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ORIGINAL ARTICLE

Does critical velocity represent the maximal lactate steady state in youth swimmers?

La vélocité critique correspond-elle à l'état stable du lactate maximal chez les jeunes nageurs ?

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KEYWORDS
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Summary
Objectives. — We investigated the relation between critical velocity (CV) and maximal lactate steady state (MLSS) in swimmers athletes of youth categories.
Equipment and methods. — Twenty well-trained competitive youth swimmers (13.84 ± 0.89 y) participated in the study. CV was determined by the linear regression slope *b* between the distance and time obtained in four maximal bouts of 50, 100, 200 and 400-meters (m) swimming freestyle each. To determine the MLSS, the subjects randomly performed three series of four bouts of 400 m (3 × 4 × 400 m) with velocity corresponding to 98, 100 and 102% of the CV. We collected 25 μl of blood from their fingertips at rest and at the end of each bout. MLSS intensity was defined as the highest workload that could be maintained for a long period of time in which the blood lactate concentration did not increase more than 1 $mmol \cdot L^{-1}$.
Results. — CV was significantly higher than velocity corresponding to MLSS in adolescents swimmers (1.31 ± 0.05 vs. 1.29 ± 0.05 $m \cdot s^{-1}$, $P < 0.001$). However, a high correlation ($r = 0.89$, $P < 0.0001$), as well as agreement determined by Bland-Altman plots (agreement limits of 95%) and a trivial Cohen's d effect size ($d = 0.16$) were observed between CV and MLSS.

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Conclusion. — Although CV overestimates MLSS in young swimmers, the strong correlation, good agreement and trivial effect size between them suggest that using CV is reliable for prescription and swimming training assessment.

MOTS CLÉS
L'état stable du lactatémie maximal ;
Vélocité critique ;
Natation ;
La capacité aérobie

Résumé
Objectifs. — L'objectif de ce travail était d'évaluer si la vélocité critique (VC) correspond à l'état stable du lactatémie maximal (ESLM) chez les athlètes de natation de calibre juniors.
Équipement et méthodes. — Vingt sujets pratiquant la natation de compétition ont participé à cette étude. La vitesse critique a été déterminée par une courbe de régression linéaire *b* entre la distance et le temps obtenus après quatre nages de 50, 100, 200 et 400 mètres (m) en crawl. Pour déterminer, l'état stable du lactate maximal, les sujets ont effectué trois séries de 400 m ($3 \times 4 \times 400$ m) randomisées à une vitesse correspondant à 98, 100 et 102 % de la vitesse critique. Au total, 25 μl de sang ont été prélevé avant et après chaque série. L'intensité de l'ESLM a été définie comme la charge de travail maximum pouvant être maintenue pendant une longue période au cours de laquelle la lactémie est constante (après de 1 mmol·L^{-1}).
Résultats. — Nous avons constaté que la vitesse critique était significativement plus élevée que l'état stable de lactate maximal chez les nageurs de calibre junior (1,31 ± 0,05 vs. 1,29 ± 0,05 m·s^{-1}, P < 0,001). Cependant, une corrélation (r = 0.89, P < 0.0001), ainsi qu'une concordance déterminée par les figures de Bland-Altman (intervalle de confiance de 95 %) et un effet négligeable de la taille de l'échantillon (d = 0.16) ont été observés entre la vélocité critique et l'ESLM.
Conclusion. — Bien que la VC est surestimée dans notre étude par rapport à l'ESLM chez les nageurs de calibre juniors, une forte corrélation, une concordance et un effet négligeable de la taille de l'échantillon suggèrent que la vélocité maximale est une mesure fiable pour la prescription et l'évaluation de l'entraînement de natation.

1. Introduction

The maximal lactate steady state (MLSS) is a gold-standard test to assess aerobic capacity in several sports, such as running, swimming, cycling and canoeing [1—4]. The term refers to the highest workload that could be maintained for a long period of time without a continuous rise in blood lactate accumulation [5]. However, despite its proven effectiveness as an aerobic index, the determination of MLSS requires large investment in equipment and specialized human resource able to collect samples and interpret data. This explains why the use of indirect methods to identify the intensity corresponding to the MLSS and anaerobic threshold (AT) has recently increased.

