Technical indexes corresponding to the critical speed and the maximal speed of 30 minutes in swimmers with different aerobic performance levels*

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ABSTRACT

The main objective of this study was to verify the effect of aerobic performance level on the relationship between the technical indexes corresponding to critical speed (CS) and maximal speed of 30 minutes (S30) in swimmers. Participated of this study 23 male swimmers with similar anthropometric characteristics, divided by aerobic performance level in groups G1 (n = 13) and G2 (n = 10). They had at least four years of experience in the modality and a weekly training volume between 30,000 to 45,000 m. The CS was determined through the angular coefficient of the linear regression line between the distances (200 and 400 m) and respective times. The S30 was determined through the maximal distance covered in a 30 minutes test. All variables were determined in front crawl. CS was higher than S30 in G1 (1.30 ± 0.04 *vs.* 1.23 ± 0.06 $m.s^{-1}$) and G2 (1.17 ± 0.08 *vs.* 1.07 ± 0.06 $m.s^{-1}$). These variables were higher in group G1. The stroke rate corresponding to CS (SRCS) and S30 (SRS30) obtained in group G1 (33.07 ± 4.34 *vs.* 31.38 ± 4.15 $cycles.min^{-1}$) and G2 (35.57 ± 6.52 *vs.* 33.54 ± 5.89 $cycles.min^{-1}$) were similar. The SRCS was significantly lower in group G1 than G2, while SRS30 was not different between groups. The stroke length corresponding to CS (SLCS) and S30 (SLS30) was significantly higher in group G1 (2.41 ± 0.33 *vs.* 2.38 ± 0.30 $m.cycle^{-1}$) than in G2 (2.04 ± 0.43 *vs.* 1.97 ± 0.40 $m.cycle^{-1}$), and had similar values in both groups. The correlation (r) between CS and S30 and technical variables corresponding to CS and S30 were significant in all comparisons (0.68 to 0.91). Thus, the relationship between the speed and technical variables corresponding to CS and S30 was not modified by the aerobic performance level.

Keywords: Stroke rate. Stroke length. Stroke index. Swimming. Aerobic capacity.

INTRODUCTION

In competitive swimming, the biodynamic aspects, which represent the swimming technique and skill, may equally contribute to performance when compared with the aspects connected with the systems of energy production. Among the biomechanical aspects, there are the propulsive force application level[1-2] as well as passive and active drag[3-4]. Studies have verified that biomechanical aspects interfere in variables such as energetic cost and propulsive efficiency, being these factors essential for dislocation in the water environment[5-6]. Besides those aspects, some anthropometric variables[7-8] and arm coordination (relation between propulsive and non-propulsive phases)[8,10], are also related with performance in this sport.

Therefore, the use of variables which represent the skill level in swimming may allow the follow up of the effects of a training program which aims to improve the swimmers' technique. Moreover, the measurement of these variables enables a more individualized training prescription. Once some of these indices are easily measured, it is possible to use them in a large number of athletes, since skilled staff and costly equipment are not needed.

Among the indices which express the swimming skill, we find the stroke rate (SR), which represents the number of strokes or cycles of strokes performed in a time unit; stroke length (SL), which represents the distance which the swimmer performs in each cycle of stroke and the stroke index (SI), which corresponds to the product of the velocity and the SL. Besides these, the index SR/SL also seems to express the level of swimming skill[8,11]. These variables have presented significant correlation with the oxygen uptake in a given submaximal velocity and with performance (100, 200, 368 and 400 m) in this sport[5-6,12-14]. Even in highly trained swimmers, the SR improvement has also been associated with performance increase[14]. The swimming velocity represents the product of the SR by the SL[15-16], therefore, in order to keep a given velocity, the swimmers generally adopt a combination of SR and SL which they consider to be the most efficient. Nevertheless, according to Dekerle *et al.*[17], elite swimmers adopt different combinations of these parameters in relation to less experienced ones, being this fact possibly one of the factors which determine their higher performance levels.

