Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000002087

Manuscript Title: Comparison of incremental intermittent and time trial testing in age-group swimmers

Running Head: Comparison of pool-based testing in age-group swimmers

Rodrigo Zacca[1,2,3], Rui Azevedo[4], Ricardo Peterson Silveira[3,5,6] João Paulo Vilas-Boas[1,2], David B. Pyne[7,8], Flávio A. de S. Castro[5], Ricardo J. Fernandes[1,2]

[1] Centre of Research, Education, Innovation and Intervention in Sport, Faculty of Sport, University of Porto, Porto, Portugal

[2] Porto Biomechanics Laboratory, University of Porto, Porto, Portugal

[3] CAPES Foundation, Ministry of Education of Brazil, Brasília - DF 70040-020, Brazil

[4] CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies (IINFACTS), Gandra PRD, Portugal

[5] School of Physical Education, Physiotherapy and Dance, Aquatic Sports Research Group, Federal University of Rio Grande do Sul, Brazil

[6] Department of Neurological, Biomedical and Movement Sciences, University of Verona, Italy

[7] Physiology, Australian Institute of Sport, Canberra, Australia

[8] Research Institute for Sport and Exercise, University of Canberra, Canberra, Australia

Address for correspondence:
Rodrigo Zacca
Centre of Research, Education, Innovation and Intervention in Sport
Faculty of Sport, University of Porto; Rua Dr. Plácido Costa, 91, 4200-450 Porto, Portugal; **Phone:** +351 22.04.25.200, **Fax:** +351 225 500 689
E-mail: rodrigozacca@yahoo.com.br

This work was funded by the by CAPES Foundation, Ministry of Education of Brazil, Brasília - DF 70040-020, Brazil

ABSTRACT

The aim of this study was to compare physiological and biomechanical characteristics between an incremental intermittent test and a time trial protocol in age-group swimmers. 11 national level age-group swimmers (6 male and 5 female) performed a 7 x 200-m incremental intermittent protocol (until exhaustion; 30 s rest) and a 400-m test (T_{400}) in front crawl on separate days. Cardiorespiratory variables were measured continuously using a telemetric portable gas analyzer. Swimming speed, stroke rate, stroke length and stroke index were assessed by video analysis. Physiological (oxygen uptake, heart rate and lactate concentrations) and biomechanical variables between 7th 200-m step (in which the minimal swimming speed that elicits maximal oxygen uptake - $v\dot{V}O_{2max}$ was identified) and T_{400} (time trial/fixed distance) were compared with a paired student's t-test, Pearson's product-moment correlation, Passing-Block regression and Bland-Altman plot analyses. There were high level of agreement and high correlations (r-values ~ 0.90; $p < 0.05$) for all physiological variables between the 7th 200-m step and T_{400}. Similarly, there were high level of agreements and high correlations (r-values ~ 0.90; $p \leq 0.05$) for all biomechanical variables, and only trivial bias in swimming speed (0.03 $m \cdot s^{-1}$; 2%). Primary physiological and biomechanical responses between incremental intermittent and representative time trial protocols were similar, but best practice dictates protocols should not be used interchangeably to minimize errors in prescribing swimming training speeds. The T_{400} is a valid, useful and easier to administer test for aerobic power assessment in age-group swimmers.

Keywords swimming · training and testing · oxygen uptake ·

INTRODUCTION

Monitoring physiological and biomechanical variables during training and competition provides important insights into preparing swimmers (29,36). Maximal oxygen uptake ($\dot{V}O_{2max}$) is an important variable underpinning the energetics of swimming, which is a primary area of interest in swimming training and performance diagnostics (12). The minimal swimming speed that elicits $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) is usually assessed to provide a measure of aerobic power (2,6,10). The functional measure $v\dot{V}O_{2max}$ combines exercise economy and $\dot{V}O_{2max}$ into a single factor and can identify aerobic differences between swimmers. This variable has been used in cyclic sports like swimming, with either continuous or discontinuous (intermittent) incremental protocols, since similar physiological results can be obtained with both protocols (5).

The 7 x 200-m incremental intermittent swimming step protocol is primarily used to estimate the aerobic component (22,30). Nowadays, with development of automated portable devices for breath-by-breath gas exchange measurement in swimming condition (37), the 7 x 200-m incremental intermittent protocol can be used to quantify $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$ and economy in swimming, providing worthwhile information on training-induced adaptations (5,10,30). This protocol, which has become the standard protocol for swimming training diagnosis, involves a graded incremental test for measurement of cardiorespiratory and metabolic responses to increasing swimming speed (*v*) (10,30).

Fixed distance or time trial protocols are used frequently by the swimming community (25,40) given their applicability for training of age-group swimmers. One example is the 400-m test (T_{400}) which has been widely used to estimate aerobic power in swimming (21,39,40) and was recently proposed for aerobic capacity assessment in age-group swimmers (40). In fact, it appears that $\dot{V}O_{2max}$ is achieved during a T_{400}, underpinning the utility of time trial protocols to indicate performance and physiological capabilities in swimming (21,28,34). The duration of the T_{400} is comparable to the time endured when swimming at $v\dot{V}O_{2max}$ (3,14,31) and its pace is situated on the severe intensity domain, which provides a good estimation of the aerobic power in swimming (14). Thus, it is well reported that the T_{400} is swum in sufficient time and intensity so that the swimmers can reach $\dot{V}O_{2max}$.

However, although practical and widely used by coaches, there is no study comparing directly the primary physiological responses between the 7 x 200-m incremental intermittent protocol (particularly at the step corresponding with $v\dot{V}O_{2max}$) and the T_{400}. Whether incremental intermittent and time trial protocols yield similar results and can be used interchangeably is unclear. Assuming that the physiological and biomechanical responses between both protocols are similar, a single and timesaving T_{400} should be easier to administer. This is particularly the case in age-group swimming training and testing sessions where squads are larger and sports science support is harder to come by.

From a biomechanical standpoint, *v* is the result of a relationship between stroke rate (SR) and stroke length (SL). This relationship is common in cyclical sports like swimming where the same motor structure is continually recruited. These two biomechanical variables are practical and reliable indicators of swimming technique (36) and easily measured poolside. These measures can be derived from video or manual timing analysis, making them attractive for coaches. A trend for SR to increase, while SL decreases from the first to the last 200-m step during an incremental intermittent front crawl protocol has been described (13,16). The stroke index (SI) is also valid and practical indicator of swimming effectiveness (36). However, it is not clear whether *v*, SL, SR and SI values between the step corresponding to $v\dot{V}O_{2max}$ and T_{400} are similar. Clarification of the comparability between time trial and incremental intermittent swim protocols is needed so that coaches can make an informed choice for prescribing training and evaluating changes in fitness.

