Journal of Exercise Physiologyonline

Volume 14 Number 1 February 2011

Official Research Journal of the American Society of Exercise Physiologists

ISSN 1097-9751

JEPonline

Reproducibility of Cycling Time to Exhaustion at VO_2 Max in Competitive Cyclists

VITOR PEREIRA COSTA[1,3], DIHOGO GAMA DE MATOS[2], LEONARDO COELHO PERTENCE[2], JONAS ALMEIDA NEVES MARTINS[2], JORGE ROBERTO PERROUT DE LIMA[2]

[1]Higher Education Center of South Region, Santa Catarina State University - UDESC, Laguna, Brazil, [2]Motor Evaluation Laboratory, Federal University of Juiz de Fora - UFJF, Juiz de Fora, Brazil. [3] Physical Effort Laboratory, Federal University of Santa Catarina

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_{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?kg^{-1}?min^{-1}) performed an incremental exercise test and two T_{max} tests. While cycling time to exhaustion was correlated for both T_{max} tests ($r = 0.80$, $p = 0.01$), the T_{max2} test (238.6 ± 33.5 sec) was significantly higher than the T_{max1} test (223.2 ± 31.3 sec, $p < 0.02$). Similarly, heart rate to exhaustion was correlated for both T_{max} tests ($r = 0.89$, $p = 0.01$) but the difference failed to have any practical value (T_{max1} = 182 ± 8 vs. T_{max2} = 183 ± 7 bpm). The blood lactate peak from the first test (10.8 ± 2.0 mmol?l^{-1}) was also correlated ($r = 0.63$, $p = 0.07$) without a significant difference between the two tests (9.8 ± 1.5 mmol?l^{-1}). VO_2 peak for the first test (56.5 ± 9.1 ml?kg^{-1}?min^{-1}) was strongly correlated ($r = 0.94$, $p = 0.06$) and did not differ from the second test (54.6 ± 7.8 ml?kg^{-1}?min^{-1}). These data demonstrate that the time to exhaustion (T_{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_{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_{max} since further improvements in VO_2 max in the highly trained athlete may only result from exercise training at or above VO_{2max} (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_{max} at VO_2 max in sub-elite runners. More recently, Laursen et al. (11) found significant differences in each T_{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_{max} in cycling. Thus, the purpose of this study was to examine the reproducibility of cycling time to exhaustion (T_{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 (VT_1) 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 (VT_2) was determined using the criteria of an increase in both the $V_E.VO_2^{-1}$ and $V_E.VCO_2^{-1}$ and a decrease in $P_{ET}CO_2$ (12). The IVO_2 max was calculated from the progressive test and defined as the load after which there was no increase in VO_2 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 VO_2: 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 (VO_2 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 IVO_{2peak} 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 VO_2 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. VO_2 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 VO_2 max and VO_2 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 1. Maximal variables from incremental exercise test.

	Mean (±SD)
HR max (b?min^{-1})	187 ± 9
PPO (W)	367.4 ± 28.6
VO_2 max (ml?kg^{-1}?min^{-1})	54.7 ± 9.0
[La] max (mmol^{-1})	10.0 ± 1.2
VT_1 (ml?kg^{-1}?min^{-1})	32.8 ± 5.4
VT_2 (ml?kg^{-1}?min^{-1})	44.4 ± 7.3

HR **max** = heart rate **max**; PPO = **max** power output; VO_2 max = maximal oxygen uptake, [La] **max** = blood lactate **max**, VT_1 = first ventilatory threshold, VT_2 = second ventilatory threshold.

Table 2 shows significant differences in time to exhaustion between T_{max1} and T_{max2} (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_{max} test.

Table 2. Variables and correlations from T_{max1} and T_{max2}.

	Mean (SD)	P	R
$Tmax_1$ (s)	223.2 ± 31.3	0.02	0.80*
$Tmax_2$ (s)	238.6 ± 33.5		
$HRTmax_1$ (b?min^{-1})	182 ± 8	0.01	0.89*
$HRTmax_2$ (b?min^{-1})	183 ± 7		
VO_2Tmax_1 (ml?kg^{-1}?min^{-1})	54.3 ± 7.8	0.06	0.94*
VO_2Tmax_2 (ml?kg^{-1}?min^{-1})	55.8 ± 9.3		
[La]$Tmax_1$ (mmol?l^{-1})	10.8 ± 2.0	0.07	0.63*
[La]$Tmax_2$ (mmol?l^{-1})	9.6 ± 1.6		

T_{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_{max2} differed from T_{max1}, with relatively good agreement (Fig. 1).