Among the physiological indices which represent the aerobic capacity, the critical velocity (CV), determined through the angular coefficient of the linear regression between distance and time; the 30-minute test or 30-minute maximal velocity (V30), in which the swimmer must complete the longest possible distance in 30 minutes, are within the most used non-invasive methods for aerobic evaluation in swimming[18-21]. The velocities obtained in these methods have presented high indices of correlation with the blood lactate response (anaerobic threshold, maximal steady state of blood lactate – MSSL) and with the aerobic performance in this sport[22-23]. Recently, Dekerle *et al.*[17] have verified that the SR determined through the angular coefficient of the linear regression between the number of strokes and the time obtained in different distances (critical stroke rate – CVSR), similar to the methodology proposed for the determination of the CV[19], is valid for the estimation of the SR kept in the V30 (SRV30). An advantage of this methodology is the use of shorter tests (i.e., 200 and 400 m), once longer tests such as the V30 min, require more time for the evaluation process and they can be difficult to be performed by less skilled swimmers.

Studies[22,24-25] have verified that the CV values are dependent on the duration of the predictive loads. Moreover, they can also interfere in its relation with the anaerobic threshold (V4 mM of blood lactate)[22]. Therefore, it is possible that the intensity as well as

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physiological and technical meaning of the CV be dependent on the performance level of the swimmers, once the athletes with higher performance complete the same distances (i.e., 200 and 400 m) in shorter times. Still concerning performance level, Dekerle *et al.*[17] point out that elite swimmers may adopt SR and SL combinations which are not the same observed in swimmers of worse performance. Therefore, it possible to hypothesize that the level of aerobic performance may change the relation among the technical variables (SR, SL and SI) corresponding to the CV (CVSR, CVSL and CVSI) and the V30 (SRV30, SLV30 and SIV30). Based on this hypothesis, the main aim of this study was to verify the effect of the aerobic performance level in the relationship between technical variables corresponding to the CV and the V30.

METHODS

Subjects

Twenty-three male swimmers, specialists in front crawl, with at least 4 years of experience, who trained a weekly volume between 30,000 and 45,000 m in 6 to 8 sessions, participated in the study. The swimmers regularly participated in state and national competitions. Prior to the participation in the protocols, the parents or responsible ones, as well as the individuals, were informed about all the test's procedures, by signing a free and informed form agreeing on the participation in the study. The study was approved by the Ethics Committee in Research of the University.

Experimental framework

The swimmers participated in 4 experimental sessions, separated by a 48-72 hour interval. The tests were conducted at the same time for each individual, at least two hours after a light meal. In the first experimental session the anthropometric variables were determined. In the other three following sessions which were randomly performed, the 200, 400 and 30-minute maximal performances were determined. All variables were determined in the freestyle in a 25 m swimming pool. Initially, the swimmers performed all the tests, being later divided in two groups with different performance levels in relation to the 30-min test: group 1 (G1) (higher performance) and group 2 (G2) (lower performance). The physical characteristics of the swimmers are expressed in table 1. There was no statistically significant difference in any of the variables ($p > 0.05$).

TABLE 1
Physical characteristics of the swimmers

	G1 (n = 13)	G2 (n = 10)
Age (years)	15.58 ± 2.07	15.00 ± 2.29
Height (cm)	174.08 ± 7.42	169.78 ± 10.37
Body mass (kg)	64.74 ± 11.45	61.56 ± 15.76
Fat percentage (%)	12.81 ± 2.99	14.81 ± 5.27

Determination of the critical velocity

In order to have the CV determined, maximal performances in the 200 and 400 m distances were conducted, with their respective times being taken note of. These trials were performed one per session during the training sessions. The CV was determined through the angular coefficient (b) of the linear regression line between distances and the respective obtained times. Previous studies verified the validation of the CV determination with two distances in trained swimmers[23,26-27].

Determination of the 30-minute velocity

In order to have the V30 determined, a maximal 30-minute sprint was performed, taking note of its respective length. The V30 was determined by dividing the distance (m) by the time (s). In the 10th min and at the end of the test, 25 μl of arterial blood were collected from the earlobe through a heparinized capillary and immediately after transferred for polyethylene micro tubes with Ependorff lid of 1.5 ml, containing 50 μl of NaF (1%) for the measurement of blood lactate (YSL 1500 STAT, Yellow Springs, OH). Blood sample collection duration was of approximately 30 s. In order to express the lactate concentration corresponding to this velocity, the mean of the values obtained in the 10th min and at the end of the test was calculated.

