Swimming Training Assessment: The Critical Velocity and the 400-m Test for Age-Group Swimmers

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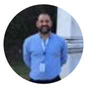

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SWIMMING TRAINING ASSESSMENT: THE CRITICAL VELOCITY AND THE 400-M TEST FOR AGE-GROUP SWIMMERS

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ABSTRACT

Zacca, R, Fernandes, RJP, Pyne, DB, and Castro, FAdS. Swimming training assessment: the critical velocity and the 400-m test for age-group swimmers. *J Strength Cond Res* 30 (5): 1365–1372, 2016—To verify the metabolic responses of oxygen consumption ($\dot{V}O_2$), heart rate (HR), blood lactate concentrations [La], and rate of perceived exertion (RPE) when swimming at an intensity corresponding to the critical velocity (CV) assessed by a 4-parameter model (CV_{4par}), and to check the reliability when using only a single 400-m maximal front crawl bout (T_{400}) for CV_{4par} assessment in age-group swimmers. Ten age-group swimmers (14–16 years old) performed 50-, 100-, 200-, 400- (T_{400}), 800-, and 1,500-m maximal front crawl bouts to calculate CV_{4par}. $\dot{V}O_2$, HR, [La], and RPE were measured immediately after bouts. Swimmers then performed 3 × 10-minute front crawl (45 seconds rest) at CV_{4par}. $\dot{V}O_2$, HR, [La], and RPE were measured after 10 minutes of rest (Rest), warm-up (Pre), each 10-minute repetition, and at the end of the test (Post). CV_{4par} was $1.33 \pm 0.08\ m\cdot s^{-1}$. $\dot{V}O_2$, HR, [La], and RPE were similar between first 10-minute and Post time points in the 3 × 10-minute protocol. CV_{4par} was equivalent to 92 ± 2% of the mean swimming speed of T_{400} (v400) for these swimmers. CV_{4par} calculated through a single T_{400} (92%v400) showed excellent agreement ($r = 0.30$; 95% CI: -0.04 to $0.05\ m\cdot s^{-1}$, $p = 0.39$), low coefficient of variation (2%), and root mean square error of $0.02 \pm 0.01\ m\cdot s^{-1}$ when plotted against CV_{4par} assessed through a 4-parameter model. These results generated the equation $CV_{4par} = 0.92 \times v400$. A single T_{400} can be used reliably to estimate the CV_{4par} typically derived with 6 efforts in age-group swimmers.

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KEY WORDS exercise physiology, training and testing, front crawl, aerobic capacity, aerobic power

INTRODUCTION

In 1925, Hill (11) showed that swimming performance can be represented by the relationship between speed and time. After 30 years (8), critical velocity (CV) seems to be a performance index derived from the concept of critical power (21,22), which can be used for the prescription and evaluation of swimming training. The CV model is based on the hyperbolic relationship between speed and time (11), but it is also expressed by the slope of the distance vs. time regression line (6,8,27) (Figure 1). Moreover, when swimming speeds (or distances), and respective times, are plotted in 2- (8,24), 3- (17), and 4- (30) parameter models, concurrently with CV, respectively, anaerobic distance capacity (ADC), maximal instantaneous velocity (Vmax), and aerobic inertia can be also determined.

Physiological responses, when swimming at CV assessed by 2-parameter models (CV_{2par}), are very sensitive to the bout's duration, as the shorter the duration, the higher the CV (30). This shortcoming could be related to the greater influence of aerobic inertia when using shorter exercise durations, elevating the contribution of anaerobic energy sources before the attainment of maximal oxygen uptake ($\dot{V}O_2max$) (28). In fact, the use of bouts shorter than 180 seconds overestimates CV_{2par} and may not adequately represent the maximal sustainable aerobic swimming speed at which there is balance between production and removal of lactate (2).

A 3-parameter model was proposed to assess more accurately the CV (CV_{3par}), regarding its eventual overestimation or underestimation of the ADC. The CV_{3par} requires at least 3 bouts of exercise of different lengths for its determination (17). Not ignoring the pragmatism of the CV_{2par} and the adjustments incorporated in the CV_{3par}, a 4-parameter model was proposed recently to address the

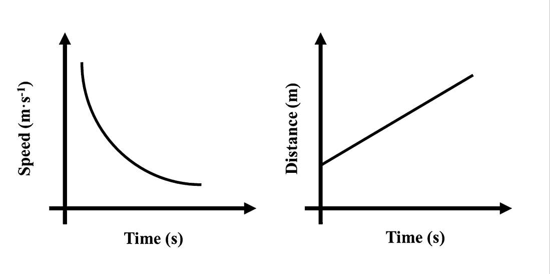

Figure 1. Critical velocity model expressed by the hyperbolic relationship between speed and time, and by the slope of the distance vs. time regression line.

