Reproducibility of Cycling Time to Exhaustion at VO\(_2\) Max in Competitive Cyclists

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**ABSTRACT**

Costa VP, Matos DG, Pertence LC, Martins JAN, Lima JRP. Reproducibility of Cycling Time to Exhaustion at VO\(_2\) Max in Competitive Cyclists. *JEPonline* 2011; 14(1):28-34. The purpose of this study was to examine the reproducibility of cycling time to exhaustion (T\(_{\text{max}}\)) at maximum oxygen uptake (VO\(_2\) max) in competitive cyclists. Seventeen subjects (age, 36.9 ± 7.8 yrs; body mass, 71.1 ± 10.1 kg; height, 1.73 ± 0.8 cm; body fat, 13.1 ± 5.7 %; VO\(_2\) max, 54.7 ± 9.0 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\)) performed an incremental exercise test and two T\(_{\text{max}}\) tests. While cycling time to exhaustion was correlated for both T\(_{\text{max}}\) tests (r = 0.80, p = 0.01), the T\(_{\text{max}2}\) test (238.6 ± 33.5 sec) was significantly higher than the T\(_{\text{max}1}\) test (223.2 ± 31.3 sec, p < 0.02). Similarly, heart rate to exhaustion was correlated for both T\(_{\text{max}}\) tests (r = 0.89, p = 0.01) but the difference failed to have any practical value (T\(_{\text{max}1}\) = 182 ± 8 vs. T\(_{\text{max}2}\) = 183 ± 7 bpm). The blood lactate peak from the first test (10.8 ± 2.0 mmol\(\cdot\)l\(^{-1}\)) was also correlated (r = 0.63, p = 0.07) without a significant difference between the two tests (9.8 ± 1.5 mmol\(\cdot\)l\(^{-1}\)). VO\(_2\) peak for the first test (56.5 ± 9.1 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\)) was strongly correlated (r = 0.94, p = 0.06) and did not differ from the second test (54.6 ± 7.8 ml\(\cdot\)kg\(^{-1}\)\(\cdot\)min\(^{-1}\)). These data demonstrate that the time to exhaustion (T\(_{\text{max}}\)) at VO\(_2\) max in a series of two cycling tests is significantly greater than the first.

**Key Words:** Reproducibility, Cycling Time to Exhaustion, VO\(_2\) Max.
INTRODUCTION

Several authors suggest the use of incremental exercise test for assessment of maximum oxygen consumption (VO\(_2\) max), peak power output (PPO) and anaerobic threshold (AT) to set training programs for cyclists (13). A common variable used is the intensity at which VO\(_2\) max is achieved. This variable combines economy and VO\(_2\) max into a single factor; which helps to explain differences in performances that these physiological based measures alone could not (3). The athlete’s cycling time to exhaustion (T\(_{\text{max}}\)) at VO\(_2\) max is the capacity to continue a task performed at the lowest intensity in which VO\(_2\) max is achieved and that which requires the mobilization of large muscle groups until exhaustion (2). During the last several decades, coaches and sports scientists have carried out more studies regarding the feasibility of using T\(_{\text{max}}\) since further improvements in VO\(_2\) max in the highly trained athlete may only result from exercise training at or above VO\(_2\)\(_{\text{max}}\) (10).

Several measures used for a controlled simulation in research or applied science purposes are from performance testing. The concept of reproducibility is central to the administration of a meaningful physiological performance test, which gives the same result after performing the same test repeatedly (7). Knowledge of the reproducibility of the athlete’s performance in an exercise test is important for the correct interpretation of the performance data. The better the reproducibility, the more precise are the measurements (15). A reliable measure of performance has small systematic changes in the mean and a small within-subject variation between repeated trials of the test (7). Billat et al. (1) reported a significant reproducibility of running T\(_{\text{max}}\) at VO\(_2\) max in sub-elite runners. More recently, Laursen et al. (11) found significant differences in each T\(_{\text{max}}\) scores measured in highly trained cyclists and triathletes. To date, there is no study that has investigated the relationship between laboratory based measured variables and T\(_{\text{max}}\) in cycling. Thus, the purpose of this study was to examine the reproducibility of cycling time to exhaustion (T\(_{\text{max}}\)) at maximum oxygen uptake (VO\(_2\) max) in competitive cyclists.