There are some studies that have examined the relationships between physiological and biomechanical variables during the 7 x 200 m incremental intermittent protocol (13,16,29), but its relationship with a time trial protocol, particularly the T_{400}, is unclear. The aim of the current study was to compare the physiological and biomechanical factors between the T_{400} and the $v\dot{V}O_{2max}$ step of the 7 x 200 m incremental intermittent protocol. We hypothesized that physiological and biomechanical variables in both protocols are comparable.

METHODS

Experimental Approach to the Problem

We compared physiological and biomechanical characteristics between an incremental intermittent and a time trial protocol in a cohort of age-group swimmers. Following a randomized order, each swimmer completed two testing sessions separated by a 24 h rest period and performed immediately after ~800-m front crawl warm up at a moderate intensity.

The first session comprised anthropometric testing, baseline measurements (after 10 min of passive recovery) and, then, a front crawl T_{400} (time trial), where physiological ($\dot{V}O_2$, heart rate - HR - and lactate concentrations - $[La^-]$) and biomechanical (*v*, SR, SL and SI) variables were assessed. In the second session (after the same baseline measurements) swimmers performed a front crawl 7 x 200-m incremental intermittent protocol for $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ assessments, using increments of 0.05 $m \cdot s^{-1}$ and 30-s rest intervals (10). Initial *v* was established according to the individual level of fitness, set at the swimmers' individual average *v* of the T_{400} minus six increments of 0.05 $m \cdot s^{-1}$. Pacing was controlled by a visual pacer (Pacer2Swim, KulzerTEC, Santa Maria da Feira, Portugal) with flashing lights on the bottom of the 25-m pool (13). Lactate concentrations, HR, SR, SL and SI were measured on each stage.

In-water starts and open turns (without underwater gliding) were employed given physical restrictions associated with using a swimming snorkel for gas collection. The experimental protocol took place in a 25-m indoor pool (27.5ºC of water temperature, 25.9ºC of air temperature and 65% of air humidity) and at the same time of the day (±1h). All participants avoided vigorous exercise in the previous 24 h, were well-fed and hydrated, and abstained from caffeine for at least 3 h before testing sessions. Swimmers were encouraged verbally to reach their maximal *v* during T_{400} and last 200-m step of the incremental intermittent protocol. For both protocols, swimmers were familiarized during three preceding months, 2-3 times per week, with snorkels and nose clips.

Subjects

Eleven freestyle national level age-group swimmers (n=11, 6 male and 5 female) volunteered to participate in this study. Table 1 summarizes their age, height, arm span, body mass and pubertal maturation stage, having, at least, 5 years of training background and ≥ 7 units (~5,000-m of volume) per week of training frequency.

(Insert Table 1 near here)

This study took place in the preparatory period from the third (and last) macrocycle (43rd week) of the training season. All swimmers were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. In addition, swimmers parents or guardians provided written consent for their participation in the current study, which was approved by the ethics board of the local university and performed according to the Helsinki Declaration.

Procedures

Pubertal maturation stage was verified by a valid and reliable self-assessment of secondary sexual characteristics (38) to determine the degree of homogeneity of the subject cohort of this study.

Physiological variables Respiratory and pulmonary gas-exchange data were measured breath-by-breath using a low hydrodynamic resistance respiratory snorkel and valve system (AquaTrainer®, Cosmed, Rome, Italy) as described previously (1). The AquaTrainer® was connected to a telemetric portable gas analyzer ($K4b^2$, Cosmed, Rome, Italy) and suspended (at a 2 m height) over the water in a steel cable. The cable system was designed to minimize disturbance of the normal swimming movements. The telemetric portable gas analyzer was calibrated before each testing session with gases of known concentration (16% O_2 and 5% CO_2) and the turbine volume transducer calibrated with a 3 L syringe. HR was monitored continuously by a Polar Vantage NV (Polar Electro Oy, Kempele, Finland) that transmitted the data telemetrically to the $K4b^2$ portable unit during both swimming protocols. A capillary blood sample (5 µL) for $[La^-]$ was collected from an earlobe before exercise, during the 30-s recovery intervals of the incremental intermittent protocol and immediately after both protocols at the first, third, fifth, and seventh min of the recovery period ($[La^-]_{peak}$). Samples were analyzed by a Lactate Pro analyzer (Arkay, Inc, Kyoto, Japan)

Biomechanical variables A surface video camera at the 25-m indoor pool (50 Hz, Sony® Handycam HDR-CX130 Japan) was used to record and analyze variables from both protocols. To exclude the influence of turning, the effective *v* of each swimmer was measured over 10 m within two points at 7.5 m distance from each end of the pool. Thus, *v* of each swimmer was measured from the time taken to cover the middle 10 m of each length (*v* = d/t10, where d = 10-m and t10 = time for the 10-m). Stroke rate (SR) was computed from the time taken to complete three consecutive stroke cycles and SL was calculated from the ratio of the *v* and the corresponding SR. Finally, SI, as a measure of swimming effectiveness, was calculated by multiplying *v* by SL (15). All these variables were measured during each 25 m of both the 7 x 200 m incremental intermittent protocol and T_{400}.

Data analysis

For both protocols, errant breaths (caused by swallowing, coughing and/or signal interruptions) were omitted from the $\dot{V}O_2$ analysis by only including those were within $\dot{V}O_2$ local mean ± 4 SD (26). Subsequently, individual breath-by-breath $\dot{V}O_2$ responses were time averaged every 10 s and smoothed using a 3-breath moving average (7). Oxygen uptake ($\dot{V}O_2$), heart rate (HR), respiratory exchange ratio (RER) and minute ventilation ($\dot{V}_E$) at the end of both protocols were calculated as the average from the last 60 s of exercise. The $\dot{V}O_2$ at the end of the 7 x 200-m incremental intermittent protocol was defined as $\dot{V}O_{2max}$ through a case-by-case inspection of the plateau in $\dot{V}O_2$ despite an increase in *v*, added to volitional exhaustion (37). The $v\dot{V}O_{2max}$ was estimated as the *v* corresponding to the first step of the 7 x 200 m incremental intermittent protocol that elicited $\dot{V}O_{2max}$. It is well-established that swimmers can sustain *v* for sufficient duration such that the kinetics reach $\dot{V}O_{2max}$ in the severe intensity domain during this protocol (3,14,31). Thus, to standardize the variables compared in this study, $\dot{V}O_2$ at the end of T_{400} was compared with $\dot{V}O_{2max}$.

Statistical analysis

A sample size of 11 subjects was deemed adequate (software G*Power 3.1.9.2© Heinrich-Heine-Universität Düsseldorf, Germany) assuming statistical power of 85% and α error probability of 0.05. Pubertal development distribution was described by frequencies and Fisher's test was used to assess differences between males and females for Tanner status. The assumption of normality was verified with the Shapiro–Wilk test. Mean and SD for descriptive analysis were obtained and reported for all studied variables. A paired t-test was used to assess differences between the swim protocols. Possible gender vs protocols effects were verified a priori with Factorial ANOVA.