unexplained aerobic inertia of the previous models (30). In this model, the first parameter, CV (CV_{4par}), is an aerobic performance index. The second parameter, ADC, is defined as the maximum distance (meters) that could be covered mainly by the anaerobic energy system (17,30). The third parameter, maximal instantaneous velocity (Vmax), is the maximal velocity that could be developed by a subject when fully rested and nourished (30). The fourth parameter, aerobic inertia, is related to the cardiorespiratory tunings of the oxygen uptake reaching its steady or maximal state (28,30). It is important to highlight that 6 bouts of different competition lengths (50, 100, 200, 400, 800, and 1,500 m) need to be conducted for the assessment of these 4 parameters (CV, ADC, Vmax, and aerobic inertia), resulting in a more representative speed-time relationship (30) with a high linearity value between bouts for each competitive swimmer ($\geq$0.999).

In swimming, 2-parameter models are the most commonly used (6,8,27) because of the requirement to use a minimum of 2 bouts of different competition lengths to plot CV and ADC. However, although 2-parameter models are more practical to be applied in the training routine, these models do not account for the Vmax and aerobic inertia assessment (28,30). The CV values obtained from 2-, 3-, and 4-parameter models were compared in young swimmers (30), suggesting that 94% of the CV variation could be explained by the mathematical models. The model effects on CV showed that CV_{2par} was higher than CV_{3par} and CV_{4par}, and CV_{3par} and CV_{4par} were similar (30). These results are consistent with other studies that observed an overestimation of CV by 2-parameter models (17).

Although the 4-parameter model seems to better represent the overall metabolic demands of swimming, its practical application is limited because it is very time consuming, mainly in age-group teams, in which several swimmers train together and most of the time in swimming series to increase both aerobic capacity and aerobic power. Aerobic capacity and aerobic power are important training zones for swimming performance. Aerobic capacity is related to the total chemical energy available to generate aerobic work, i.e., the amount of total work done is taken into consideration regardless of the time factor (15). The concept of aerobic power refers to the rate of oxidative energy synthesis, i.e., the maximum power at which the oxidative system can operate (15). Single bouts with a predefined duration or distance are commonly used to prescribe swimming training intensities at aerobic capacity speed, for example, the 30-minute (T_{30}) or the 2,000-m ($T_{2,000}$) continuous swimming tests (18,21). A good example of a shortest and practical test is the 400-m freestyle bout–T_{400} (14,25). The swimming intensity of the T_{400} corresponds to the $\dot{V}O_2max$ and the associated aerobic power training zones (9). A single 400-m test should be easier to administer in training routine and testing sessions (1,19). As no study, to our knowledge, has yet described physiological responses while swimming at CV_{4par} intensity and also because of the disadvantage from a practical standpoint when performing 2–6 exhaustive events for CV assessment, the aim of this study was to verify the metabolic responses of oxygen consumption ($\dot{V}O_2$), heart rate (HR), blood lactate concentrations [La], and rate of perceived exertion (RPE) when swimming at an intensity corresponding to the CV assessed by a 4-parameter model, and to check the reliability when using only a single T_{400} for CV_{4par} assessment in age-group swimmers. We hypothesized that age-group competitive swimmers should be able to endure a high fraction of $\dot{V}O_2max$ without a significant accumulation of blood lactate [La] when swimming at CV_{4par}; furthermore, the high linearity between bouts enhances the probability to reliably access this performance index using only the T_{400}, as its behavior is not dependent on the swimmer's skills (30).

METHODS

Experimental Approach to the Problem

Within a 2-week period, swimmers performed 2 testing protocols in a 25-m outdoor pool where they usually trained (air temperature 29.6 ± 0.8 and water temperature 25.9 ± 2.0° C). Both protocols were performed immediately after the same warm-up (~800 m), performed at low intensity.

The first protocol involved a randomized performance assessment of 50-, 100-, 200-, 400- (T_{400}), 800-, and 1,500-m maximal front crawl bouts, all with a push start, and a 24-hour interval between each bout. The time to complete each distance was recorded in seconds using 2 manual stopwatches (S056-4000; Seiko, Chūō, Tokyo, Japan; the mean value was used). Mean swimming speeds and corresponding times were used to calculate CV_{4par} in a MatLab (7.8.0 R2009a) routine (30), expressing swimming speed as a function of time. Mean swimming speeds were calculated as the ratio between the total linear distance and time of each event. $\dot{V}O_2$ (with the exception of the 50- and 100-m bouts because of insufficient time to reach $\dot{V}O_2max$) (20), HR, [La], and RPE (6–20 points, Borg scale) (4) were measured immediately after all bouts.

