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

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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 (T400) 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 - vVO2max was identified) and T400 (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 T400. Similarly, there were high level of agreements and high correlations (r-values ~ 0.90; p ≤ 0.05) for all biomechanical variables, and only trivial bias in swimming speed (0.03 m·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 T400 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 ($V\dot{O}_{2\text{max}}$) 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 $V\dot{O}_{2\text{max}}$ ($vV\dot{O}_{2\text{max}}$) is usually assessed to provide a measure of aerobic power (2,6,10). The functional measure $vV\dot{O}_{2\text{max}}$ combines exercise economy and $V\dot{O}_{2\text{max}}$ 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 $V\dot{O}_{2\text{max}}$, $vV\dot{O}_{2\text{max}}$ 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-
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group swimmers (40). In fact, it appears that \( \dot{VO}_{2\text{max}} \) 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 \( v\dot{VO}_{2\text{max}} \) (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 \( \dot{VO}_{2\text{max}} \).

However, although practical and widely used by coaches, there is no study comparing
directly the primary physiological responses between the \( 7 \times 200\)-m incremental
intermittent protocol (particularly at the step corresponding with \( v\dot{VO}_{2\text{max}} \)) 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 $v\dot{VO}_{2\text{max}}$ 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 $v\dot{VO}_{2\text{max}}$ 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 (VO\(_2\), 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 VO\(_{2\text{max}}\) and vVO\(_{2\text{max}}\) assessments, using increments of 0.05 m·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·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 (27.5°C of water temperature, 25.9°C 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 (K4b², 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\textsubscript{2} and 5% CO\textsubscript{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\textsuperscript{2} portable unit during both swimming protocols. A capillary blood sample (5 µL) for [La\textsuperscript{-}] 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\textsuperscript{-}]_{\text{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 (\(v = d/\text{t}10\), where \(d = 10\)-m and \(\text{t}10 = \) 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\textsubscript{400}. 

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Data analysis

For both protocols, errant breaths (caused by swallowing, coughing and/or signal interruptions) were omitted from the VO\textsubscript{2} analysis by only including those were within VO\textsubscript{2} local mean ± 4 SD (26). Subsequently, individual breath-by-breath VO\textsubscript{2} responses were time averaged every 10 s and smoothed using a 3-breath moving average (7). Oxygen uptake (VO\textsubscript{2}), heart rate (HR), respiratory exchange ratio (RER) and minute ventilation (V\textsubscript{E}) at the end of both protocols were calculated as the average from the last 60 s of exercise. The VO\textsubscript{2} at the end of the 7 x 200-m incremental intermittent protocol was defined as VO\textsubscript{2max} through a case-by-case inspection of the plateau in VO\textsubscript{2} despite an increase in v, added to volitional exhaustion (37). The vVO\textsubscript{2max} was estimated as the v corresponding to the first step of the 7 x 200 m incremental intermittent protocol that elicited VO\textsubscript{2max}. It is well-established that swimmers can sustain v for sufficient duration such that the kinetics reach VO\textsubscript{2max} in the severe intensity domain during this protocol (3,14,31). Thus, to standardize the variables compared in this study, VO\textsubscript{2} at the end of T\textsubscript{400} was compared with VO\textsubscript{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 VO₂ values of 7 x 200-m incremental intermittent protocol and T₄₀₀ are presented in Figure 1. The vVO₂max 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 T₄₀₀ (311 ± 17 s) and vVO₂max (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 (vVO₂max) and T₄₀₀, with no differences being evident. Correlations (all p < 0.0001) were excellent for absolute VO₂max (r = 0.98), relative VO₂max (r = 0.94), HR (r = 0.92) and VE (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 (vVO₂max) and the T₄₀₀ (Table 2).
Passing-Bablok regression between physiological and biomechanical variables from the 7th step of the 7 x 200-m incremental intermittent protocol (vVO₂max) and the T₄₀₀ are presented in Figure 2.

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 (vVO₂max) and the T₄₀₀ are presented in Figure 3.
Systematic error (linear regression) was identified only for VO₂ in Bland-Altman plot (r² = 0.50; 95%CI - 4.9 to 5.4, p = 0.01), indicating that swimmers who have a VO₂ greater than ~ 55 mL·kg⁻¹·min⁻¹ reach slightly higher values of VO₂ during T₄₀₀ than in the 7th 200-m step (vVO₂max).