Determination of the technical indices corresponding to the critical velocity

The stroke rate corresponding to the critical velocity (CVSR) was determined through the counting of the time needed to perform 5 strokes. This counting was performed at each 50 meters in the 200 and 400 m distances and hence having the mean of the obtained values calculated. Moreover, it was performed 10 minutes after the lap, in order to avoid the influence of this velocity in the swimming. The CVSR was determined through the angular coefficient of the linear regression between the number of strokes and the time obtained in the 200 and 400 m distances. The stroke length corresponding to the CV (CVSL) was obtained through the quotient between the velocity and the CVSR. The stroke index corresponding to the CV (CVSI) was determined through the product between SL and velocity.

Determination of the technical indices corresponding to the 30-minute critical velocity

The stroke rate corresponding to the V30 (SRV30) was determined through the counting of the time needed to perform 5 strokes. This counting was performed each 400 m and hence the mean of the obtained values calculated. Moreover, it was performed 10 m after the lap to avoid its influence over the swimming velocity. The SL corresponding to the V30 (SLV30) was obtained by the quotient between the velocity and the SRV30. The stroke index corresponding to the V30 (SIV30) was determined through the product between SL and velocity.

Statistical analysis

The values are expressed as mean ± standard-deviation (SD). The comparison of the technical variables corresponding to the CV and the V30 was performed through ANOVA TWO WAY (method x group), complemented by the Scheffé test. The comparison of the anthropometric variables between groups was performed through the *t*-Student test for non-paired data. The correlation of the velocity and the technical variables corresponding to the CV and the V30 was performed through the Pearson correlation test. For all performed tests the significance level of $p \leq 0.05$ was adopted.

RESULTS

Table 1 presents the physical characteristics of the swimmers. There was no statistically significant difference ($p > 0.05$) between groups in the age, height, body mass and body fat percentage (%G) variables.

Table 2 presents the mean values ± SD of the maximal velocity of 200 (V200) and 400 m (V400), CV, V30 variables and lactate concentration corresponding to the V30 ([LAC]) obtained in groups G1 and G2. The V200, V400, CV and V30 were significantly higher in the swimmers of G1 ($p < 0.05$), except for [LAC] which was not different between groups. The CV and the V30 were statistically different in the two groups. There was significant correlation between the CV and V30 in group G1 ($r = 0.68$) and in G2 ($r = 0.84$) ($p < 0.05$).

Table 3 presents the mean values ± SD of the stroke rate, stroke length and stroke index variables corresponding to the CV (CVSR,

TABLE 2
Mean ± SD values of the 200 (V200) and 400 m (V400) maximal velocities variables, critical velocity (CV), 30-minute velocity (V30) and lactate concentration corresponding to the V30 ([LAC]) (mM) obtained in groups G1 and G2

	V200 ($m.s^{-1}$)	V400 ($m.s^{-1}$)	CV ($m.s^{-1}$)	V30 ($m.s^{-1}$)	[LAC] (mM)
G1 (n = 13)	1.45 ± 0.09	1.37 ± 0.05	1.30 ± 0.04	1.23 ± 0.06	4.03 ± 1.40
G2 (n = 10)	1.32 ± 0.11[a]	1.23 ± 0.09[a]	1.17 ± 0.08[a]	1.07 ± 0.06[a]	3.88 ± 1.48

[a] $p < 0.05$ concerning group 1.

TABLE 3
Mean and + SD values of the stroke rate, stroke length and stroke index variables corresponding to the CV (CVSR, CVSL and CVSI, respectively) and to the V30 (SRV30, SLV30 and SIV30, respectively) in groups G1 and G2

	CVSR ($cycles.min^{-1}$)	CVSL ($m.cycle^{-1}$)	CVSI	SRV30 ($cycles.min^{-1}$)	SLV30 ($m.cycle^{-1}$)	SIV30
G1 (n = 13)	33.07 ± 4.34	2.41 ± 0.33	3.14 ± 0.45	31.38 ± 4.15	2.38 ± 0.30	2.92 ± 0.40[b]
G2 (n = 10)	35.57 ± 6.52[a]	2.04 ± 0.43[a]	2.40 ± 0.64[a]	33.54 ± 5.89	1.97 ± 0.40[a]	2.11 ± 0.52[a,b]

[a] $p < 0.05$ in relation to G1, [b] $p < 0.05$ in relation to CVSI.