Among the different non-invasive methods used to predict the response of blood lactate during exercise, Critical Power (CP) stands out due to its strong correlation with the intensity corresponding to AT and blood lactate concentration of 4 mmol·L^{-1} [6]. CP is a theoretical concept that assumes the existence of a linear relationship between the total amount of work performed during an exercise bout (Wlim) and its corresponding time to exhaustion (Tlim) [7]. The CP suggests that the intercept a of the equation Wlim = $a + b$. Tlim corresponds to the energy contained in high-energy phosphate bonds, called anaerobic work capacity (AWC) and the regression coefficient b is the magnitude that determines the maximum power performed without achieving fatigue muscle work [8].

In the early 90s, the CP was applied in swimming and the term critical swimming velocity (CV) was then proposed as a representation of the maximal swimming velocity that can be accomplished for a long time without fatigue [9]. This concept is based on the distance (d) vs. time (t) relationship obtained in 2 to 5 maximal intensity bouts [10], and has been accepted as a reliable and practical index of aerobic evaluation in swimming [9,11]. However, studies with young swimmers are still controversial. Prior studies conducted in children and adolescents showed that CV underestimates [12,13] or overestimates [14,15] the velocity corresponding to AT. The potential reasons leading to conflicting results are several, including the high interindividual variability in lactate concentration in speed corresponding to the AT, the use of different protocols adopting fixed lactate concentrations and the low level of experience in swimming [13,16,17,14,18—21]. Thus, with a similar approach used by Wakayoshi et al., [22], that adopt MLSS as a gold-standard method for the measurement of lactate concentration, we investigated the relation between CV and MLSS in swimmers athletes of youth categories.

2. Materials and methods

2.1. Ethical approval

All procedures were approved by the Ethical Committee for Research of the Faculty of Medical Science of the University

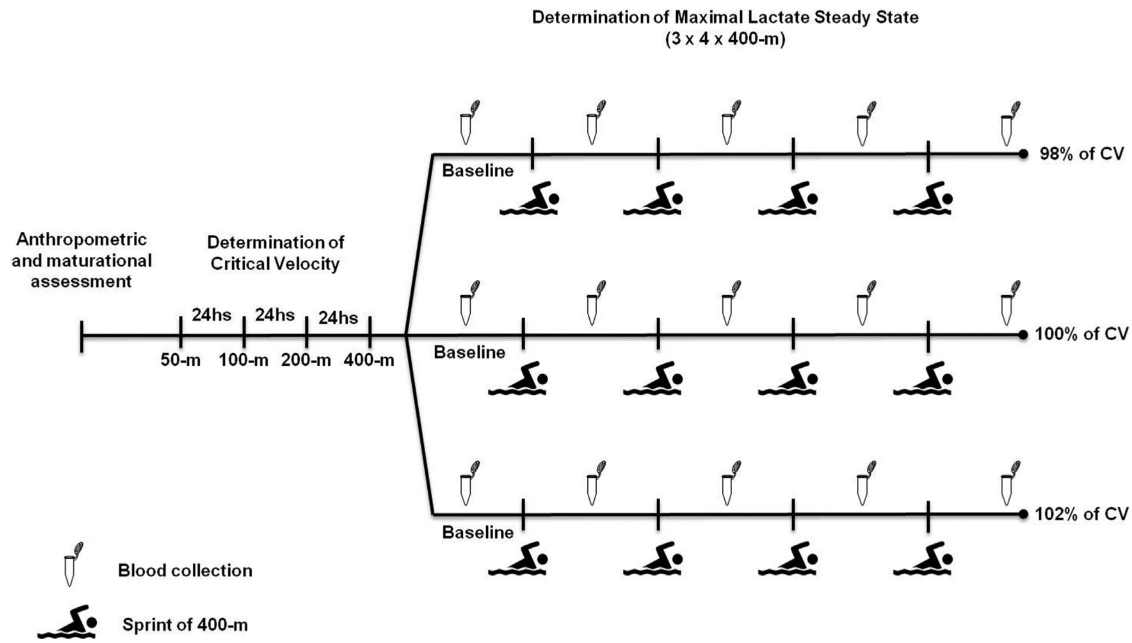

Figure 1 Schematic representation of the experimental protocol. CV: critical velocity; MLSS: maximal lactate steady state.

of Campinas (#774/2007) and are in agreement with the Declaration of Helsinki. All subjects and their guardians, when necessary, signed a written informed consent prior to their participation.