Pearson's product–moment correlation coefficient was used to quantify the degree of association between variables measured during 7 x 200-m incremental intermittent protocol and T_{400}, and interpreted as follows: <0.40 poor, 0.40-0.75 fair to good and >0.75 excellent (17). Validity was assumed when the correlation between variables was >0.90, according to established guidelines (19). However, while correlation analysis indicates the degree to which two variables are associated, it does not necessarily indicate the extent to which values agree or disagree. Thus, agreement between both swimming protocols (one of them used as the reference) was evaluated using both Passing-Bablok regression (MedCalc Software, version 11.6, Mariakerke, Belgium) and Bland–Altman plot analysis (GraphPad Prism version 6.00 for Windows, GraphPad Software, La Jolla California USA). The Passing-Bablok regression analysis (27) is a scatter diagram of variables measured with two different methods. Variables are deemed proportional when the 95% confidence interval of the slope includes 1 value and the 95% confidence interval of the intercept includes the zero value. Random differences were verified by the residual standard deviation, a measure of the random differences between the two methods.

The Cusum test for linearity was used to evaluate how well a linear model fitted the data. A small P value (< 0.05) indicates that the relationship between the two measurements is non-linear and the Passing-Bablok method deemed not applicable (27). The Bland-Altman plot (4) was used to assess the absence of systematic differences between two measurements. The mean of the two measurements was plotted against the difference between them with 95% of the differences expected to lie within the limits of agreement (mean ± 1.96 SD). The inspection of the slope of the linear regression

(Bland–Altman plot) between both protocols (to check for systematic error) was performed. Significance level alpha was established at 0.05.

RESULTS

No differences ($p = 0.45$) in pubertal maturation stage were identified between males and female subjects. Preliminary data analysis indicated no differences between genders when comparing both protocols. No interaction between gender and protocol was detected for any variable ($p = 0.27$ to 0.99), i.e., the results obtained from both protocols were similar for male and female. Thus, male and female data were subsequently pooled and analyzed as a single group.

The estimated $\dot{V}O_2$ values of 7 x 200-m incremental intermittent protocol and T_{400} are presented in Figure 1. The $v\dot{V}O_{2max}$ was identified during the 7th 200-m step (duration of the stage: 151 ± 7s) for all 11 swimmers. A very large correlation was observed between the performance of T_{400} (311 ± 17 s) and $v\dot{V}O_{2max}$ ($r = -0.79$; 95%CI -0.94 to -0.36, $p = 0.004$). Table 2 shows the physiological and biomechanical variables obtained in both protocols, particularly the comparison between 7th 200-m step ($v\dot{V}O_{2max}$) and T_{400}, with no differences being evident. Correlations (all $p < 0.0001$) were excellent for absolute $\dot{V}O_{2max}$ ($r = 0.98$), relative $\dot{V}O_{2max}$ ($r = 0.94$), HR ($r = 0.92$) and $\dot{V}E$ ($r = 0.94$), good for $[La^-]$ ($r = 0.69$; $p < 0.05$) and poor for RER ($r = 0.31$; $p = 0.35$). Although correlations for biomechanical variables (all $p <0.0001$) were excellent for SL ($r = 0.90$), SR ($r = 0.89$) and SI ($r = 0.92$), and good for v ($r = 0.78$; $p < 0.05$), larger differences were identified in SL, v and SI between 7th step of the 7 x 200-m incremental intermittent protocol ($v\dot{V}O_{2max}$) and the T_{400} (Table 2).

(Insert Figure 1 near here)

(Insert Table 2 near here)

Passing-Bablok regression between physiological and biomechanical variables from the 7th step of the 7 x 200-m incremental intermittent protocol ($v\dot{V}O_{2max}$) and the T_{400} are presented in Figure 2.

(Insert Figure 2 near here)

The 95% confidence intervals of the slope obtained from the Passing-Bablok regression analysis included, or were very close to 1. Similarly, the 95% confidence intervals of the intercept included, or were very close to 0 value. The Cusum test showed linearity for all regressions between both protocols ($p > 0.05$) (Figure 2).

Similarly, the Bland-Altman plots revealed a consistent distribution with all values inside the limits of agreement and a small bias observed for all the selected physiological and biomechanical variables. The limits of agreement, bias and slope of the linear regression (Bland–Altman plot) between physiological and biomechanical variables obtained at the 7th step of the 7 x 200-m incremental intermittent protocol ($v\dot{V}O_{2max}$) and the $T_{400.}$ are presented in Figure 3.

(Insert Figure 3 near here)

Systematic error (linear regression) was identified only for $\dot{V}O_2$ in Bland-Altman plot (r = 0.50; 95%CI - 4.9 to 5.4, p = 0.01), indicating that swimmers who have a $\dot{V}O_2$ greater than ~ 55 $mL \cdot kg^{-1} \cdot min^{-1}$ reach slightly higher values of $\dot{V}O_2$ during T_{400} than in the 7th 200-m step ($v\dot{V}O_{2max}$).

DISCUSSION

We compared the primary physiological and biomechanical responses between an incremental intermittent and a time trial protocol. The T_{400} is valid and easier to administer, particularly for age-group swimmers, since it provides direct evidence of the strong relationship with $v\dot{V}O_{2max}$ (3,14,31). However, although outcome measures from both protocols are similar, we advise not to use them interchangeably to avoid errors in prescribing swimming training speeds.

Performance and physiological characteristics of the T_{400} have been studied extensively. Lavoie et al. (21) reported a high correlation (r=0.92, p < 0.01) between the Douglas bag and 20 s post-exercise recovery methods for estimating $\dot{V}O_{2max}$ in swimming with the T400. In the early 2000s, Rodríguez et al (34) suggested that T_{400} yields similar and high correlated $\dot{V}O_2$ values to maximal incremental treadmill running (r = 0.87; p ≤ 0.001) and maximal incremental cycle ergometer test (r = 0.83; p ≤ 0.001). Since then, T_{400} is a method to assess aerobic power and prescribe swimming training intensities (40). However, a validation study was needed to determine whether theT_{400} have similar physiological and biomechanical estimates to the 7th 200-m step ($v\dot{V}O_{2max}$), and it was confirmed in our study. The level of agreement between both protocols was confirmed for all physiological and biomechanical variables with the Bland and Altman and Passing-Bablok regression analysis. However, the estimated small difference in *v* (0.03

m·s^{-1} equating to 0.9 s per 50 m) between both protocols suggests a lack of direct interchangeability. Whichever protocol is chosen (7 x 200-m incremental intermittent protocol or T_{400}), we recommend keeping the same for subsequent testing to avoid small but meaningful differences in *v* during training sessions.

Physiological variables The minimal swimming speed that elicits $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) contains both $\dot{V}O_{2max}$ and swimming economy in one term (2). Training sets performed at $v\dot{V}O_{2max}$ can improve both $\dot{V}O_{2max}$ and swimming economy (12). In fact, there was an inverse relationship between the T_{400} and $v\dot{V}O_{2max}$. These results are in agreement with other recent studies (9,31), i.e. the performance of T_{400} is related with both aerobic power ($\dot{V}O_{2max}$) and swimming economy (2,14,31).