DISCUSSION

We compared the primary physiological and biomechanical responses between an incremental intermittent and a time trial protocol. The T₄₀₀ is valid and easier to administer, particularly for age-group swimmers, since it provides direct evidence of the strong relationship with vVO₂max (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 T₄₀₀ 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 VO₂max in swimming with the T400. In the early 2000s, Rodríguez et al (34) suggested that T₄₀₀ yields similar and high correlated VO₂ 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, T₄₀₀ is a method to assess aerobic power and prescribe swimming training intensities (40). However, a validation study was needed to determine whether the T₄₀₀ have similar physiological and biomechanical estimates to the 7th 200-m step (vVO₂max), 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 VO$_{2\text{max}}$ ($vVO_{2\text{max}}$) contains both VO$_{2\text{max}}$ and swimming economy in one term (2). Training sets performed at $vVO_{2\text{max}}$ can improve both VO$_{2\text{max}}$ and swimming economy (12). In fact, there was an inverse relationship between the T$_{400}$ and $vVO_{2\text{max}}$. These results are in agreement with other recent studies (9,31), i.e. the performance of T$_{400}$ is related with both aerobic power (VO$_{2\text{max}}$) and swimming economy (2,14,31).

Comparison of ventilatory variables between two incremental protocols (continuous and intermittent) for VO$_{2\text{max}}$ and $vVO_{2\text{max}}$ assessment in swimming was first conducted a decade ago (5). The incremental intermittent protocol was deemed suitable for both VO$_{2\text{max}}$ and $vVO_{2\text{max}}$ assessment. At the same time, the VO$_2$ kinetics during a T$_{400}$ was examined (33), where VO$_{2\text{peak}}$ 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 $vVO_{2\text{max}}$ (14,31) and also because VO$_{2\text{max}}$ is achieved during a T$_{400}$ (21,28,34). Our study goes beyond these 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 7$^{th}$ 200-m step (the one in which $vVO_{2\text{max}}$ was identified).
There were only trivial bias in estimates of physiological variables between the 7th 200-m step (\(vV\mathring{O}_{2\text{max}}\)) and the T\(_{400}\) (Table 2), with [La\(^-\)] values in agreement with other data on age group swimmers (13). High correlations for \(V\mathring{O}_{2\text{max}}\), HR and VE, 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 (\(vV\mathring{O}_{2\text{max}}\)) and the T\(_{400}\). Linear regression analysis (Bland-Altman plot) indicated a systematic error for estimation of \(VO_2\) between the 7th step (\(vV\mathring{O}_{2\text{max}}\)) and T\(_{400}\) (Figure 3, a). Although high reproducibility and accuracy were identified for all physiological variables, systematic error for \(VO_2\) 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 \(V\mathring{O}_2\) to increase to a maximal value. Secondly, swimming intensity needs to lie within the severe domain, since it is characterized by attainment of \(V\mathring{O}_{2\text{max}}\) (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 \(V\mathring{O}_{2\text{max}}\) was achieved. Likewise, the range between the minimum and maximum times of 7th 200-m step (\(vV\mathring{O}_{2\text{max}}\)) (~139 and 163 s) agrees with the minimal duration required for attainment of \(V\mathring{O}_{2\text{max}}\). Assuming that different step lengths might affect the \(V\mathring{O}_{2\text{max}}\) assessment, \(V\mathring{O}_2\) values from incremental intermittent protocols with 200, 300 and 400-m length steps were compared, and observed that 200-m distances are valid for \(V\mathring{O}_{2\text{max}}\) (11). Moreover, the minimum and maximum performances of T\(_{400}\) (~293 and 342 s, respectively) are in agreement with the time endured at \(vV\mathring{O}_{2\text{max}}\) reported in the literature (14). Swimming intensity of T\(_{400}\)
is similar to the intensity of the 7th 200-m step (vVO\textsubscript{2max}), given trivial differences between the physiological variables (Table 2). Swimming coaches and scientists can be advised that the T\textsubscript{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 VO\textsubscript{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\textsubscript{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\textsubscript{400}, with high correlations and level of agreements observed between T\textsubscript{400} and the 7th 200-m step (vVO\textsubscript{2max}) for all biomechanical variables. This is an important result, since both physiological and biomechanical results were similar between protocols, which makes the T\textsubscript{400} even more
helpful for the assessment of age-group swimmers. Coaches could apply the T₄₀₀ in
their workouts as a feasible, short and practical protocol for age-group swimmers.