2.2. Subjects

Twenty well-trained competitive swimmers (12 boys and 8 girls) participated in the study. All swimmers were ranked in the top six in the Rio de Janeiro State Championships in youth categories, and twelve swimmers obtained index to participate in the Brazilian Championships of the youth category. From these, two swimmers won the first place in the Brazilian Youth Championship on 200 m medley and 200 m freestyle, another won the third place in the 200 m freestyle, and six swimmers were among the top ten in 50 m freestyle, 800 m freestyle, 100 m breaststroke, 200 m butterfly and 400 m medley.

2.3. Study design

Athletes performed a total of seven visits to the water training facility. On the first visit, all athletes responded to informed consent containing the main study procedures, as well as performed an anthropometric and maturational evaluation. Then, the athletes randomly performed 4 maximum sprint tests within 24 h of rest between them in the crawl style including the following distances: 50 m, 100 m, 200 m, and 400 m. In the next visits, athletes performed three tests in three different intensities of CV (98%, 100%, 102%) aiming to achieve the MLSS. Lactate concentration was evaluated in five periods (baseline, and after 4×400 m) in the three percentage related effort to CV. All visits were carried out at the same time of day with a water temperature of 26 °C, and maximum duration of 4 weeks. Fig. 1 illustrates schematic representation of the experimental protocol.

2.4. Anthropometric measurements

The anthropometric evaluation consisted of measurements of height, weight and subcutaneous tissue thickness. Height was measured with a wall-mounted stadiometer and body weight was measured using the same calibrated digital scale for all participants. Skinfold thickness of the abdominal, supra-iliac, scapula, triceps, biceps, midaxillary, calf (medial) and thigh sites were measured by using a scientific caliper Cescorf® [23]. The estimation of body density [24] was performed using the equation for adolescent athletes [25], and Lohman's equation was used to determine body fat [23].

2.5. Maturational assessment

The assessment of sexual maturation was based on stages of development of secondary sexual characteristics: genital development stages (GD1 to GD5) and pubic hair (PH1 to PH6) in boys and breast development stages (BD1 to BD5) and pubic hair (PH1 the PH6) in girls [26]. The development stages were determined through self-assessment [27].

2.6. Critical velocity

CV was determined through four front crawl bouts of 50, 100, 200, and 400 m in a randomised order with an interval of at least 24 hours between them. Swimmers were instructed to start the maximal bouts from the water. CV was determined by the slope *b* of the linear regression line between the distances and the times obtained during each bout [22]. Anaerobic work capacity (AWC) was determined by

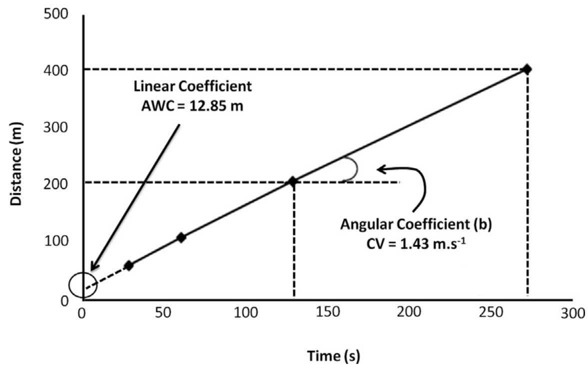

Figure 2 Linear relationship between distance and time for maximal crawl sprints of 50, 100, 200, and 400 m for one athlete. AWC: anaerobic work capacity; CV: critical velocity.

extending the line of linear regression [28]. Fig. 2 illustrates the linear relation model of distance/time.

2.7. Maximal lactate steady state

Volunteers underwent three series of four sprints of 400 m ($3 \times 4 \times 400$ m) in randomised order with constant speed corresponding to 98%, 100%, and 102% of CV. A pause of 45 to 60 seconds was used after each bout of exercise to blood collection and 48 hours among the series [29]. The fingertip was punctured with an automatic lancet and 25 μl of capillary blood sample was collected at rest and at the end of each bout. The blood sample was transferred to a microtube containing 50 μl of 1% sodium fluoride and blood lactate concentration was determined in an electrochemical analyser (YSL 2300, STAT Yellow Spring Co., USA). Intensity at maximal lactate steady state (MLSS) was defined as the highest workload that could be maintained for a long period of time in which the blood lactate concentration did not increase more than 1 mmol·L^{-1} [5].