The second protocol consisted of 3 × 10-minute front crawl intervals (with 45 seconds of rest between repetitions)

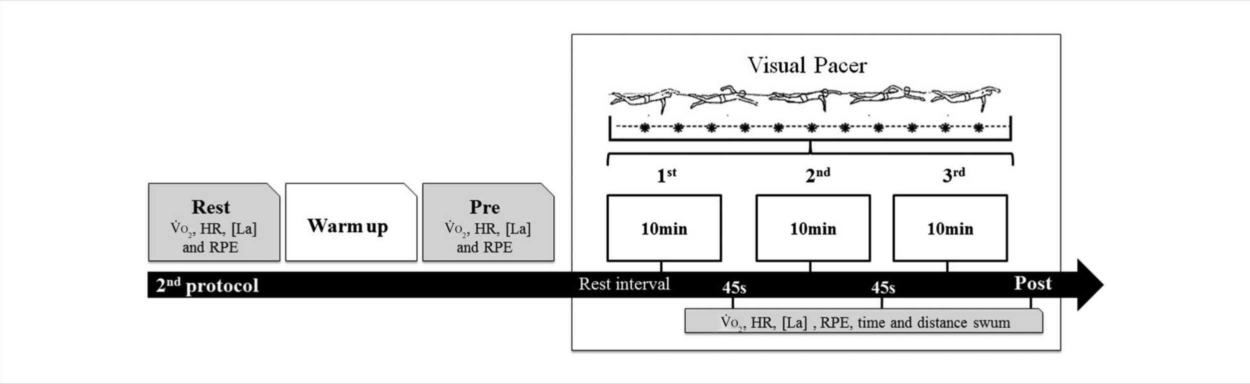

Figure 2. Design of the 3 × 10-minute continuous test at CV_{4par} (second protocol). Oxygen consumption ($\dot{V}O_2$), heart rate (HR), blood lactate concentration [La], and rate of perceived exertion (RPE) were measured immediately after the 10-minute rest (Rest), warm-up (Pre), each 10 minutes repetition, and at the end of the test (Post).

at an intensity corresponding to CV_{4par}, controlled by an underwater visual pacer with flashing lights on the bottom of the pool (Technical Instrument for Cycle Observation, Porto Alegre, Brazil). When a swimmer could no longer keep up with the flashing lights, the test was ended. $\dot{V}O_2$, HR, [La], and RPE were measured at rest (Rest), warm-up (Pre), each 10-minute repetition, and at the end of the test (Post) (Figure 2). Time was recorded as described above. For both protocols, the swimmers were familiarized during the 2 previous weeks.

Subjects

Ten freestyle age-group swimmers participated in this study (7 males and 3 females, respectively: 15.7 ± 1.0 and 15.6 ± 0.2 years old, body mass 66.9 ± 5.0 and 54.4 ± 3.4 kg, height 179.0 ± 7.3 and 165.8 ± 2.6 cm, arm span 186.9 ± 5.8 and 168.7 ± 9.0 cm, short-course 400-m freestyle personal best time of 4:24 ± 0:09 and 4:50 ± 0:50; minutes:seconds, representing 79 ± 4 and 81 ± 8% of the World Record). Swimmers had at least 6 years of competitive experience and trained normally during the data collection (7 ± 1 days) period with 4,700 ± 400 m of volume per session. This study was conducted in the first macrocycle (6 weeks) of the training season. All swimmers were in the base training period and performed 30 training sessions before the protocols. Swimmers were informed of the benefits and risks of the investigation before signing an institution-approved informed consent document to participate in the study. In addition, swimmers' parents or guardians provided written consent. The study was approved by the Ethics Board of Federal University of Rio Grande do Sul (Porto Alegre, Brazil). The study conforms to the Code of Ethics of the World Medical Association (approved by the ethics advisory board of Swansea University) and required players to provide informed consent before participation.

