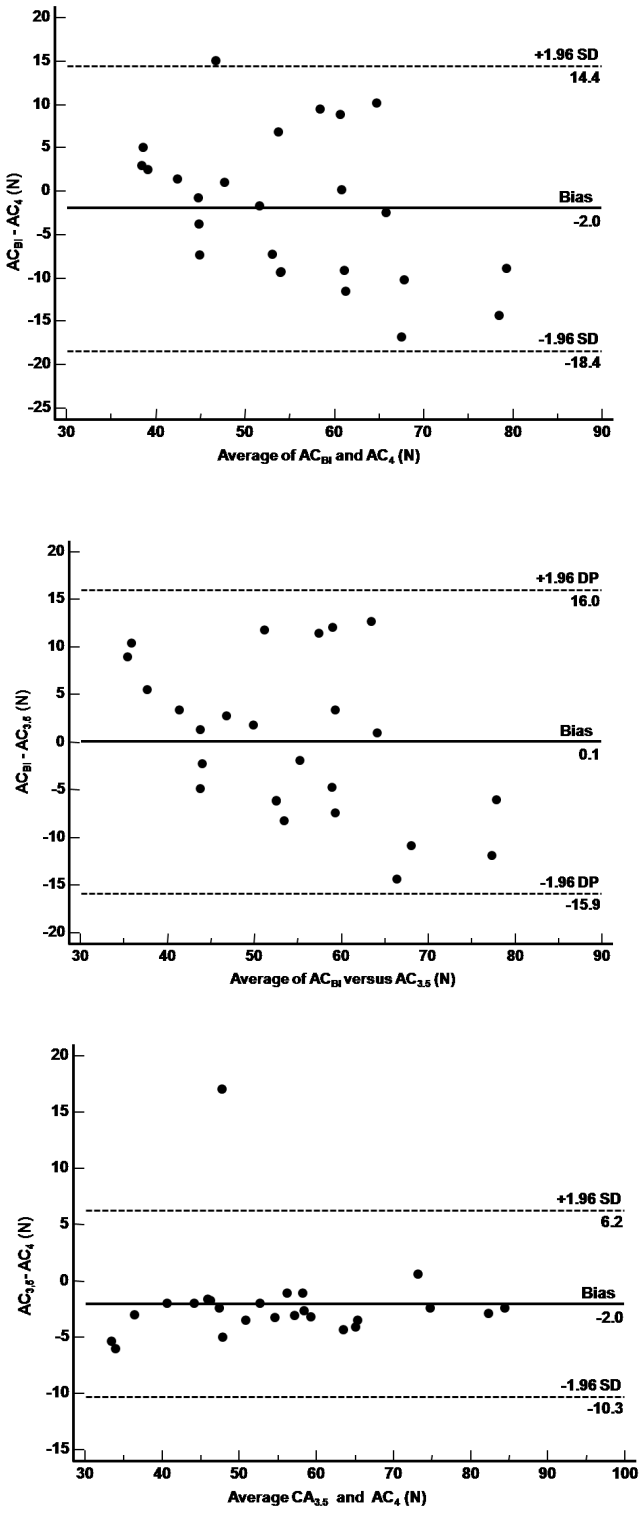

Figure 4. Mean differences in aerobic capacity values between (a) bi-segmented (AC_{BI}) and fixed blood lactate concentration of 4mmol.l^{-1} (AC_4); (b) AC_{BI} and fixed blood lactate concentration of 3.5mmol.l^{-1} ($AC_{3.5}$); and (c) $AC_{3.5}$ and AC_4.

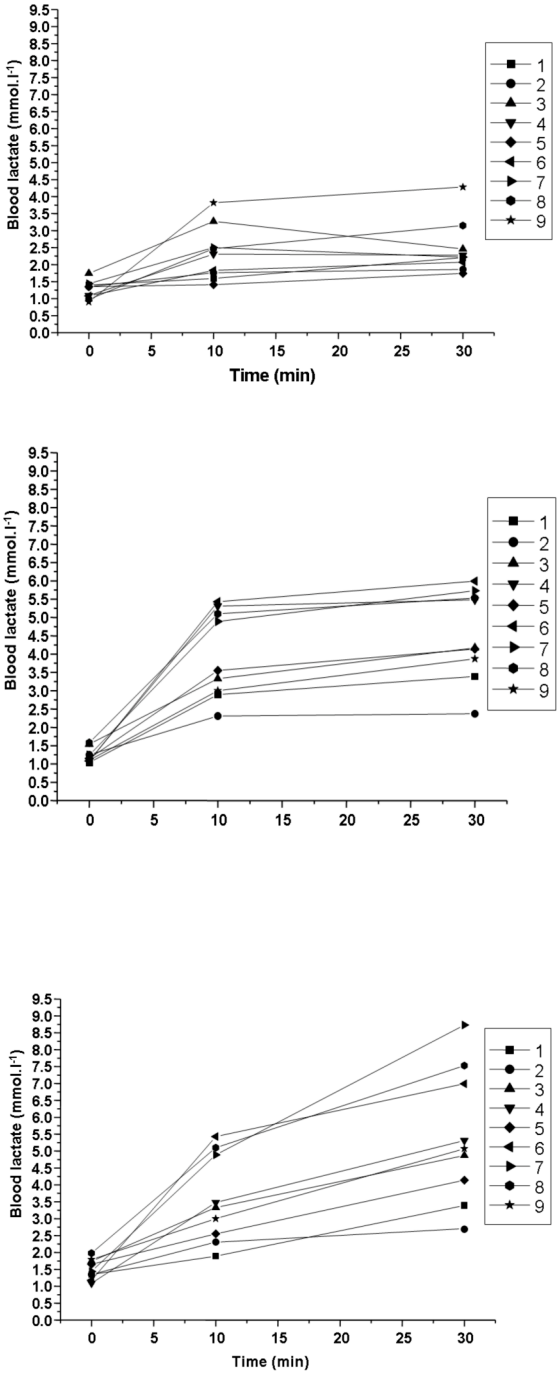

Figure 5. Blood lactate values at rest, 10th and 30th minute of rectangular exercise in tethered swimming performed at (a) 90%, (b), 100%, and (c) 110% of the aerobic capacity determined by the bi-segmented method.

significantly correlated with V30 (1.07±0.15m.s^{-1}) and V400 (1.23±0.10m.s^{-1}).