CVSL and CVSI, respectively) and to the V30 (SRV30, SLV30 and SIV30, respectively) in groups G1 and G2. The CVSR was significantly lower in G1 than in G2 ($p < 0.05$), while the SRV30 was not different between groups ($p > 0.05$). There was not significant difference between CVSR and SRV30 in the two groups ($p > 0.05$). The CVSL and the SLV30 were significantly higher in G1 ($p < 0.05$). The CVSL was statistically equal to the SLV30 ($p > 0.05$) in the two groups. Likewise, the CVSI and the SIV30 were significantly higher in G1 ($p < 0.05$). The CVSI was significantly higher than the SIV30 in the two groups ($p < 0.05$).

Table 4 presents the correlation values between CV and V30, SR, SL and SI corresponding to the CV and the V30 in G1 and G2. There was significant correlation among all variables in G1 and G2 ($p < 0.05$).

TABLE 4
Correlation values between CV and V30, and between SR, SL, SL and SI corresponding to CV and V30 in groups G1 and G2

	CV x V30	CVSR x SRV30	CVSL x SLV30	CVSI x SIV30
Group 1 (n = 13)	0.68[a]	0.84[a]	0.90[a]	0.88[a]
Group 2 (n = 10)	0.84[a]	0.88[a]	0.90[a]	0.91[a]

[a] $p < 0.05$.

DISCUSSION

The main aim of this study was to verify the effect of anaerobic performance in the relationship among SR, SL and SI corresponding to the CV and V30 in swimming. The main finding was that although the technical indices have been different between groups, the relationship among SR, SL and SI corresponding to the CV and V30 does not seem to depend on the level of anaerobic performance analyzed. Thus, the determination of the CV may simultaneously provide data about anaerobic capacity and technical fitness in this sport.

Dekerle *et al.*[17] found values of CVSR (37.79 $cycles.min^{-1}$), SRV30 (36.41 $cycles.min^{-1}$), CV (1.35 $m.s^{-1}$e) and V30 (1.31 $m.s^{-1}$) higher than the ones obtained in the present study in G1 and G2 (table 2). These outcomes agree with the literature's data which suggest that higher swimming velocities are associated with higher SR[8,14,28]. Although the SL values have not been reported in the study by Dekerle *et al.*[17], the difference found in the SR values obtained in the present study may be partially explained by a lower performance level, once the swimming velocity corresponds to the product of SR and SL[15-16]. More importantly though, is the fact that Dekerle *et al.*[17] did not verify difference statistically significant between CVSR and SRV30 either, nor a high level of correlation between them (r = 0.86), which reinforces our data that the CVSR and SRV30 relationship seems to be independent from anaerobic performance.

In the present study, the CVSL and the SLV30 were higher in group G1, which is according to the data obtained by studies which investigated the association of SL with performance in distances of 100 to 400 m[5-6,11-14,30-31]. Moreover, in a study in which the authors compared individuals with different performance levels, more skilled swimmers presented a higher SL in distances of 50 to 3000 m[32]. As far as we are concerned, no study has ever investigated the relationship between CVSL and SLV30. Nevertheless, Dekerle *et al.*[33] verified that the SL corresponding to the MLSS, which is considered the gold-standard method for determination of anaerobic fitness, was similar to the one obtained in the highest velocity in which the swimmer was able to perform keeping his maximal SL. Above this velocity, there was a significant decrease in the SL. The authors suggest that there is a relationship between metabolic fatigue and decrease of skill in swimming, represented by the SL, once in intensities above the MLSS a decrease in the SL was experienced.