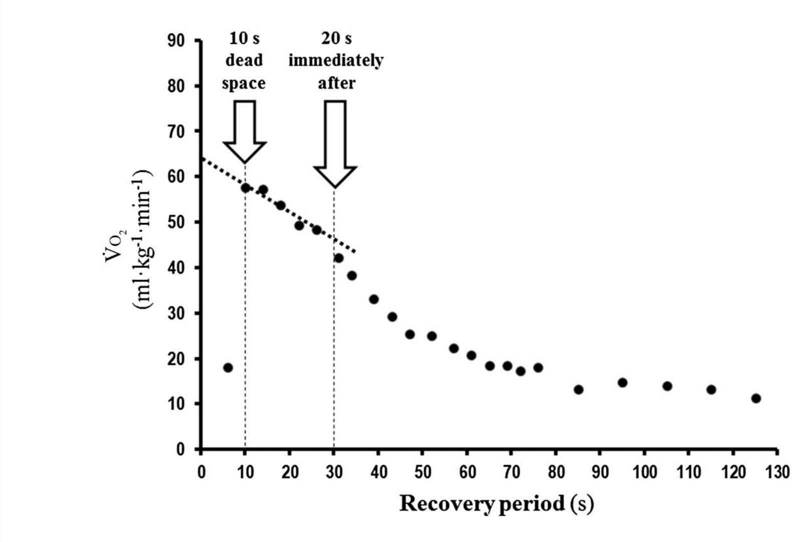

Figure 3. Example of the $\dot{V}O_2$ determination through backward extrapolation after the 400-m maximal front crawl.

Procedures

$\dot{V}O_2$ was measured using a portable metabolic device ($\dot{V}O_2$000, Portable Metabolic Testing System; MedGraphics, Saint Paul, MN, USA), which was calibrated before each test with a gas of known concentration (16% O_2 and 5% CO_2), providing a 3-breath $\dot{V}O_2$ average. Gas

Table 1. Time, oxygen consumption ($\dot{V}O_2$), heart rate (HR), blood lactate concentration [La], and rate of perceived exertion (RPE) obtained after 50- to 1,500-m front crawl bouts (mean ± *SD*).

Distance (m)	50	100	200	400	800	1,500
Time (s)	27.0 ± 2	59.7 ± 4	131.1 ± 7	278 ± 16	574 ± 34	1,117 ± 67
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)			48.7 ± 8.7	64.5 ± 8.6*	53.3 ± 6.0	50.1 ± 4.4
HR ($b \cdot min^{-1}$)	166 ± 11†	168 ± 7†	176 ± 11	184 ± 15	187 ± 13	183 ± 9
[La] ($mmol \cdot L^{-1}$)	11.1 ± 1.6‡	12.0 ± 1.7‡	11.9 ± 1.8‡	10.6 ± 2.1	9.8 ± 1.4	9.0 ± 1.7
RPE (6–20 points)	17 ± 2	18 ± 2	18 ± 1	18 ± 2	18 ± 1	18 ± 2

*Higher than all ($p < 0.01$; $\eta^2 = 0.70$).
†Lower than 400, 800, and 1,500 m ($p < 0.01$; $\eta^2 = 0.37$).
‡Higher than 800 and 1,500 m ($p \le 0.05$; $\eta^2 = 0.44$).

was collected 10 seconds after the end of the test to ensure that dead space gas was not measured. Within 2 seconds of the completion of each bout, a mouthpiece and a nose clip were applied to the face of the swimmer while standing up immersed in water to the level of the shoulders (23). $\dot{V}O_2$ at the end of the test ($\dot{V}O_2$post) was assessed by backward extrapolation (16), using a linear regression curve between time (20 seconds immediately after the 10 seconds relative to the dead space) and $\dot{V}O_2$, to estimate the value at time zero (Figure 3). Costill et al. (5) reported a typical error of less than 5.9% in estimation of $\dot{V}O_2$ by backward extrapolation. In our recent study, we reported an underestimation of only −1.4 $ml \cdot kg^{-1} \cdot min^{-1}$ or −2.6% (29). $\dot{V}O_2$max was considered to be reached according to the following secondary physiological criteria: high values of HR ≥90%, [La] ≥8 $mmol \cdot L^{-1}$, and RPE ≥18 points, visually controlled (12).