METHODS

Subjects

Seventeen competitive cyclists volunteered for this study. All subjects provided a written informed consent in accordance with the Federal University of Juiz de Fora ethics policy (Juiz de Fora, Brazil). Their physical characteristics (and years of training and racing, respectively) include the following: age 36.9 ± 7.8 yrs, body mass 71.1 ± 10.1 kg, height 173.0 ± 0.1 cm, body fat, 13.2 ± 6.6 %, and 12.4 ± 6.6 years. The athletes were in the middle of the base phase of their season. At the time of testing, they cycled between 12 to 18 hours per week.

Procedures

Initially, the cyclists reported to the laboratory to 1) obtain anthropometric measurements to estimate the percentage of body fat (BF) according to Jackson and Pollock’s three site formula: pectoral, abdomen and quadriceps (8), and 2) perform an incremental cycling test. The incremental exercise test was performed on an electromagnetic braked cycle ergometer (Ergo Fit 167, Pirmansens, Germany) that was modified with clip-in pedals and racing saddle. The saddle and handle bar positions of the cycle ergometer were adjusted to approximate each subject’s own bike. The cyclists completed a 5-min warm-up period at 70 W followed by a 2-min of passive recovery. The test began at 100 W and the intensity was increased by 15 W every 30 sec until volitional exhaustion or when they were unable to maintain a cadence of more than 60 rpm. Expired air was collected continuously using a pre-calibrated metabolic analyzer (VO2000, Medical Graphics Inc., Minnesota, USA). The workloads corresponding to ventilatory thresholds 1 and 2 (VT\(_1\) and VT\(_2\), respectively) were also
identified. Ventilatory threshold 1 (VT₁) was determined using the criteria of an increase in both $V_E.VO_2^{-1}$ and $P_{ET}O_2$ with no concomitant increase in $V_E.VCO_2^{-1}$ (12). Ventilation threshold 2 (VT₂) was determined using the criteria of an increase in both $V_E.VO_2^{-1}$ and $V_E.VCO_2^{-1}$ and a decrease in $P_{ET}CO_2$ (12). The IVO₂ max was calculated from the progressive test and defined as the load after which there was no increase in VO₂ greater than 2.1 ml·kg⁻¹·min⁻¹ (despite an increase in workload, 15W each 30 sec). Heart rate was continuously recorded during the test with a heart rate monitor (Polar S725X, Polar Electro OY, Finland). One minute after the end of the test, capillary blood samples were obtained from the right ear lob of each subject and immediately analyzed using an electromagnetic technique (YSI® 1500 Sport, Yellow Springs Instruments, Ohio, USA). The analyzer was calibrated in accordance with the manufacture’s recommended procedures. All subjects completed at least two of the three criteria for the test to be considered maximum VO₂: 1) respiratory exchange ratio (RER) = 1.1, 2) lactate peak greater than 8 mM, and 3) maximum heart rate above 90% of the predicted maximum for each age (14).

Twenty-four hours following the incremental test, the subjects performed the first $T_{max}$ as a familiarization test. Then, for analysis of reproducibility of the cycling time to exhaustion ($T_{max}$) at maximum oxygen uptake (VO₂ max), the $T_{max}$ test was repeated twice (with a one-week interval between both tests, $T_{max1}$ and $T_{max2}$) at the same time of the day. A 5-min warm-up was performed at an intensity of 2 W·kg⁻¹ with two bouts of 30 to 60 sec at 4 W·kg⁻¹, separated by 30 sec of recovery with 2 W·kg⁻¹. The subjects were then timed for the duration at which they could maintain at IVO₂peak in a cadence above 60 rpm (11). At the end of the test, 25 µl of lactate from the earlobe was collected. Heart rate and VO₂ were recorded at 30-sec intervals during exercise. Following exercise, the subjects were encouraged to cool-down at a reduced cadence and power for 5 min.