2.8. Statistical analysis

The data are expressed as the mean ± standard deviation (SD). Data normality was assessed by the Shapiro-Wilk test. A two-way analysis of variance (ANOVA) was used to compare blood lactate concentration in the 400-m sprints at the three intensities (98%, 100%, and 102% of CV) followed by Tukey's post-hoc test. Paired Student's *t*-test was used to compare CV and MLSS, and Cohen's *d* effect size test was used to establish the effect size magnitude. Pearson's correlation coefficient was used to determine the relationship between CV and MLSS, and Bland-Altman plot was used to calculate the bias and limits of agreement between the variables. Differences with *P*-values of less than 0.05 were considered significant. All the calculations were performed using a commercially available computer-based statistical package (GraphPad InStat 5.0, GraphPad Software, San Diego, California, USA).

Table 1 Subject's characteristics ($n = 20$).

Variables	Mean ± SD
Age (years)	13.84 ± 0.89
Training experience (years)	5.02 ± 1.71
Weight (kg)	55.60 ± 8.21
Height (cm)	166.17 ± 7.31
% Fat (%)	13.33 ± 4.42

3. Results

Table 1 presents the subject's characteristics, regarding age, training experience and anthropometric results. Maturational assessment by secondary sexual characteristics development showed that ten boys were in GD3 and PH3 stage and two boys were in GD4 and PH4. Among girls, three were in BD3 and PH3 stage and five were in stages BD4 and PH4.

Regarding the CV results, Table 2 shows the results for maximum freestyle sprints of 50, 100, 200 and 400 m used for the CV determination.

Blood lactate concentrations after the sprints to determine MLSS ($3 \times 4 \times 400$ m) at intensities corresponding to 98%, 100%, and 102% of CV are presented in Fig. 3. The velocity at MLSS occurred at 98% of CV, which corresponded to blood lactate concentrations of 3.78 ± 1.05; 3.75 ± 1.26; 3.76 ± 1.46; and 3.80 ± 1.56 mmol·L^{-1} in each bout. We did not observe a dynamic equilibrium in lactate during exercise at intensities of 100% (4.44 ± 0.64; 5.03 ± 1.48; 5.43 ± 1.64; and 5.64 ± 1.89 mmol·L^{-1}) and 102% of CV (4.87 ± 1.05; 5.93 ± 1.26; 6.75 ± 1.46; and 6.77 ± 1.56 mmol·L^{-1}).

Although the CV overestimated the MLSS velocity Fig. 4, we observed a high correlation between them ($r = 0.89$, $P < 0.0001$ — Fig. 5A). Furthermore, Fig. 5B shows the results of the Bland-Altman 95% LoA analysis between CV and MLSS. The bias was −0.015 ± 0.01 m·s^{-1} and the LoA ranged from 0.05 m·s^{-1} (+1.96 SD) to −0.03 m·s^{-1} (−1.96 SD), evidencing a good agreement. Moreover, magnitude of the differences represented by effect size magnitude was classified as trivial ($d = 0.17$) by Cohen's *d* effect size test.

4. Discussion

The main findings of this study are as follows:

- the CV overestimates MLSS in well-trained adolescents' swimmers;
- the strong correlation between CV and MLSS, good agreement and trivial size effect between them suggests the use of CV as reliable for prescription and evaluation of swimming training.

In recent years, several studies have sought for indexes that can determine the adaptations to aerobic training, and allow the prescription of exercise intensity [30,31]. Maximal oxygen uptake (VO_2max) and anaerobic threshold (AT) are largely used in this context [32]. However, the high cost with equipment and the time spent in assessment prevent its widespread use. This explains why the interest on CV has

Table 2 Mean ± SD of the times (s) obtained in maximal bouts of 50, 100, 200, and 400 m used for critical velocity determination.