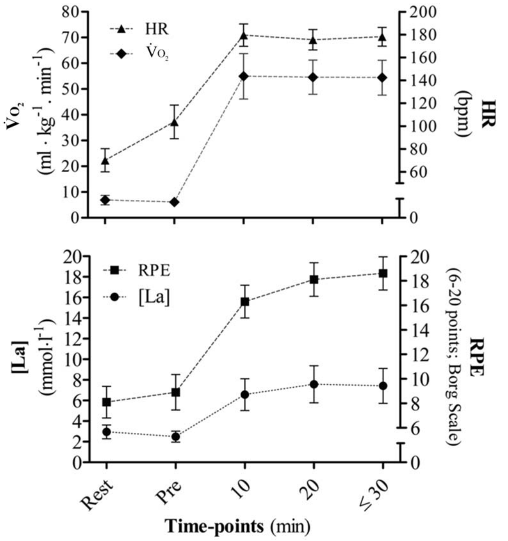

Figure 4. Oxygen consumption ($\dot{V}O_2$), heart rate (HR) (top), blood lactate concentrations [La], and rate of perceived exertion (RPE) (bottom) at rest, after warm-up (Pre), 10, 20 and 30 minutes (or sooner if the stage has not been reached, ≤30).

The HR was registered continuously by a Polar Electro (S-610; Kempele, Finland) monitor, and its maximum value (HRmax) was defined as the highest HR value reached in the first protocol. All swimmers used a homemade vest with black electrical tape to ensure reliable HR data at high swimming speeds/turns. A capillary blood sample (~25 μl) for analysis of [La] was collected from the fingertip, with the peak [La] ($[La]_{peak}$) considered as the highest value obtained 1, 3, 5, or 7 minutes after the end of the protocol using an Accutrend Plus Roche analyzer (Hoffmann-La Roche AG, Basel, Switzerland). The change in lactate concentration (Δ[La]) was determined as the difference between the maximal value measured after the test and that measured after the warm-up (9). Self-reported RPE was assessed after the end of each bout (6–20 points Borg scale) (4). All swimmers and coaches were very motivated and engaged in the data collection.

In the second protocol, $\dot{V}O_2$ at rest ($\dot{V}O_2$rest) and after the warm-up ($\dot{V}O_2$pre) were defined as the mean values measured immediately 90 seconds after 10-minute rest and warm-up, respectively (7). $\dot{V}O_2$ after each 10-minute repetition and at the end of the test ($\dot{V}O_2$post) were assessed by the same backward extrapolation (16) as the first protocol, using a linear regression curve between time (20 seconds immediately after the 10 seconds of dead space) and $\dot{V}O_2$, to estimate the value at time zero (Figure 3).

Statistical Analyses

Mean and *SD* were calculated after data normality was confirmed with the Shapiro-Wilk test. Sphericity was checked with the Mauchly test. In the first protocol, 1-way analysis of variance (ANOVA) for repeated measures was applied for comparing values of HR, [La], and RPE after the 6 bouts, and $\dot{V}O_2$ after 4 bouts (200, 400, 800, and 1,500 m). In the second protocol (3 × 10 minutes), comparisons of selected parameters were performed with 1-way ANOVA for repeated measures. Main effects were tested with the Bonferroni post hoc test and the Greenhouse-Geisser Epsilon

Table 2. Oxygen consumption ($\dot{V}O_2$), heart rate (HR), blood lactate concentration [La], and rate of perceived exertion (RPE) at rest, pre, 10 minutes, and at the end of the 3 × 10-minute test at CV_{4par} (post).*

	Rest	Pre	10 min	Post
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	6.9 ± 1.9	6.1 ± 1	54.9 ± 9	54.4 ± 7
HR ($b \cdot min^{-1}$)	70 ± 10	104 ± 15	175 ± 9	178 ± 8
[La] ($mmol \cdot L^{-1}$)	2.9 ± 0.7	2.5 ± 0.5	6.6 ± 1.5	7.4 ± 1.7
RPE (6–20 points)	8 ± 1	9 ± 1	16 ± 1†	19 ± 1

*Differences between 10-minute and post time points are identified (mean ± *SD*).
†Different from post ($p \leq 0.05$; $\eta^2 = 0.924$).

correction factor applied when necessary. Magnitudes of effects were characterized by the eta squared test. Intraclass correlation coefficient, as an index of stability, was calculated (using measures taken over time) to verify how strongly units in the same group resembled each other during the 3 × 10-minute protocol. Intraclass correlation coefficient values were interpreted as follows: >0.75, excellent; 0.40–0.75, fair to good; and <0.40, poor (10).

The accuracy of CV_{4par} assessment through the T_{400} test was compared with the swimming speeds of the 200-, 400-, 800-, and 1,500-m bouts. The root mean square error (RMSE) between CV_{4par} and its relative percentage to the T_{400} speed (v400), i.e., the predicted value (%v400), was also determined. The 95% confidence intervals of %v400 were calculated to indicate the uncertainty of the (unknown) true value. The limits of agreement between methods were also evaluated (3). Linear regression between CV_{4par} and v400 data was calculated to obtain the CV_{4par} prediction from the v400. Alpha was established at 5%.