### Statistical Analysis

Descriptive statistics were calculated for all measured variables from the laboratory and field tests using Graph-pad Prism 5.0 software. Comparisons between variables during $T_{max}$ were analyzed using a paired t-test. Pearson product moment correlation was used to establish the relationship between measured variables. Bland-Altman plot of the differences between the two $T_{max}$ tests were also made. For all analyses the level of statistical significance was established at an alpha level of $p<0.05$.

### RESULTS

Table 1 presents the physiological results from incremental exercise test, and Figure 2 presents the two $T_{max}$ tests. VO₂ max and lactate from the progressive test was not significantly different compared with both cycling time to exhaustion tests. However, the mean value of the heart rate from both $T_{max}$ tests was significantly lower than the HR peak recorded during the progressive cycle test ($p < 0.001$). Also, non-significant correlations were found between VO₂ max and VO₂ during $T_{max1}$ and $T_{max2}$ (-0.05; -0.04), and between PPO vs. $T_{max1}$ and $T_{max2}$ (-0.11; -0.08); respectively.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$T_{max1}$ (Mean ± SD)</th>
<th>$T_{max2}$ (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR max (b/min⁻¹)</td>
<td>187 ± 9</td>
<td>187 ± 9</td>
</tr>
<tr>
<td>PPO (W)</td>
<td>367.4 ± 28.6</td>
<td>360.3 ± 25.2</td>
</tr>
<tr>
<td>VO₂ max (ml/kg⁻¹·min⁻¹)</td>
<td>54.7 ± 9.0</td>
<td>54.8 ± 9.1</td>
</tr>
<tr>
<td>[La] max (mmol⁻¹)</td>
<td>10.0 ± 1.2</td>
<td>10.1 ± 1.3</td>
</tr>
<tr>
<td>VT₁ (ml/kg⁻¹·min⁻¹)</td>
<td>32.8 ± 5.4</td>
<td>32.9 ± 5.4</td>
</tr>
<tr>
<td>VT₂ (ml/kg⁻¹·min⁻¹)</td>
<td>44.4 ± 7.3</td>
<td>44.2 ± 7.1</td>
</tr>
</tbody>
</table>

$HR_{max}$ = heart rate max; $PPO_{max}$ = max power output; VO₂ max = maximal oxygen uptake, [La] max = blood lactate max, VT₁ = first ventilatory threshold, VT₂ = second ventilatory threshold.
Table 2 shows significant differences in time to exhaustion between $T_{\text{max}1}$ and $T_{\text{max}2}$ (223.2 ± 31.3 vs. 238.6 ± 33.5 sec, p < 0.02). There were no significant differences HR (182 ± 8 bpm and 183 ± 7 bpm, p < 0.01), blood lactate (10.8 ± 2.0 and 9.8 ± 1.5 mmol l$^{-1}$, p < 0.07), and VO$_2$ peak (54.3 ± 7.8 and 55.8 ± 9.3 ml kg$^{-1}$ min$^{-1}$, p < 0.06). High and significant correlations were found between all parameters measured during both $T_{\text{max}}$ tests.