Comparison of ventilatory variables between two incremental protocols (continuous and intermittent) for $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ assessment in swimming was first conducted a decade ago (5). The incremental intermittent protocol was deemed suitable for both $\dot{V}O_{2max}$ and $v\dot{V}O_{2max}$ assessment. At the same time, the $\dot{V}O_2$ kinetics during a T_{400} was examined (33), where $\dot{V}O_{2peak}$ was directly correlated with *v* proving to be a good predictor of swimming performance. The *v* of T_{400} has been used for training and research, on the basis that the duration of the T_{400} is similar to the time endured when swimming at $v\dot{V}O_{2max}$ (14,31) and also because $\dot{V}O_{2max}$ is achieved during a T_{400} (21,28,34). Our study goes beyond theses previous studies by validating the usefulness of T_{400} for age-group swimmers, confirming a high level of agreement for all physiological variables between the T_{400} and 7th 200-m step (the one in which $v\dot{V}O_{2max}$ was identified).

There were only trivial bias in estimates of physiological variables between the 7th 200-m step ($v\dot{V}O_{2max}$) and the T_{400} (Table 2), with [La^-] values in agreement with other data on age group swimmers (13). High correlations for $\dot{V}O_{2max}$, HR and $\dot{V}E$, and a high reproducibility for all physiological variables in Passing-Bablok regression and Bland-Altman analysis indicate close agreement between the 7th step of the 7 x 200 m incremental intermittent protocol ($v\dot{V}O_{2max}$) and the T_{400}. Linear regression analysis (Bland-Altman plot) indicated a systematic error for estimation of $\dot{V}O_2$ between the 7th step ($v\dot{V}O_{2max}$) and T_{400} (Figure 3, a). Although high reproducibility and accuracy were identified for all physiological variables, systematic error for $\dot{V}O_2$ most likely relates to limitations of the fixed distance protocols used in this study.

Time to accomplish fixed distance protocols should address two main requirements. First, exercise durations cannot be too short, i.e. swimming bouts for which time to reach fatigue is less than 2 min do not allow enough time for the $\dot{V}O_2$ to increase to a maximal value. Secondly, swimming intensity needs to lie within the severe domain, since it is characterized by attainment of $\dot{V}O_{2max}$ (18). In fact, the 7th step from the incremental intermittent protocol was performed at severe intensity domain in our study (8), since it lies with the step in which $\dot{V}O_{2max}$ was achieved. Likewise, the range between the minimum and maximum times of 7th 200-m step ($v\dot{V}O_{2max}$) (~139 and 163 s) agrees with the minimal duration required for attainment of $\dot{V}O_{2max}$. Assuming that different step lengths might affect the $\dot{V}O_{2max}$ assessment, $\dot{V}O_2$ values from incremental intermittent protocols with 200, 300 and 400-m length steps were compared, and observed that 200-m distances are valid for $\dot{V}O_{2max}$ (11). Moreover, the minimum and maximum performances of T_{400} (~293 and 342 s, respectively) are in agreement with the time endured at $v\dot{V}O_{2max}$ reported in the literature (14). Swimming intensity of T_{400}

is similar to the intensity of the 7th 200-m step ($v\dot{V}O_{2max}$), given trivial differences between the physiological variables (Table 2). Swimming coaches and scientists can be advised that the T_{400} should produce similar physiological responses to the 7th step from the incremental intermittent protocol.

The constraints of finding an adequate sample of national level age-group swimmers with homogeneous pubertal maturation leaded us to pool and analyze male and female swimmers as a combined single group. However, although this methodological limitation should be considered, preliminary data analysis with all variables indicated that the results obtained from both protocols were similar for male and female swimmers. Coaches can prescribe similar interval-training workouts for male and female swimmers with equal training background, since the main $\dot{V}O_2$ kinetics parameters are comparable at similar relative exercise intensities (32).

Biomechanical variables The biomechanical profile of a swimmer detailing relationships between SR, SL, SI and performance is a relevant and practical tool for swimming coaches. During incremental exercise, *v* rises with the combination of an increase in SR and a decrease in SL (16). Likewise, a decline in *v* is almost completely accounted by a decrease in SL, given that the SR remains stable (or is slightly higher in last 100-m) during a T_{400}, highlighting a loss of technical effectiveness (20,24,35). We also observed loss of efficiency from the first to the last 200 m step of the 7 x 200 incremental intermittent protocol and during the T_{400}, with high correlations and level of agreements observed between T_{400} and the 7th 200-m step ($v\dot{V}O_{2max}$) for all biomechanical variables. This is an important result, since both physiological and biomechanical results were similar between protocols, which makes the T_{400} even more helpful for the assessment of age-group swimmers. Coaches could apply the T_{400} in their workouts as a feasible, short and practical protocol for age-group swimmers.

It is important to verify the validity of the T_{400} in reproducing the biomechanical responses of the 7th 200-m step ($v\dot{V}O_{2max}$), since T_{400} is commonly used due to its practicality for training and testing (24,40). Correlations and reproducibility were very high for all biomechanical variables, in spite of a trivial difference in paired t-test for *v*, SL and SI. Oliveira et al. (24) observed higher bias for *v* (1.39 ± 0.6 $m \cdot s^{-1}$ and 1.34 ± 0.08 $m \cdot s^{-1}$ for the 7th 200-m step and $T_{400,}$ respectively) than our study (Table 2), but it was not enough to infer a significant difference. Differences observed in SL and SI most likely relate to the difference in the fixed distance protocols used in this study (200 vs 400-m). As young swimmers have a well-developed oxidative metabolism and disadvantages in activities predominantly supported by anaerobic metabolism when compared to adults, this lower anaerobic system participation could have contributed to the failure in maintaining technical patterns during T_{400}, decreasing SL and consequently v and SI (23,35).

However, despite these differences, the high correlation and reproducibility observed in Passing-Bablok regression and Bland-Altman plots between both protocols confirms their comparability and the validity of using the $T_{400.}$ Estimates from both methods lies within the severe intensity domain (similar $\dot{V}O_{2max}$). Nevertheless, if we calculate $v\dot{V}O_{2max}$ training paces for 100, 200 and 400-m distances throughout both protocols (1.32 and 1.29 $m \cdot s^{-1}$ for the 7th 200-m step and $T_{400,}$ respectively), the difference (0.03 $m \cdot s^{-1}$) is in fact ~2 s (1:16 and 1:18), ~ 3 s (2:32 and 2:35) and ~ 7 s (5:03 and 5:10) for 7th 200-m step and T_{400} (minutes:seconds) respectively. Thus, the use of the protocols interchangeably is not recommended, since minor bias in *v* can occur when prescribing training sets.