RESULTS

The mean and *SD* values of time, $\dot{V}O_2$, HR, [La], and RPE obtained for the 50-, 100-, 200-, 400-, 800-, and 1,500-m front crawl bouts are presented in Table 1.

We observed a high linearity ($r > 0.99$) of mean swimming speeds and respective times among the 6 bouts used in this study. The difference between the times at 50- to 1,500-m bouts in the first protocol and the personal best of each swimmer was ~3%. $\dot{V}O_2max$ was considered to be reached in the T_{400} as it was the highest value of all bouts (for all subjects, 64.5 ± 8.6 $ml \cdot kg^{-1} \cdot min^{-1}$; $p < 0.01$; $\eta^2 = 0.70$). All the required secondary physiological criteria (12) were attained (with HR representing 95 ± 6% of the HRmax after this bout; mean ± *SD*). The metabolic responses ($\dot{V}O_2$, HR, [La], and RPE values) during the 3 × 10-minute protocol at the CV_{4par} intensity are displayed in Figure 4. As not all swimmers completed the total protocol (27 ± 5 minutes; mean ± *SD*), the Post values refers to the end of the protocol when comparing the above-referred parameters (Table 2).

Metabolic responses at 10 minutes and Post time points were similar when swimming at CV_{4par}, and linear regression analysis revealed an excellent ($r = 0.96$), fair ($r = 0.35$), and good ($r = 0.54$) agreement among swimmers for $\dot{V}O_2$, HR, and [La], respectively ($p \leq 0.05$). $\dot{V}O_2$ averaged 82 ± 10% of maximal values obtained in the T_{400}. The HR and Δ[La] averaged 92 ± 5% of the HRmax and 4.9 ± 1.8 $mmol \cdot L^{-1}$, respectively.

Table 3. Comparison between CV_{4par} (1.33 ± 0.08 $m \cdot s^{-1}$) and mean swimming speeds of 50, 100, 200, 400 (v400), 800 and 1,500 m front crawl bouts, and CV_{4par} as percentage from these mean swimming speeds (mean ± *SD*, minimal and maximal).

	Swimming speed ($m \cdot s^{-1}$)	CV_{4par} (%)	Min (%)	Max (%)
50 m	1.86 ± 0.12*	72 ± 3	66	81
100 m	1.68 ± 0.10*	79 ± 3	75	86
200 m	1.53 ± 0.08*	87 ± 3	83	93
400 m	1.44 ± 0.08*	92 ± 2	90	95
800 m	1.40 ± 0.08*	95 ± 1	94	97
1,500 m	1.35 ± 0.08*	99 ± 1	98	100

*Different from CV_{4par} ($p < 0.01$; $\eta^2 = 0.92$).

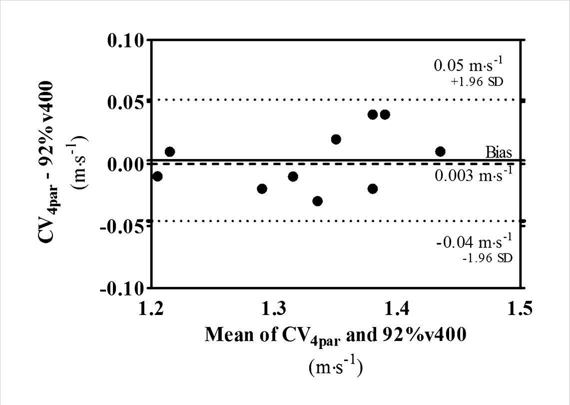

Figure 5. Limits of agreement (black dotted lines) and bias (black dashed line) between CV_{4par} and 92%v400.

Mean CV_{4par} was 1.33 ± 0.08 $m \cdot s^{-1}$ (mean ± *SD*) for the total sample, averaging 92 ± 2% of v400 (Table 3). To prescribe CV_{4par} by T_{400}, we verified that the difference between CV_{4par} and the swimming speed prescribed at 92% of v400 was -0.01 ± 0.02 $m \cdot s^{-1}$ (mean ± *SD*). Moreover, the RMSE between the swimming speeds prescribed at 92%v400 and CV_{4par} of each swimmer was 0.02 ± 0.01 $m \cdot s^{-1}$. The limits of agreement and bias between methods (CV_{4par} and 92%v400) are presented in Figure 5 (3).