<table>
<thead>
<tr>
<th>Variables and correlations from $T_{\text{max}1}$ and $T_{\text{max}2}$</th>
<th>Mean (SD)</th>
<th>P</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{max}1}$ (s)</td>
<td>223.2 ± 31.3</td>
<td>0.02</td>
<td>0.80*</td>
</tr>
<tr>
<td>$T_{\text{max}2}$ (s)</td>
<td>238.6 ± 33.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRT$_{\text{max}1}$ (b$^{-1}$min$^{-1}$)</td>
<td>182 ± 8</td>
<td>0.01</td>
<td>0.89*</td>
</tr>
<tr>
<td>HRT$_{\text{max}2}$ (b$^{-1}$min$^{-1}$)</td>
<td>183 ± 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO$_{2\text{max}1}$ (ml kg$^{-1}$ min$^{-1}$)</td>
<td>54.3 ± 7.8</td>
<td>0.06</td>
<td>0.94*</td>
</tr>
<tr>
<td>VO$_{2\text{max}2}$ (ml kg$^{-1}$ min$^{-1}$)</td>
<td>55.8 ± 9.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[La]$_{\text{Tmax}1}$ (mmol l$^{-1}$)</td>
<td>10.8 ± 2.0</td>
<td>0.07</td>
<td>0.63*</td>
</tr>
<tr>
<td>[La]$_{\text{Tmax}2}$ (mmol l$^{-1}$)</td>
<td>9.6 ± 1.6</td>
<td></td>
<td></td>
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</tbody>
</table>

$T_{\text{max}}$ = Time to exhaustion; HR = heart rate; VO$_2$ = oxygen uptake; [La] = blood lactate.

Figure 1 presents the Bland-Altman plots with bars corresponding to two standard deviations from the mean. While the two values of time to exhaustion from cycling time to exhaustion tests were strongly correlated (Table 2), $T_{\text{max}2}$ differed from $T_{\text{max}1}$, with relatively good agreement (Fig. 1).

**DISCUSSION**

The purpose of this study was to determine the reproducibility of physiological measures and time during cycling time to exhaustion at VO$_2$ max in competitive cyclists. The main findings indicate that
there were significant correlations between all laboratory measures after test-retest at constant pace. However, significant differences were found between the tests in time to exhaustion time. Smaller and non-significant correlations were also found between the physiological measures from both constant tests and the incremental exercise test.

Direct measures of $T_{\max}$ at VO$_2$ max indicate that it ranges from 2 min and 30 sec to 10 min, and it depends on the discipline mode. Billat et al. (1) reported that the time limit at VO$_2$ max is 222 ± 91 sec for cyclists, 376 ± 134 sec for kayakers, 287 ± 160 sec for swimmers, and 321 ± 84 sec for runners. The well-trained cyclists and triathletes investigated by Laursen et al. (11) show similar values at $T_{\max1}$ (237 ± 57 sec, and $T_{\max2}$ (245 ± 57 sec) compared with the cyclists from the French group. Indeed, the time limit reported for cyclists in previous studies is in agreement with the present study where $T_{\max1} = 223.2 \pm 31.3$ sec and $T_{\max2} = 238.6 \pm 33.5$ sec, respectively. The differences in time limit at VO$_2$ max for sports are related in part to muscle mass involved during the activity. The power output of kayak paddlers at VO$_2$ max was 57% that of the cyclists. However, the time of exhaustion for these athletes was significantly higher than the cyclists (1). In contrast, higher values of PPO and VO$_2$ max in trained athletes mean lower time to exhaustion. In fact, the inverse relationship between time to exhaustion and VO$_2$ max is observed in various modalities. In the study of Billat et al. (1), the runners who had the highest VO$_2$ max and the highest velocity or power at VO$_2$ peak reached their exhaustion time earlier. In the present study, we also found a non-significant negative correlation between PPO, VO$_2$ max, and both $T_{\max}$.