Some studies suggest that the decrease in the SL observed during a series is related with the lower capacity to develop the strength needed in order to surpass resistance to movement[30,34] the reduction in work per stroke and in the propulsive efficiency[35]. Therefore, besides the biomechanical factors, the physiological factors may also influence the swimmer's style. Some studies suggest that muscular fatigue may decrease the SL during efforts performed in intensities above the anaerobic threshold[28,36-39]. Among the factors which may explain the decrease in frequency of movements in sports as cycling and running, are the change in recruiting of the motor units[40-41], in muscle perfusion[41], neuromuscular[42] and muscular fatigue[40-41]. In swimming, although these mechanisms have not been well-defined, it is known that biomechanical aspects may be fairly compromised by physiological mechanisms associated with fatigue.

Concerning the SI, both the CVSI and the SIV30 were significantly higher in group G1, which is according to the studies in the literature which suggest a relationship between SI and swimming technical skill[43] and that faster swimmers have higher SI values[29]. Nonetheless, the CVSI overestimated the SIV30 in the two groups. Since there was no difference in the SL corresponding to these intensities in the two groups, the highest value of CV in relation to the V30 observed in the two groups was responsible for such found difference. The level of correlation between the two indices was significant both in G1 (r = 0.88) and G2 (r = 0.91). Therefore, although the aerobic performance level determines different values of CVSI and SIV30, the relationship between the two indices does not seem to be modified either. An important aspect of this study is that although the SR and SL corresponding to the CV and V30 were statistically similar in the two groups, the CV was higher than the V30. One may expect therefore, that one of the two indices (SR or SL) was statistically different. A possible explanation would be the occurrence of Type 2 error (it is assumed that two variables are equal, when they may be different), possibly determined by N (G1 = 13 and G2 = 10) relatively reduced for the statistical analysis used (TWO-WAY ANOVA), being it a possible limitation of our study.

As previously mentioned, the values corresponding to CV and V30 are lower than the ones obtained by Dekerle *et al.*[17] who have used the same methodology in the CV determination. However, Dekerle *et al.*[17] found similar CV and V30 values, which differ from the behavior found by this study. Although the same distances (200 and 400 m) have been used for the determination of the CV, the duration of the trials was longer in the two groups (G1 and G2). Due to this fact, the expectation would be to have the CV value similar to the V30 in our study. Nonetheless, a factor which can have contributed for this result is the little experience from the part of these athletes in performing prolonged tests such as the 30 min, since highly-skilled swimmers are able to keep high intensities even in prolonged exercises[23]. Despite these aspects, Dekerle *et al.*[17] suggest that the CV is decreased in 3.9%, once it was this difference which was found in their study between CV and V30. In another study, the same group of authors have verified that the CV (1.31 $m.s^{-1}$) determined by the same distances overestimated the MLSS (1.24 $m.s^{-1}$)[23]. Regardless these aspects, the correlation between CV and V30 in G1 ($r = 0.68$) and G2 ($r = 0.84$) was statistically significant, which agrees with the studies by Dekerle *et al.*[17] who verified a correlation level of 0.86 between CV and V30 and Dekerle *et al.*[23], who verified a correlation level of 0.87 between the CV and MLSS. Thus, the CV validity determined through two distances (a fast and of easy application method) as an aerobic capacity index, seems to be independent of the aerobic performance level, corroborating the data obtained by Dekerle *et al.*[17,23] and Wakayoshi *et al.*[26].

An aspect which should be taken into consideration in swimming regardless the method for determination of the aerobic capacity (MLSS, anaerobic threshold or critical velocity), is that several training protocols for the improvement of aerobic capacity in this sport are intermittently performed. This way of performing exercise increases the velocity corresponding to the MLSS[44], due to the recovery of phosphate creatine reserves and removal of blood lactate which occur during the pause. Therefore, in the use for prescription of training intensity, it is important to adjust the intensity which is obtained in the test.

CONCLUSIONS

Based on these data, one may conclude that the aerobic performance level does not seem to influence the relationship among SR, SL and SI corresponding to the CV and V30. Thus, the protocol of the CV determination may simultaneously provide data about physiological aspects (aerobic fitness) and indices associated with the swimming skill. In addition to that, it can be an important way of evaluating, controlling and prescribing training in this sport, once less-skilled athletes may have difficulty in swimming to their maximal ability for 30 minutes.

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