In conclusion, incremental intermittent and time trial (fixed distance) protocols are broadly comparable in terms of physiological and biomechanical characteristics, although use both interchangeably is not recommended. The T_{400} is a valid and easier option for aerobic power assessment in age-group swimmers, since it showed similar physiological and biomechanical responses to the 7th 200-m step ($v\dot{V}O_{2max}$). These outcomes confirm the viability of the T_{400} in monitoring the fitness, performance and technical characteristics of age-group swimmers.

PRACTICAL APPLICATIONS

Attractive protocols for age-group swimmers should be characterized for having strong ecological validity, that is, reflecting real swimming conditions, unlike laboratory settings. In this way, researchers compared two methods (a new method with an established one) to determine whether the new approach is worth employing. Given the strong relationship observed between T_{400} and $v\dot{V}O_{2max}$, we consider the T_{400} valid. Although the 7 x 200-m incremental intermittent protocol provides additional worthwhile information on training-induced adaptations over the T400, a single test is more convenient and easy to conduct for assessing $v\dot{V}O_{2max}$ in age-group swimmers. Age-group swimming coaches could use the T_{400} intermittently throughout the training season, but we do not recommend using the 7 x 200-m incremental intermittent protocol ($v\dot{V}O_{2max}$) and T_{400} interchangeably, since using the same protocol will provide a better control (reducing the errors) of estimated training velocities. Future studies should investigate the effects of gender and swimming technique/distance specialty on 7 x 200 m incremental intermittent protocol and T_{400}. Further work to examine the small bias in *v*, SL and SI during time to exhaustion at $v\dot{V}O_{2max}$ between both protocols would be also be useful.

REFERENCES

1. Baldari C, Fernandes R, Meucci M, Ribeiro J, Vilas-Boas J, and Guidetti L. Is the new AquaTrainer® snorkel valid for VO2 assessment in swimming? *Int J Sports Med* 34: 336, 2013.
2. Billat LV, Koralsztein JP. Significance of the Velocity at $\dot{V}O_{2max}$ and Time to Exhaustion at this Velocity. *Sports Med* 22 (2):90-108, 1996.
3. Billat V, Faina M, Sardella F, Marini C, Fanton F, Lupo S, Faccini P, De Angelis M, Koralsztein J, Dalmonte A. A comparison of time to exhaustion at VO_{2max} in elite cyclists, kayak paddlers, swimmers and runners. *Ergonomics* 39 (2):267-277, 1996.
4. Bland, JM and Altman, DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1:307–310, 1986.
5. Cardoso C, Fernandes R, Magalhães J, Santos P, Colaço P, Soares S, Carmo C, Barbosa T, Vilas-Boas J. Comparison of continuous and intermittent triangular protocols for direct VO_{2max} assessment in swimming. In: Proceedings of the IXth Symposium on Biomechanics and Medicine in Swimming JC Chatard, ed., Université de Saint-Etienne, France: Jean Monnet University 2003 pp. 313-318.
6. Daniels JT.A physiologist's view of running economy. *Med Sci Sports Exerc* 17 (3):332-338, 1985

7. de Jesus K, Guidetti L, de Jesus K, Vilas-Boas JP, Baldari C, Fernandes RJ. Which are the best VO2 sampling intervals to characterize low to severe swimming intensities? *Int J Sports Med* 35 (12):1030-1036, 2014
8. de Jesus K, Sousa A, de Jesus K, Ribeiro J, Machado L, Rodriguez F, Keskinen K, Vilas-Boas JP, and Fernandes RJ. The effects of intensity on VO2 kinetics during incremental free swimming. *Appl Physiol Nutr Metab* 40: 918-923, 2015.
9. Espada MC, Reis JF, Almeida TF, Bruno PM, Vleck VE, Alves FB. Ventilatory and Physiological Responses in Swimmers Below and Above Their Maximal Lactate Steady State. *J Strength Cond Res* 29 (10):2836-2843, 2015.
10. Fernandes RJ, Cardoso CS, Soares SM, Ascensao A, Colaco PJ, Vilas-Boas JP. Time limit and VO_2 slow component at intensities corresponding to VO_{2max} in swimmers. *Int J Sports Med* 24 (8):576-581, 2003.
11. Fernandes RJ, de Jesus K, Baldari C, de Jesus K, Sousa AC, Vilas-Boas JP, and Guidetti L. Different VO2max time-averaging intervals in swimming. *Int J Sports Med* 33: 1010-1015, 2012.
12. Fernandes RJ, Keskinen KL, Colaco P, Querido AJ, Machado LJ, Morais PA, Novais DQ, Marinho DA, Vilas Boas JP. Time limit at VO2max velocity in elite crawl swimmers. *Int J Sports Med* 29 (2):145-150, 2008.
13. Fernandes RJ, Sousa M, Machado L, Vilas-Boas JP. Step length and individual anaerobic threshold assessment in swimming. *Int J Sports Med* 32 (12):940-946, 2011.
14. Fernandes RJ, Vilas-Boas JP. Time to Exhaustion at the VO_{2max} Velocity in Swimming: A Review. *J Hum Kinet* 32:121-134, 2012.

15. Ferreira MI, Barbosa TM, Neiva HP, Marta CC, Costa MJ, and Marinho DA. Effect of Gender, Energetics, and Biomechanics on Swimming Masters Performance. *J Strength Cond Res* 29: 1948-1955, 2015.

16. Figueiredo P, Morais P, Vilas-Boas JP, Fernandes RJ. Changes in arm coordination and stroke parameters on transition through the lactate threshold. *Eur J Appl Physiol* 113 (8):1957-1964, 2013.

17. Fleiss, J. *The Design and Analysis of Clinical Experiments.* New York, NY: John Wiley& Sons, 1986.

18. Hill DW, Poole DC, Smith JC. The relationship between power and the time to achieve $\dot{V}O_{2max}$. *Med Sci Sports Exerc* 34 (4):709-714, 2002.

19. Hopkins, WG. A new view of statistics. Internet Society for Sport Science: http://www.sportsci.org/resource/stats/ , 2000.

20. Laffite LP, Vilas-Boas JP, Demarle A, Silva J, Fernandes R, Billat VL. Changes in physiological and stroke parameters during a maximal 400-m free swimming test in elite swimmers. *Can J Appl Physiol* 29 Suppl:S17-31, 2004.

21. Lavoie JM, Leger LA, Montpetit RR, Chabot S. Backward extrapolation of VO_2 from the O_2 recovery curve after a voluntary maximal 400 m swim. In: Hollander AP, Huijing PA, De Groot G (eds) *Biomechanics and medicine in swimming.* Human Kinetics Publishers, Campaign.,1983. pp. 222-227.