There was no significant difference between VO$_2$ max measured during the incremental exercise test and VO$_2$ during both $T_{\max}$ tests. This finding is similar to that reported from previous $T_{\max}$ research conducted by Laursen et al. (11). Like that study, the findings in the present study suggest VO$_2$ max can be assessed using an exhaustion constant test in competitive cyclists. Also, the present study indicates that peak blood lactate achieved during the incremental test ($10.0 \pm 1.2$ mmol?l$^{-1}$) was not significantly different from that obtained during the $T_{\max}$ tests ($10.8 \pm 2.0$ vs. $9.6 \pm 1.6$ mmol?l$^{-1}$). It has been recognized that both muscle and blood lactate have time-dependent as well as work rate-dependent variations during incremental and constant-load exercise. In the skeletal muscle, blood lactate increases rapidly early in exercise to yield a concentration gradient necessary for movement of lactate into the blood. As the duration at any work rate is prolonged, the muscle to blood gradient decreases; however, the open-loop features of $T_{\max}$ at VO$_2$ max performed until volitional exhaustion shows similar lactate to incremental exercise test. We also found that max HR achieved during the progressive exercise test was significantly higher than that obtained during both constant tests. Laursen et al. (11) reported that the peak HR achieved during the $T_{\max1}$ test ($182 \pm 10$) was significantly lower than that obtained during the progressive exercise test ($192 \pm 11$, $p < 0.001$).

Previously, Billat et al. (1) reported no difference between two $T_{\max}$ scores in a group of 8 sub-elite runners. In fact, they reported high reliability in $T_{\max}$ time ($404 \pm 101$ sec vs. $402 \pm 113$ sec) and high correlation between the tests ($r = 0.86$, $p < 0.05$). Later, Hinckson and Hopkins (6) used several approaches to derive estimates of test-retest error of measurement from times to exhaustion in tests conducted at constant running speed. They suggested that time to exhaustion is a reliable measure, and that a choice of the model can make substantial differences in the predictions for the race distances. For time to exhaustion in the 1- to 10-min range, the log-log model appears to be appropriate and superior to others. Recently, Laursen et al. (9) confirmed the validation of the log-log model of Hinckson and Hopkins (6) from direct comparison of the reliability of time-to-exhaustion tests in runners.
While studies have investigated time to exhaustion tests in runners, only the study from Laursen et al. (11) reported the reliability of constant pace tests in cyclists and triathletes. The main finding by the authors was that the second of two $T_{\text{max}}$ measurements in a group of highly trained athletes was correlated ($r = 0.88$, $p < 0.001$) and significantly greater than the first ($p = 0.047$). This is in agreement with the present study where competitive cyclists showed significant differences between $T_{\text{max1}}$ and $T_{\text{max2}}$ as well as high correlation between both tests. The small improvement in time in the $T_{\text{max2}}$ was probably due to the psychological effects since the results show that physiological variables (i.e., HR, [La], and $\text{VO}_2$) were not different between both time limits. Hickey et al. (4) reported that the significant difference in time trial at constant workload and the physiological variables were not different between time trials. The authors attributed the time difference to psychological factors. In agreement, Laursen et al. (11) reported that $\text{VO}_2$, RER, and HR were also not significantly different between both $T_{\text{max}}$. Therefore, the previous studies in cycling and the findings from the present study support the contention that of psychological factors as a strong possibility for the significantly longer time recorded for the final $T_{\text{max}}$ test.

**CONCLUSIONS**

Since power output at $\text{VO}_2 \text{max}$ contains both $\text{VO}_2 \text{max}$ and cycling economy in one term, the intensity at $\text{VO}_2 \text{max}$ should be used to monitor cycling training. Theoretically, the minimal power needed to elicit $\text{VO}_2 \text{max}$ is the ideal workload for short and middle distance events in cycling. The data from this study is similar to Laursen and colleagues (11). Collectively, it demonstrated that the interpretation of the results may have caution because training programs for cyclists based on $T_{\text{max}}$ may not be calibrated with the optimal workload. Also, there were significant correlations between all the laboratory measures after test-retest of time limit. However, significant differences were found between the $T_{\text{max}}$ tests in exhaustion time. Therefore, we found that the second score in a series of two cycling times during two exhaustion tests may be significantly greater than the first in competitive cyclists.

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