Variables	50 m	100 m	200 m	400 m
Time (s)	30.15 ± 1.30	64.48 ± 2.76	139.59 ± 6.20	294.31 ± 11.97
Velocity (m.s^{-1})	1.66 ± 0.07	1.55 ± 0.07	1.44 ± 0.07	1.36 ± 0.06

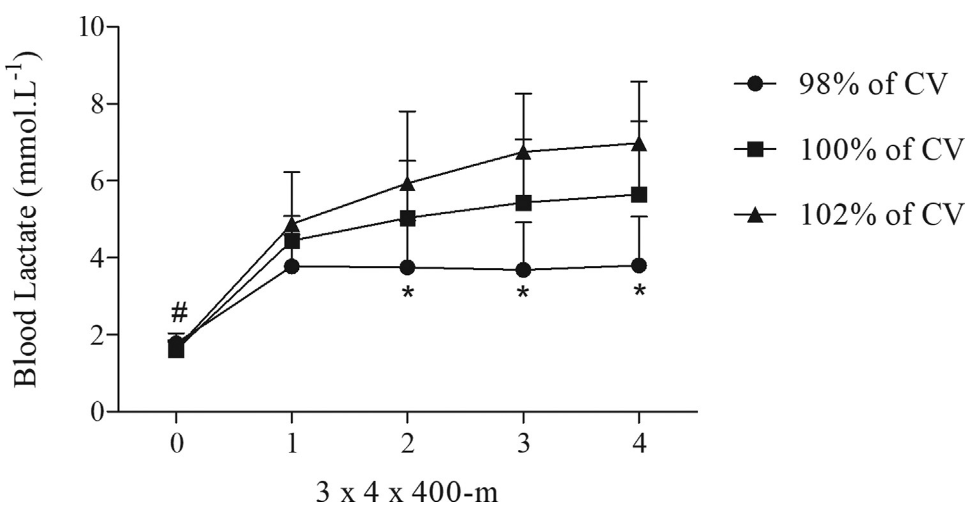

Figure 3 Blood lactate concentration in the three series of 400 m sprints at 98%, 100%, and 102% of CV, used for the determination of MLSS. #$P < 0.05$ vs. all sprints. *$P < 0.05$ vs. 100 and 102%

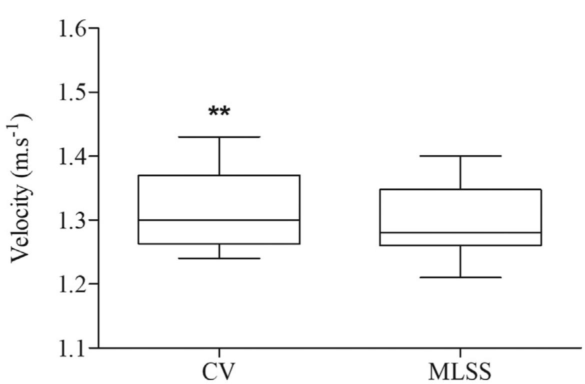

Figure 4 Mean ± SD for critical velocity and maximal lactate steady state velocity of youth swimmers. **$P < 0.001$.

increased, mainly because it is an easy method to apply and does not require blood sample collection or sophisticated equipment to obtain the results. Several studies with adults swimmers have shown that CV corresponding to AT, is a sensitive method to training, adapting to the different stimuli. Nonetheless, CV behaviour in well-trained adolescent swimmers, as well as the lactate kinetics in this population is still controversial [12,14,15].

The present results demonstrated that the CV overestimates in 1.52% intensity corresponding to the MLSS of adolescent swimmers. Previous data depict that intensity approximately 2% over the CV leads to a lactate concentration increase and consequently, premature exhaustion of young and adult male swimmers [9,11,33]. Nonetheless, CV and MLSS were highly correlated (0.89; $P < 0.0001$),