22. Madsen, O., & Lohberg, M. The lowdown on lactates. *Swimming Technique,* 24, 21-26, 1987.

23. Mezzaroba PV, Machado FA. Effect of age, anthropometry, and distance in stroke parameters of young swimmers. *Int J Sports Physiol Perform* 9 (4):702-706, 2014

24. Oliveira MFM, Caputo F, Lucas RD, Denadai BS, Greco CC. Physiological and stroke parameters to assess aerobic capacity in swimming. *Int J Sports Physiol Perform* 7 (3):218-223, 2012

25. Oussama R, Gheorghe M. Comparison of Three Tests for Assesing the Aerobic Aptitude to the Elite Swimmers. *Procedia Soc Behav Sci* 117:307-311, 2014.

26. Özyener F, Rossiter HB, Ward SA, Whipp BJ. Influence of exercise intensity on the on- and off-transient kinetics of pulmonary oxygen uptake in humans. *J Physiol* 533 (Pt 3):891-902, 2001.

27. Passing H, Bablok W. A new biometrical procedure for testing the equality of measurements from two different analytical methods. Application of linear regression procedures for method comparison studies in clinical chemistry. Part I. *J Clin Chem Clin Biochem*; 21: 709–720, 1983.

28. Poujade B, Hautier C, Rouard A. Determinants of the energy cost of front-crawl swimming in children. *Eur J Appl Physiol* 87 (1):1-6, 2002.

29. Psycharakis S, Cooke C, Paradisis G, O'Hara J, Phillips G. Analysis of selected kinematic and physiological performance determinants during incremental testing in elite swimmers. *J Strength Cond Res* 22: 951 – 957, 2008.

30. Pyne DB, Lee H, and Swanwick KM. Monitoring the lactate threshold in world-ranked swimmers. *Med Sci Sports Exerc* 33: 291-297, 2001.

31. Reis JF, Alves FB, Bruno PM, Vleck V, Millet GP. Oxygen uptake kinetics and middle distance swimming performance. *J Sci Med Sport* 15 (1):58-63, 2012.

32. Reis JF, Millet GP, Bruno PM, Vleck V, and Alves FB. Sex and Exercise Intensity Do Not Influence Oxygen Uptake Kinetics in Submaximal Swimming. Frontiers in Physiology 8, 2017.

33. Rodríguez F, Keskinen K, Malvela M, et al. Oxygen uptake kinetics during free swimming: a pilot study. In: Proceedings of the IXth Symposium on Biomechanics and Medicine in Swimming JC Chatard, ed., Université de Saint-Etienne, France: Jean Monnet University 2003 pp. 2003. pp. 379–384.

34. Rodríguez F. Maximal oxygen uptake and cardiorespiratory response to maximal 400-m free swimming, running and cycling test in competitive swimmers. *J Sports Med Phys Fitness* 40 (2):87, 2000.

35. Schnitzler C, Seifert L, Chollet D. Variability of coordination parameters at 400-m front crawl swimming pace. *J Sports Sci Med* 8 (2):203-210, 2009.

36. Smith DJ, Norris SR , Hogg JM. Performance evaluation of swimmers. Scientific tools. *Sports Med* 32: 539 – 554, 2002.

37. Sousa A, Figueiredo P, Pendergast D, Kjendlie PL, Vilas-Boas JP, Fernandes RJ. Critical evaluation of oxygen-uptake assessment in swimming. *Int J Sports Physiol Perform* 9 (2):190-202, 2014.

38. Tanner JM, Whitehouse RH, Takaishi M. Standards from birth to maturity for height, weight, height velocity, and weight velocity: *British children, 1965. II. Arch Dis Child* 41: 613–635, 1966:

39. Wakayoshi, K, Ikuta, K, Yoshida, T, Udo, M, Moritani, T, Mutoh, Y, and Miyashita, M. Determination and validity of critical velocity as an index of swimming performance in the competitive swimmer. *Eur J Appl Physiol Occup Physiol* 64: 153–157, 1992

40. Zacca R, Fernandes RJ, Pyne DB, Castro FA Swimming Training Assessment: The Critical Velocity and the 400-m Test for Age-Group Swimmers. *J Strength Cond Res* 30 (5):1365-1372. 2016.

ACKNOWLEDGMENTS

The authors thank the support of coaches, swimmers, and all those who were involved in this study. This work was funded by the by CAPES Foundation, Ministry of Education of Brazil, Brasília—DF, Brazil. The authors declare that they have no conflict of interest.

Figure legends

Figure 1. $\dot{V}O_2$ values (mean ± SD) among baseline (BL), end of T_{400} and 7 x 200-m incremental intermittent protocol (7^{th} step = $v\dot{V}O_{2max}$).

Figure 2. Passing-Bablok regression of physiological and biomechanical variables obtained during the 7^{th} step of the 7 x 200-m incremental intermittent protocol ($v\dot{V}O_{2max}$) and the T_{400}. The solid and dashed lines indicate the regression equation and the identity, respectively. The regression equation ($y = a + bx$) shows if there is constant [regression line's intercept (a)] and proportional [regression line's slope (b)] difference and respective confidence intervals of 95% (95% CI). If the 95% CI for intercept includes value zero, it means that there was no significant difference between the intercept value and zero, and thus there was no constant difference between two protocols. Where the 95% CI for the slope includes the value of one then difference between obtained slope value and value one is deemed significant, and thus there was no proportional difference between both protocols. Thus, we could assume that $x = y$ and that there was no significant difference between protocols. A P value > 0.05 indicates that the relationship between the two measurements is linear and the Passing-Bablok method deemed applicable.

Figure 3. Limits of agreement (black dotted lines), bias (black dashed line) and slope of the linear regression of physiological and biomechanical variables between the 7th step of the 7 x 200-m incremental intermittent protocol ($v\dot{V}O_{2max}$) and the T_{400}.

Table 1. Subjects characteristics (mean ± SD).