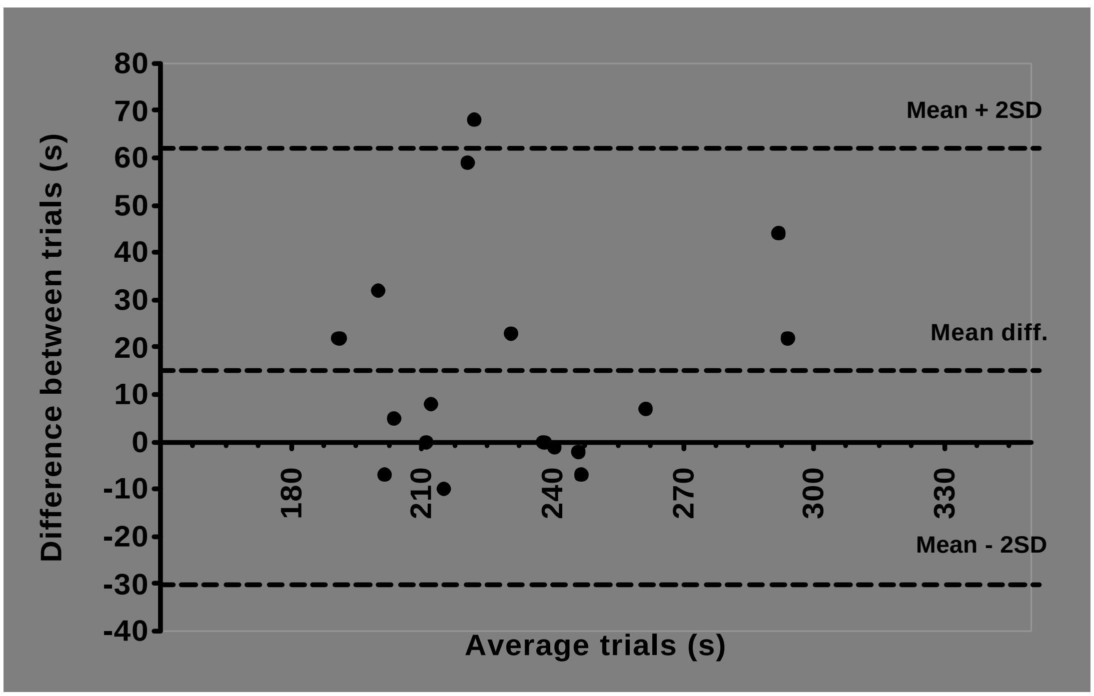

Figure 1 - Bland-Altman plot shows the difference between T_{max1} and T_{max2} for each subject.

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 el 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 ± 31.3 sec and T_{max2} = 238.6 ± 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 ± 1.2 $mmol?l^{-1}$) was not significantly different from that obtained during the T_{max} tests (10.8 ± 2.0 vs. 9.6 ± 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 ± 10) was significantly lower than that obtained during the progressive exercise test (192 ±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 ± 101 sec vs. 402 ± 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_{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_{max1} and T_{max2} as well as high correlation between both tests. The small improvement in time in the T_{max2} was probably due to the psychological effects since the results show that physiological variables (i.e., HR, [La], and 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 VO_2, RER, and HR were also not significantly different between both T_{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_{max} test.

CONCLUSIONS

Since power output at VO_2 max contains both VO_2 max and cycling economy in one term, the intensity at VO_2 max should be used to monitor cycling training. Theoretically the minimal power needed to elicit VO_2 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_{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_{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.

ACKNOWLEDGEMENTS

We would like to thank the cyclists volunteered for this study.

Address for correspondence: Vitor Pereira Costa, MS, Higher Education Center of South Region, Santa Catarina State University - UDESC, Laguna, Brazil. Phone: +55 (48) 8462-8399; E-mail: vitorcosta@racepace.com.br; costavp2@yahoo.com.br.

REFERENCES

1. Billat V, Faina M, Sardella F, Marini C, Fanton F, Lupo S, Faccini P, De Angelis M, Koralsztein JP, Dalmonte A. A comparison of time to exhaustion at VO_2max in elite cyclists, kayak paddlers, swimmers and runners. ***Ergonomics*** 1996;39(2):267-277.

2. Billat LV, Koralsztein JP. Significance of the velocity at VO_2max and time to exhaustion at this velocity. ***Sports Med*** 1996;22:90-108.

3. Di Prampero PE. The energy cost of human locomotion on land and in water. ***Int J Sports Med*** 1986;7:55-52.

4. Hickey MS, Costill DL, McConell GK, Widrick JJ, Tanaka H. Day to day variation in time trial cycling performance. ***Int J Sports Med*** 1992;13:467-470.

5. Hill DW, Leiferman JA, Lynch NA, Dangelmaier BS, Burt SE. Temporal specificity in adaptations to high-intensity exercise training. ***Med Sci Sports Exerc*** 1998;30:450-455.

6. Hinckson EA, Hopkins WG. Reliability of time to exhaustion analyzed with critical-power and log-log modeling. ***Med Sci Sports Exerc*** 2005;37(4):696-701.

7. Hopkins WG. Measures of reliability in sports medicine and science. ***Sports Med*** 2000;30(1):1-15

8. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. ***Br J Nutr.*** 1978; 40(3):497-504.

9. Laursen PB, Francis GT, Abbiss CR, Newton MJ, Nosaka N. Reliability of time-to-exhaustion versus time-trial running tests in runners. ***Med Sci Sports Exerc*** 2007;39(8):1374-1379.

10. Laursen PB, Jenkins DG. The scientific basis for high-intensity interval training: Optimising training programmes and maximising performance in highly trained endurance athletes. **Sports Med.** 2002;32(1):53-73.

11. Laursen PB, Shing CM, Jenkins DG. Reproducibility of the cycling time to exhaustion at VO_2peak in highly trained cyclists. ***Can J Appl Physiol*** 2003;28(4):605-615.

12. Lucia A, Hoyos J, Perez M, et al. Heart rate and performance parameters in elite cyclists: a longitudinal study. ***Med Sci Sports Exerc*** 2000;32:1777-82.

13. Paton CD, Hopkins WG. Tests of cycling performance. ***Sports Med*** 2001;31:489-96.

14. Taylor HL, Buskirk E, Henschel A. Maximal oxygen intake as objective measure of cardiorespiratory performance. ***J Appl Physiol*** 1955;8:73-80.

15. Watt KKO, Hopkins WG, Snow, RJ. Reliability of performance in repeated sprint cycling tests. ***J Sci Med Sport*** 2002;5(4):354-361.

Disclaimer