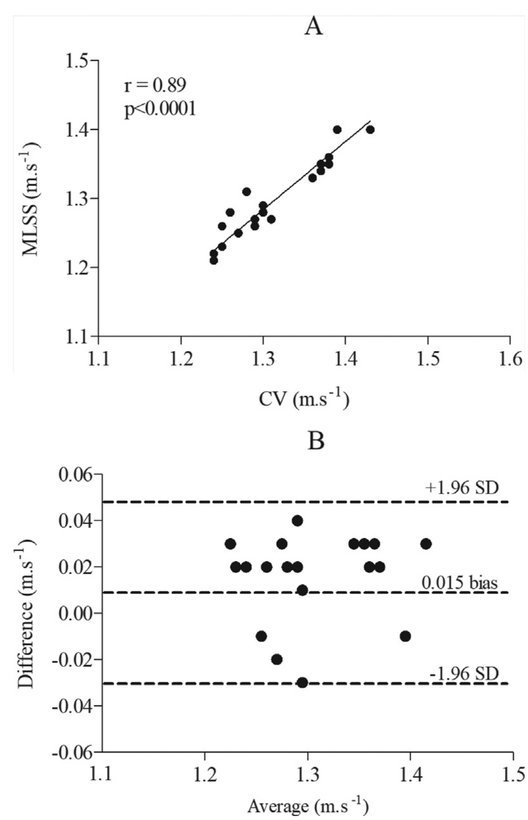

Figure 5 Pearson's correlation coefficient between critical velocity and maximal lactate steady state (A) and Bias ± LoA 95% assessed by Bland-Altman plot from CV and MLSS (B).

corroborating with previous studies performed with swimmers of different technical levels [1,34]. Moreover, a trivial size of effect found (Cohen's *d* effect size test) demonstrates that 96% of the results in the two tests will overlap. Thus, although CV did not correspond to the maximum exercise intensity that can be maintained for a long period of time without a continuous increase in the concentration of lactate, the very high correlation and a trivial size effect identified between CV and MLSS suggests the use of CV as reliable for prescription and evaluation of swimming training.

As a result of the experimental procedures, an average blood lactate of $3.76 \pm 1.19\,\text{mmol}\cdot\text{L}^{-1}$ was observed in the MLSS. Values below $4\,\text{mmol}\cdot\text{L}^{-1}$ may be due to the maturational aspect of the subjects, since it is well known that children present a smaller average lactate concentration at AT than adults [35,36]. This occurs due to a lower anaerobic glycolysis rate during childhood, that tends to increase with aging, whilst the oxidative enzymes' activity reduces [37,38]. In this study, ten boys were in the stage GD3 and PH3 and two in the GD4 and PH4 stage. Regarding the girls, three were in the BD3 and PH3 stage and five in the BD4 and PH4 stages. According to the growth and development stages proposed by Tanner [26], subjects classified in the three (GD3 and PH3) and four (GD4 and PH4) stages still present a continued sexual maturity, and therefore cannot be considered mature [26]. While conducting a treadmill protocol, Willians and Armstrong [36] found values of 2.1 ± 0.05 and $2.3 \pm 0.06\,\text{mmol}\cdot\text{L}^{-1}$ corresponding to the AT of untrained boys and girls; respectively, with an average age of 13 [36]. Previous studies conducted in young and prepuberal boys, using a treadmill protocol, were observed an average lactate values of 4.6 [39] and $5\,\text{mmol}\cdot\text{L}^{-1}$ [40]. Similar to our study, Toubekis et al. [14] found the concentration of $3.16 \pm 1.20\,\text{mmol}\cdot\text{L}^{-1}$ in swimmers of 12 and 13 years.

We observed a high interindividual variability in the lactate concentration corresponding to MLSS (2.23 to $6.55\,\text{mmol}\cdot\text{L}^{-1}$). However, these results are in agreement with the variability presented in previous studies ($\approx$1.4 to $7.5\,\text{mmol}\cdot\text{L}^{-1}$) [4,14,41—43]. In a recent study, Hauser et al. (2014) [44] evaluated the maximum lactate production rate during constant load tests and observed an interindividual variability in lactate production of approximately 48% (0.67 to $1.39\,\text{mmol}\cdot\text{L}^{-1}.\text{s}^{-1}$). Panteghini et al. (1993) [45] evaluated the biological variation of blood lactate in 8 apparently healthy individuals. Blood samples were collected for 5 consecutive days, and the interindividual variation observed was greater than 16%. Although several human being characteristics share similar anatomical and physiological traits, they possess biological individuality due either to basic hereditary differences or environmental modifications [46]. Moreover, several factors may contribute to the variability of lactate values among individuals, such as formation, transport, diffusion and elimination of lactate [44]. However, in terms of physical training control, it is important to emphasize that the determination of physical capacity is multifaceted, encompassing the cardiopulmonary, metabolic and psychological domains, and the use of a single reference value may be insufficient for an accurate result, especially in individuals in full maturational development [42,44,47].

5. Conclusion

In conclusion, this study demonstrated that although CV overestimates MLSS in young swimmers, the strong correlation, good agreement and trivial effect size between them suggest that using CV is reliable for prescription and swimming training assessment.

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Disclosure of interest

The authors declare that they have no competing interests.

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