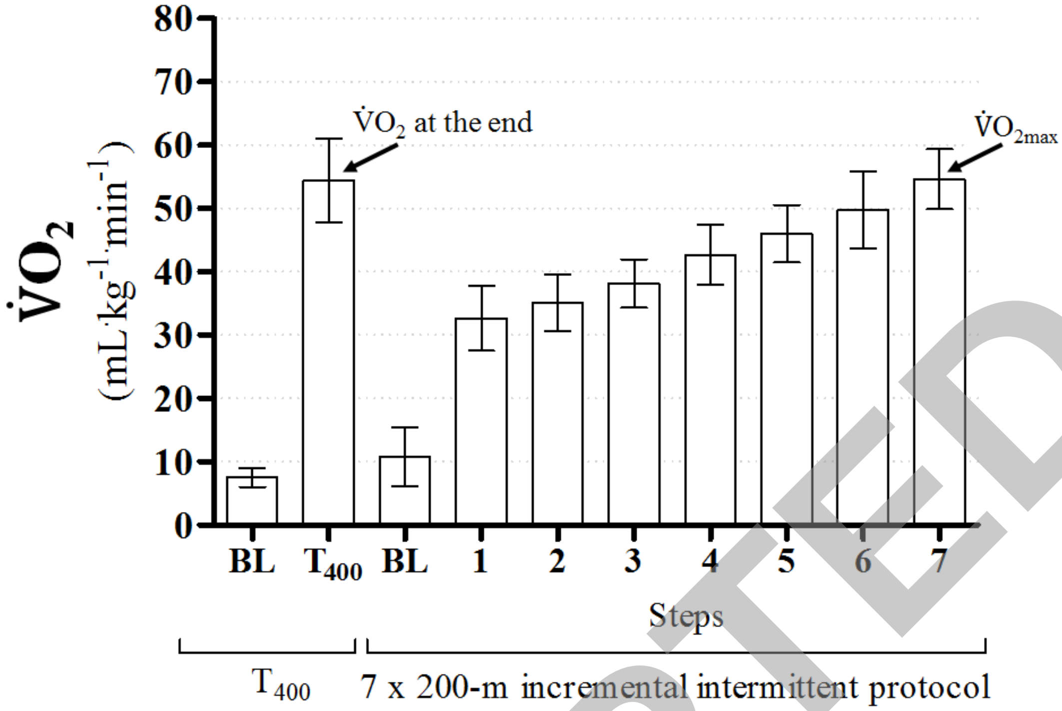
	Male (n =6)	Female (n = 5)	n = 11
Age, years	15.5 ± 0.5	15.0 ± 0.7	15.3 ± 0.6
Height, m	174.3 ± 3.7	162.4 ± 6.9	168.9 ± 8.1
Arm span, cm	179.9 ± 4.4	168.8 ± 10.8	174.88 ± 9.6
Body mass, kg	70.5 ± 3.4	55.4 ± 6.8	63.6 ± 9.3
Tanner * (I/II/III/IV/V)	(0/0/0/6/0)	(0/0/0/4/1)	(0/0/0/10/1)

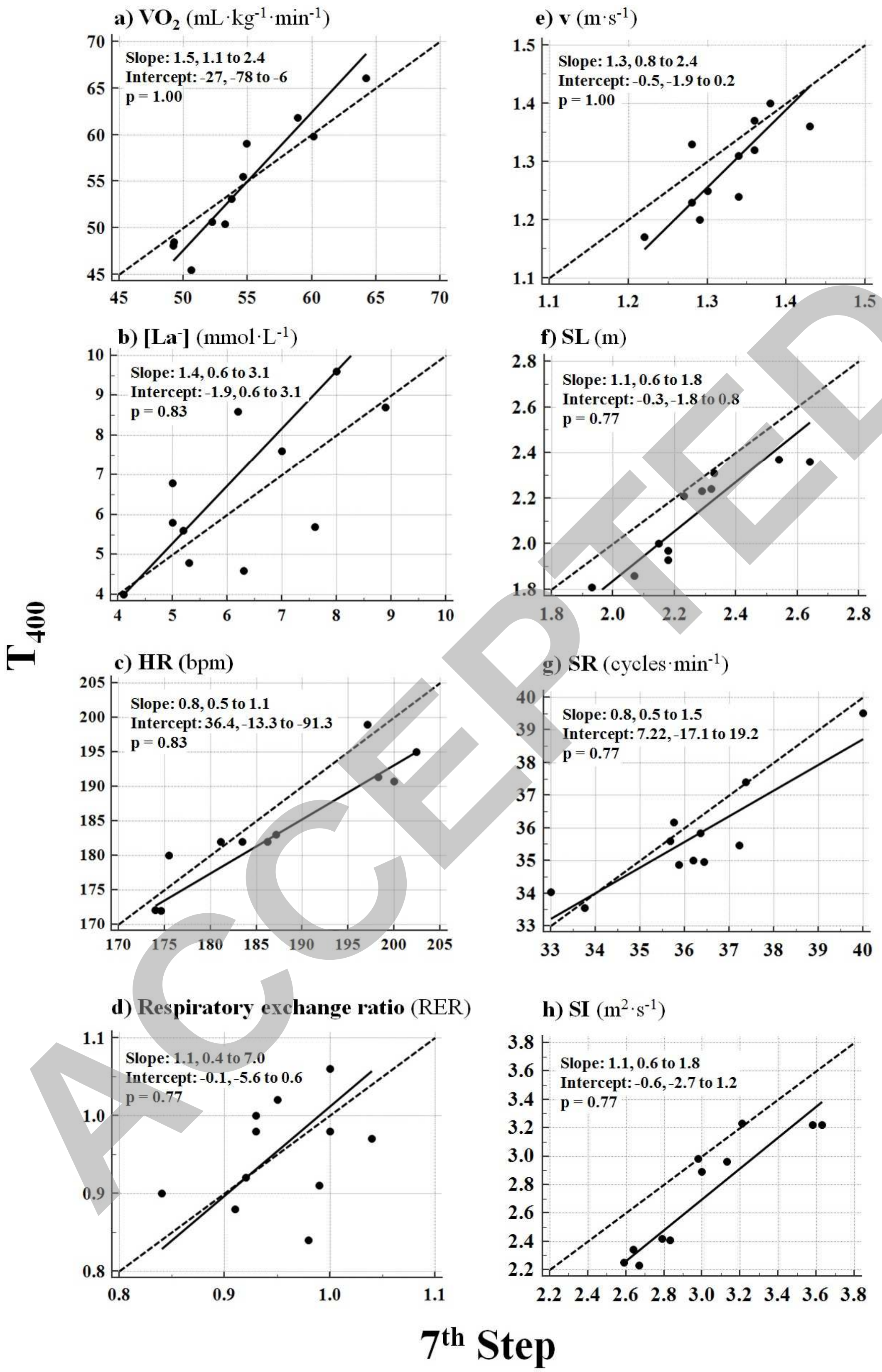
* Tanner: prepubertal (Tanner stage I), early-pubertal (Tanner stage II,), peripubertal (Tanner III), latepubertal (Tanner IV) and postpubertal (Tanner V)

Table 2. Physiological and biomechanical variables obtained at the step corresponding to $v\dot{V}O_{2max}$ and T_{400}