The *r* value between the difference and the corresponding average was low ($r = 0.30$; 95% CI: -0.04 to 0.05 $m \cdot s^{-1}$, $p = 0.39$). Based on these results, it seems that the CV_{4par} can be estimated reliably with a single test of 400 m (T_{400}) at maximal effort, using equation 1 ($r^2 = 0{,}92$), among age-group swimmers:

$$CV_{4par} = 0.92 \cdot v400 \tag{1}$$

where CV_{4par} is the CV obtained from the 4-parameter model and v400 is the mean swimming speed in meter per second during the T_{400}.

DISCUSSION

The cardiorespiratory and metabolic parameters of $\dot{V}O_2$, HR, and [La] remained stable at CV_{4par} for the proposed protocol. Moreover, assessing CV_{4par} through a single 400-m maximal bout (T_{400}) is possible when using the derived prediction equation (equation 1). These results show the physiological responses when intervals of 50-, 100-, 200-, 400-, 800-, and 1,500-m are used to calculate the CV in a model that better represents the overall swimming metabolic demands (4-parameter model). Our approach eliminates the problem of having to conduct, at least, 6 maximal efforts, and therefore brings a viable and practical tool for age-group swimming training.

We observed that the high linearity shown among the 6 efforts used when plotting CV ($r > 0.99$) was essential to allow CV_{4par} assessment through this approach using the derived prediction equation. This high linearity is in accordance with previous studies and brings new insights for, and applications of, noninvasive assessment of endurance swimming performance (21,24).

Three secondary physiological criteria to consider $\dot{V}O_2max$ attained after the 400-m bout were confirmed (HR 94 ± 7% HRmax, $[La]_{peak}$ 10.6 ± 2.1 $mmol \cdot L^{-1}$, and RPE 18 ± 2) and are consistent with earlier recommendations (12). Thus, our assumption that there was enough time and intensity to achieve $\dot{V}O_2max$ at the end of 400-m maximal effort is in agreement with other findings (14,16,19). Lavoie et al. (14) reported similar values ($r = 0.92$) between $\dot{V}O_2$ values assessed during the first 20 seconds of recovery (backward extrapolation) and $\dot{V}O_2$ values (using Douglas bag) reached during a T_{400} (both in freestyle). Taken together, the result of the studies indicates that $\dot{V}O_2$ assessment after the end of exercise is a good indicator of $\dot{V}O_2peak$ during exercise, with the advantage of only 1 sample collection. In fact, $\dot{V}O_2$ values obtained for 200-, 400-, 800-, and 1,500-m in the first protocol of our study were in close agreement with other values reported for these distances (13). The backward extrapolation of the $\dot{V}O_2$ technique was chosen over direct assessments to make the test environment as real as possible, i.e., to allow the swimmers to perform at each distance as they would do in a competition, with start, swimming, and turns.

Typically, age-group teams are large, and using invasive techniques such as blood [La] sampling for evaluating energetic contributions is costly and time consuming. Thus, the use of noninvasive protocols such as the T_{400} is an attractive alternative for coaches. In this study, T_{400} duration (4 minutes 40 ± 17 seconds) was very similar to the efforts at the minimum speed for which the individual's maximal oxygen uptake is reached, i.e., aerobic power (the maximum amount of chemical energy that can be transformed by the structures of mitochondria per unit time) (9,15), which suggests that it is a reliable noninvasive method for assessment of maximal aerobic velocity (14,16).

The swimming time in the second protocol was 27 ± 5 minutes, with $\dot{V}O_2$, HR, and [La] stabilized from 10 minutes until the end of the test at CV_{4par}, and RPE increased. Dekerle et al. (6) reported severe physiological stress when 9 competitive swimmers performed a similar protocol (sets of 10 minutes with 40 seconds recovery in between) at CV_{2par} (assessed by 100, 200, 400, and 800 m), with exhaustion reached in 24 ± 5 minutes. This difference in mean performance time and metabolic behavior can most likely be attributed to adjustments made in relation to the 2-parameter model. Different results were evident when 8 swimmers were instructed to swim 1,600 m (divided into 4 × 400 m with 30–45 seconds of recovery in between) at CV_{2par} (assessed by 200 and 400 m events), in which [La] showed a steady-state behavior, probably because of the shorter distance and rest periods of the interval set performed (26). The limited metabolic stress observed in the 3 × 10-minute protocol suggests that CV_{4par} can be a useful index for prescribing aerobic capacity training (15).