DISCUSSION

The main finding of the present investigation was that the aerobic capacity determined in tethered swimming corresponded to the MLSS. The tethered swimming method have been used to determine anaerobic fitness (11, 22, 23), maximal oxygen consumption (36, 37), stroke rate (9), and aerobic capacity (AC) by invasive (18) and non-invasive methods (1, 14).

In the current study, AC was determined using the bi-segmented method (AC_{BI}), and the fixed blood lactate concentrations of 3.5 ($AC_{3.5}$) and 4.0mmol.l^{-1} (AC_4). Tokmakidis et al. (29) verified that AC measured by visual inspection was significantly inferior (≅ 7%) to AC corresponding to the fixed blood lactate concentration of 4mmol.l^{-1}. In addition to that, these authors observed that depending on the criteria used, the differences in AC determination could reach up to 15%. However, in our investigation, the AC values were not different and presented significant correlations. On the other hand, Bland and Altman (8) graphical analysis revealed a "poor" concordance for AC_{BI} with $AC_{3.5}$ and AC_4.

Heck et al. (13) suggested the use of the fixed blood lactate concentration of 3.5mmol.l^{-1} in efforts during up to 3 minutes. In efforts during five minute or more, the authors indicated the fixed blood lactate concentration of 4mmol.l^{-1}. However, Pereira et al. (24) observed that in efforts during approximately 5 minutes, the MLSS presented more similarity with the AC determined using the fixed blood lactate concentration of 3.5mmol.l^{-1} in comparison with the fixed blood lactate concentration of 4mmol.l^{-1}. In addition to that, these researchers reported that the AC could overestimate the MLSS in approximately 4%.

We verified that the AC_{BI} corresponded to the MLSS, but due to methodological difficulties, the intensities above and below AC_{BI} used to identify MLSS were 10%. Thus, the AC_{BI} could have been underestimated to MLSS by up to 9%. Considering that a specific swimmer has an AC_{BI} of 50N, for him to make an effort corresponding to 110% (55N), according to the protocol used, he has to advance one meter while for an increase of 3.5%, which is the difference between AC_{BI} and AC_4, an advance of only 35cm would be necessary. Although the swimmers used reference markers placed on the side of the pool, during rectangular efforts, variations of approximately 20cm of the swimmer's head in relation to the markers were used as references. Therefore, with the ergometer method used, this study presented limitations in intensity increase of approximately 20cm or 1N.

Almeida et al. (1) found significant reductions in blood lactate concentrations when swimmers were submitted to 30-min effort in tethered swimming at 110% AC_{NA} (using the critical power model) compared to the 100% values. These researchers believed that the swimmers "adjusted" their swimming technique for tethered swimming which resulted in less lactate concentration than at 100% AC. This effect could be related to a possible ergometer adaptation during tethered swimming efforts. However, they did not report

whether swimmers underwent an adaptation period to the tethered swimming system. In our study, the adaptation period in the tethered swimming may be the responsible by the sensitivity of the lactemia to the variations of 10% in exercise intensity above and below AC.

Despite the disagreements related to the evaluation methods in tethered swimming, it is well established in the literature that the mean force during efforts varying from 30 to 60s have high correlations with performances at distances between 50 and 400m in free style swimming (11, 22), and that they are sensitive to training (26) and to taper period (27). However, few studies have evaluated the relationships between AC in tethered swimming and aerobic performance in free swimming. Papoti et al. (21) applied the lactate minimum test (LMT) and determined aerobic capacities in free and tethered swimming, and although there were high coefficients of determination from the polynomial equations obtained from the relationships between lactemia and exercise intensity, no significant correlations were seen in LMT values between free and tethered swimming. The explanations for these results were both the lack of adaptation of swimmers to the tethered swimming system and the limitation of the LMT test in tethered swimming to predict LMT velocity in free swimming. In the current study, the AC determined by the different methods (i.e. AC_{BI}, AC_4, and $AC_{3.5}$) correlated with V30min and V400.

The findings of our study suggest that AC in tethered swimming can be used as a predictor of aerobic performance in free swimming and that the tethered swimming system can be used for aerobic development in places where official sized swimming pools are not available, such as rehabilitation clinics and health clubs.

From this method of AC determination, theoretically, it would be possible to adapt tethered swimming for easy (End-1), moderate (End-2), and intense (End-3) aerobic training, as suggested by Maglischo (15, 16). However, as the mechanics of swimming are subject to changes in this situation (17, 38), additional studies are required to study the possible effects of tethered swimming training on stroke mechanical parameters and free swimming performance.

Although the reproducibility and sensitivity of AC in tethered swimming and its effects on conventional swimming training have not been verified in this study, we have shown that the AC_{BI} corresponds to the MLSS, and both the AC - individually determined - and the AC - determined using fixed blood lactate concentrations of 3.5 and 4.0mmol.l^{-1} - can be used to predict the mean velocity of 30min and 400m in free style swimming. In addition to that, the tethered swimming system can be used for aerobic development in places where official sized swimming pools are not available, such as rehabilitation clinics and health clubs.

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