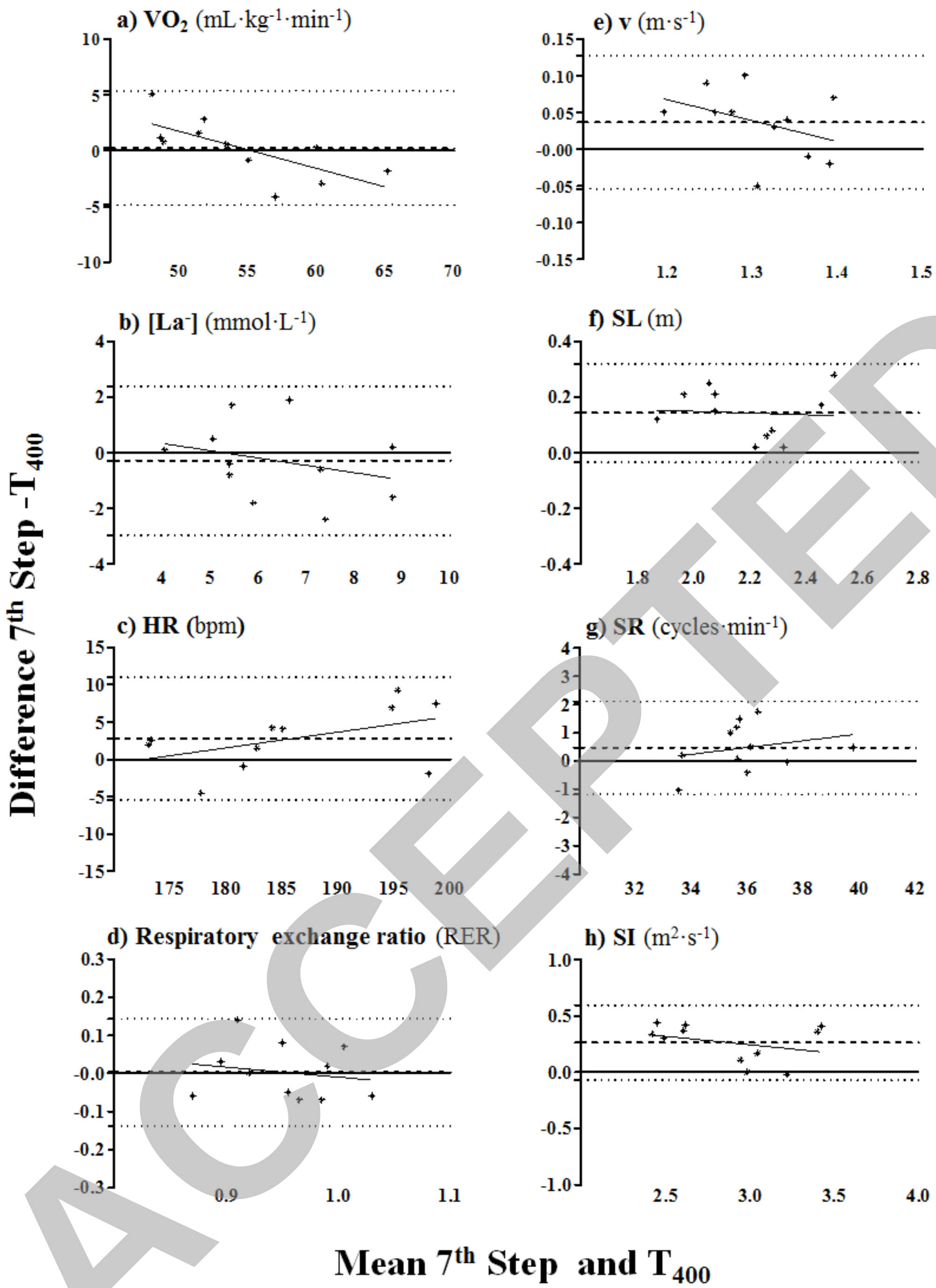
	7th x 200-m ($v\dot{V}O_{2max}$) mean ± SD	T_{400} mean ± SD	Mean difference (95% confidence interval)	Correlation coefficient (r)
$\dot{V}O_2$, L·min^{-1}	3.48 ± 0.61	3.47 ±0.70	0.01 (-0.10 to 0.12)	0.98**
$\dot{V}O_2$, mL·kg^{-1}·min^{-1}	54.6 ± 4.7	54.4 ± 6.6	0.2 (-2.0 to 2.0)	0.94**
HR, bpm	187 ± 10	184 ± 9	2.8 (-0.03 to 5.60)	0.93**
RER	0.95 ± 0.05	0.95 ± 0.06	0.002 (-0.046 to 0.051)	0.31
$\dot{V}_E$, L·min^{-1}	101 ± 21	98 ± 26	3 (-4 to 9)	0.94**
[La$^-$], mmol·L^{-1}	6.2 ± 1.5	6.5 ± 1.9	-0.3 (-1.2 to 0.6)	0.69*
v, m·s^{-1}	1.32 ± 0.05†	1.29 ± 0.07†	0.03 (0.005 to 0.067)	0.78*
SL, m	2.3 ± 0.2††	2.1± 0.2††	0.1 (0.1 to 0.2)	0.90**
SR, cycles·min^{-1}	36.1± 2.5	35.7 ± 1.7	0.5 (-0.1 to 1.0)	0.89**
SI, m^2·s^{-1}	3.0 ± 0.4†	2.4 ± 0.4†	0.3 (0.1 to 0.4)	0.91**

Oxygen uptake ($\dot{V}O_2$); heart rate (HR), respiratory exchange ratio (RER); minute ventilation ($\dot{V}_E$); lactate concentrations ([La$^-$]); swimming speed (*v*); stroke length (SL); stroke rate (SR) and stroke index (SI).
t-test (p-value): † $p < 0.05$; †† $p \leq 0.0001$
Correlation coefficient (p-value): * $p < 0.05$; ** $p \leq 0.0001$


80
70
60
50
40
30
20
10
0
V̇O2
(mL·kg-1·min-1)
V̇O2 at the end
V̇O2max
BL
T400
BL
1
2
3
4
5
6
7
Steps
T400
7 x 200-m incremental intermittent protocol



a) VO2 (mL·kg-1·min-1)
Slope: 1.5, 1.1 to 2.4
Intercept: -27, -78 to -6
p = 1.00
e) v (m·s-1)
Slope: 1.3, 0.8 to 2.4
Intercept: -0.5, -1.9 to 0.2
p = 1.00
b) [La-] (mmol·L-1)
Slope: 1.4, 0.6 to 3.1
Intercept: -1.9, 0.6 to 3.1
p = 0.83
f) SL (m)
Slope: 1.1, 0.6 to 1.8
Intercept: -0.3, -1.8 to 0.8
p = 0.77
c) HR (bpm)
Slope: 0.8, 0.5 to 1.1
Intercept: 36.4, -13.3 to -91.3
p = 0.83
g) SR (cycles·min-1)
Slope: 0.8, 0.5 to 1.5
Intercept: 7.22, -17.1 to 19.2
p = 0.77
d) Respiratory exchange ratio (RER)
Slope: 1.1, 0.4 to 7.0
Intercept: -0.1, -5.6 to 0.6
p = 0.77
h) SI (m2·s-1)
Slope: 1.1, 0.6 to 1.8
Intercept: -0.6, -2.7 to 1.2
p = 0.77
T400
7th Step


a) VO2 (mL·kg-1·min-1)
e) v (m·s-1)
b) [La-] (mmol·L-1)
f) SL (m)
c) HR (bpm)
g) SR (cycles·min-1)
d) Respiratory exchange ratio (RER)
h) SI (m2·s-1)
Difference 7th Step - T400
Mean 7th Step and T400
ACCEPTED