Attractive methods for swimming coaches are characterized by having strong ecological validity, i.e., reflecting real swimming conditions, unlike laboratory situations. Whenever possible, the degree of reliability should also be assessed. The origin of the variability measurement (human error, equipment error, biological variation, or motivational factors when performing the test) needs to be taken into account. Studies proposing the prescription of aerobic training intensities (swimming speeds) through a single bout highlight that these tests are closer to the training sessions (14,18). Although some competition swimming events do not exceed the duration of 2 minutes (e.g., 50, 100, and 200 m), the bioenergetics related to $\dot{V}O_2max$ is relevant in swimming. Likewise, the similarity of speed and performance time between T_{400} average speed and the minimum speed that elicits $\dot{V}O_2max$ ($v\dot{V}O_2max$) (9), added to the observed results in the first protocol, highlights the applicability of the T_{400} for assessing aerobic power (14,16). However, to our knowledge, no study has verified whether it is possible to prescribe 2 different swimming training intensities (aerobic capacity, CV_{4par} and aerobic power, v400) with this noninvasive test.

The need to perform 2–6 exhaustive events for the assessment of CV is a disadvantage from a practical standpoint. However, our results give a new insight on CV assessment. The high level of agreement between CV_{4par} and 92%v400, the low *r* value between the difference and the corresponding average ($r = 0.30$; $p = 0.39$; 95% CI: -0.04 to $0.05\ m\cdot s^{-1}$), and the RMSE ($0.02 \pm 0.01\ m\cdot s^{-1}$) suggest that CV_{4par} can be prescribed reliably using a single T_{400} in competitive swimmers (equation 1). Similar results were observed for sprinters and swimmers (30), in which case the mean CV_{4par} were $1.23 \pm 0.02\ m\cdot s^{-1}$ and $1.25 \pm 0.02\ m\cdot s^{-1}$ (mean ± *SD*) for sprinters ($n = 7$) and endurance swimmers ($n = 7$), respectively, averaging 93% of v400 for both groups. Similar values can also be noted in finalists at the world championships (women: 93–95% of v400; men: 92–93% of v400) when swimming speeds and corresponding times of 50–1,500 m from 1994–2013 were used to calculate CV_{4par} (data from world's swimming ranking, www.swimrankings.net). However, it is possible that occasionally the relationship between CV_{4par} and v400 cannot improve linearly or to the same extent, moving away according to the endurance level of the swimmer. Regarding this, we encourage more studies to test this equation and validate its use across different groups. While acknowledging the inherent limitations of noninvasive tests, T_{400} makes evaluation and prescription of aerobic training shorter, economical, and reliable, with strong ecological validity. Although invasive tests are obviously more reliable than noninvasive tests, they are costly and sometimes bring some ethical conflicts, especially when applied to young swimmers. Likewise, a unique coach evaluating a high number of age-group swimmers in a training session is common but time consuming.

In conclusion, this study provides a new and practical way to assess CV in swimming. Our results have shown that the strong relationship between CV_{4par} and v400 in age-group competitive swimmers (~16 years old) allows coaches and practitioners to reliably determine CV_{4par} through a single T_{400}, using the predictive equation $CV_{4par} = 0.92\cdot v400$. Estimation of the 2 different metrics of aerobic capacity and aerobic power should be useful for prescription and evaluation of swimming training.

PRACTICAL APPLICATIONS

CV_{4par} assessment through the T_{400} is attractive for swimming coaches because it requires just 1 instead of the 2–6 exhaustive swimming events. T_{400} can be used to estimate both aerobic capacity (CV_{4par}) and aerobic power in age-group swimmers (14–16 years old). Swimming coaches should just conduct 400-m time trials intermittently throughout the training season (e.g., once every training period or macrocycle on a set training day of the week). Prescribing CV_{4par} as percentages relative to shorter events (e.g., 200 m) was less accurate in this study because of the higher dispersion, indicated in Table 3 by the large *SD* (87 ± 3%). Moreover, it is not possible to assess aerobic power in 200 m because of the short time for $\dot{V}O_2max$ to be achieved (9). Although the CV_{4par} assessment through 1 long event (e.g., 800 and 1,500 m) suggests lower dispersion (±1%, Table 3), it is more time consuming and can undermine training routines. Also, the aerobic power prescription is not possible because of the lower swimming speed (intensity) (9). CV_{2par} assessment requires a minimum of 2 distances that would be enough to justify this new approach of only T_{400}. However, 2-parameter models do not account for the aerobic inertia (28,30). It is important to highlight that this is a potentially useful swimming test only for age-group swimmers. More studies need to replicate this test across different groups.

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