It is important to verify the validity of the T₄₀₀ in reproducing the biomechanical
responses of the 7th 200-m step (vVO₂max). since T₄₀₀ 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·s⁻¹ and 1.34 ±
0.08 m·s⁻¹ for the 7th 200-m step and T₄₀₀, 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 T₄₀₀, 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 T₄₀₀. Estimates from both methods lies
within the severe intensity domain (similar VO₂max). Nevertheless, if we calculate
vVO₂max training paces for 100, 200 and 400-m distances throughout both protocols
(1.32 and 1.29 m·s⁻¹ for the 7th 200-m step and T₄₀₀, respectively), the difference (0.03
m·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 T₄₀₀ (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 T400 is a valid and easier option for aerobic power assessment in age-group swimmers, since it showed similar physiological and biomechanical responses to the $7^{th}$ 200-m step ($vV\dot{O}_{2\text{max}}$). These outcomes confirm the viability of the T400 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 T400 and $vV\dot{O}_{2\text{max}}$, we consider the T400 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 $vV\dot{O}_{2\text{max}}$ in age-group swimmers. Age-group swimming coaches could use the T400 intermittently throughout the training season, but we do not recommend using the 7 x 200-m incremental intermittent protocol ($vV\dot{O}_{2\text{max}}$) and T400 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 \(vVO_2\max\) between both protocols would be
also be useful.

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Figure legends

Figure 1. VO$_2$ values (mean ± SD) among baseline (BL), end of T$_{400}$ and 7 x 200-m incremental intermittent protocol ($7^{th}$ step = vVO$_{2max}$).

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 (vVO$_{2max}$) 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 (vVO$_{2\text{max}}$) and the T$_{400}$.
Table 1. Subjects characteristics (mean ± SD).

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

* 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 vVO\textsubscript{2max} and T\textsubscript{400}

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean difference (95% confidence interval)</th>
<th>Correlation coefficient (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V\text{\textsubscript{O}}_2), L·min\textsuperscript{-1}</td>
<td>0.01 (-0.10 to 0.12)</td>
<td>0.98**</td>
</tr>
<tr>
<td>(V\text{\textsubscript{O}}_2), mL·kg\textsuperscript{-1}·min\textsuperscript{-1}</td>
<td>0.2 (-2.0 to 2.0)</td>
<td>0.94**</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>2.8 (-0.03 to 5.60)</td>
<td>0.93**</td>
</tr>
<tr>
<td>RER</td>
<td>0.002 (-0.046 to 0.051)</td>
<td>0.31</td>
</tr>
<tr>
<td>(V\text{\textsubscript{E}}), L·min\textsuperscript{-1}</td>
<td>3 (-4 to 9)</td>
<td>0.94**</td>
</tr>
<tr>
<td>[La\textsuperscript{-}], mmol·L\textsuperscript{-1}</td>
<td>-0.3 (-1.2 to 0.6)</td>
<td>0.69*</td>
</tr>
<tr>
<td>(\bar{v}), m·s\textsuperscript{-1}</td>
<td>0.03 (0.005 to 0.067)</td>
<td>0.78*</td>
</tr>
<tr>
<td>SL, m</td>
<td>0.1 (0.1 to 0.2)</td>
<td>0.90**</td>
</tr>
<tr>
<td>SR, cycles·min\textsuperscript{-1}</td>
<td>0.5 (-0.1 to 1.0)</td>
<td>0.89**</td>
</tr>
<tr>
<td>SI, m\textsuperscript{2}·s\textsuperscript{-1}</td>
<td>0.3 (0.1 to 0.4)</td>
<td>0.91**</td>
</tr>
</tbody>
</table>

Oxygen uptake (\(V\text{\textsubscript{O}}_2\)); heart rate (HR); respiratory exchange ratio (RER); minute ventilation (\(V\text{\textsubscript{E}}\)); lactate concentrations ([La\textsuperscript{-}]); swimming speed (\(\bar{v}\)); stroke length (SL); stroke rate (SR) and stroke index (SI).

t-test (p-value): *p < 0.05; **p ≤ 0.0001
Correlation coefficient (p-value): *p < 0.05; **p ≤ 0.0001
7th Step
Mean 7th Step and T400